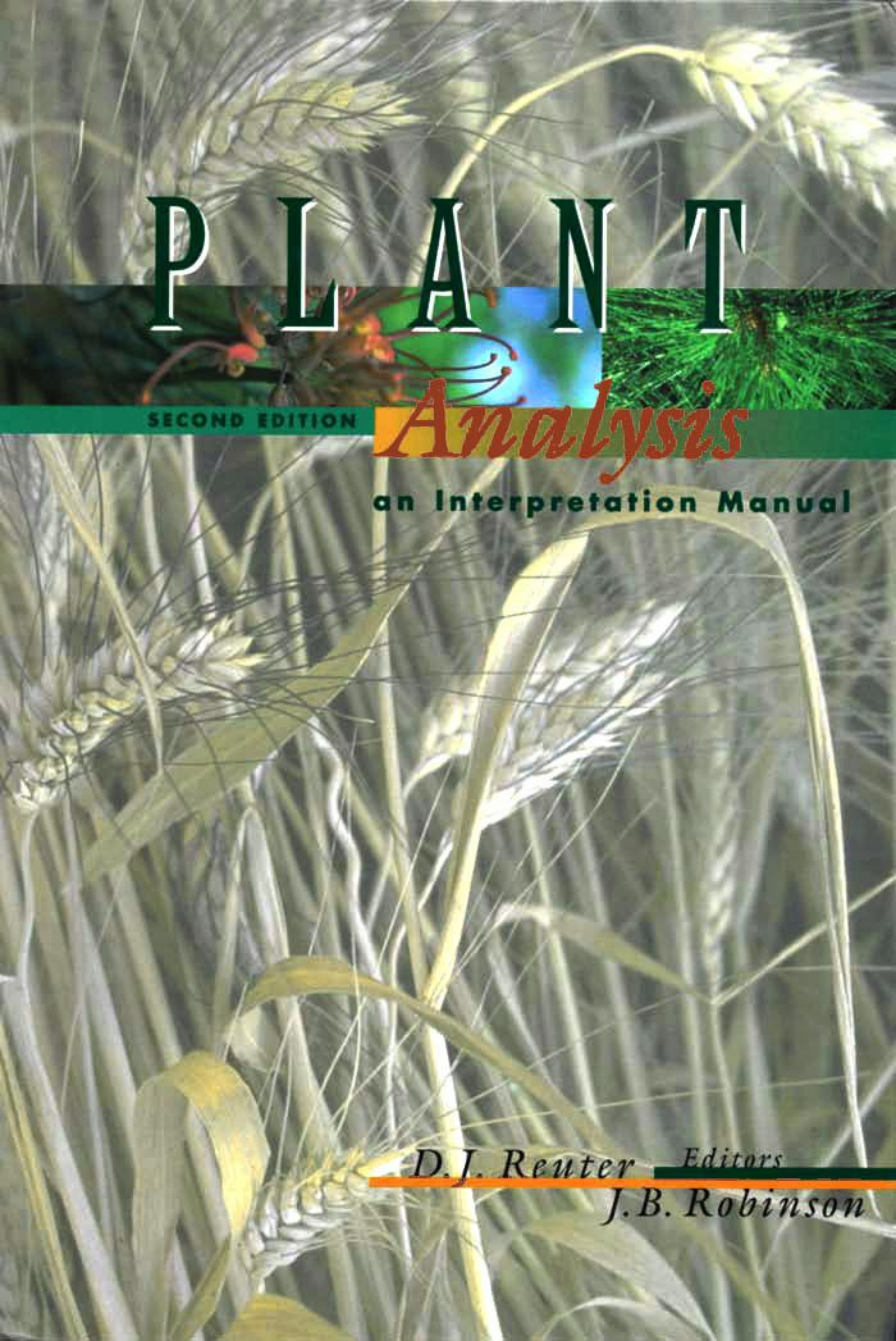
PLANT
SECOND EDITION
Analysis
an Interpretation Manual
D.J. Reuter
J.B. Robinson
Editors

PLANT Analysis

SECOND EDITION

an Interpretation Manual

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PLANT Analysis

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an Interpretation Manual

Editors

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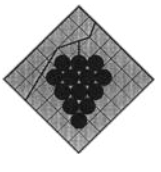

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FOREWORD

Nutrient management in agriculture is attracting close scrutiny from natural resource managers and environmental protection authorities. This follows community concern that nutrients are moving from the land to streams and groundwaters in excess of natural rates. Coincidentally, primary producers the world over are confronted with increasingly complex production systems, changing soil fertility, demands for high product quality, and a requirement to be both economically competitive and sustainable. Plant chemical analysis can help achieve these outcomes, when supported by reliable interpretative guidelines, often in conjunction with other diagnostic tools such as soil testing.

When the Australian Soil and Plant Analysis Council (ASPAC) was established in 1990, it was seen by its inaugural members as providing a forum and information clearing house for those interested in the science and practical application of soil and plant analysis. The need to provide sound interpretative guidelines for soil and plant chemical tests across a range of geographic conditions was recognised by members at a very early stage. Moreover, government could no longer be expected to commit resources to a task able to be competently undertaken by others.

At the time, the first edition of this *Plant Analysis Interpretation Manual* had been in use for five years. While the first edition made a major contribution in Australia to the understanding and use of plant chemical analysis as a diagnostic and research tool, ASPAC members recognised the time for a second edition was approaching. This need was reinforced at ASPAC's First National Workshop on Soil and Plant Analysis in 1993, with a resolution to commission a Working Party to review the need for a second edition. It was pleasing that the inaugural Editors, Dr Doug Reuter and Dr Ben Robinson, accepted this challenge on behalf of ASPAC.

To their credit, the Editors — supported by Cecilia Dutkiewicz and funded by ASPAC, the Australian Centre for International Agricultural Research, and several of Australia's Rural Research Funding Corporations — assembled a team of authors with recognised skills in plant chemical analysis and interpretation. The challenge, now achieved, was to fully update the manual from cover to cover, without losing the 'easy-to-use' character of the first edition.

Ultimately, an entirely new chapter on forest species was introduced, while other chapters covering concepts and principles, plant symptoms, guidelines for sampling, crops, pastures, vegetables, ornamentals and fruit trees, nuts and vines have been considerably enhanced and updated. The inclusion of interpretative guidelines for species grown in regions north of Australia, and compiled tables of widely accepted diagnostic standards for many plant species are among the new initiatives in this second edition. All chapters and tabulations were peer reviewed.

As Chairperson of ASPAC for the period when most of the manual was prepared, I extend thanks on behalf of all ASPAC members. These thanks go to Doug, Ben, Cecilia, contributing authors, reviewers of chapters, and CSIRO Publishing for their individual efforts in making this second edition a reality. The world scarcity of well compiled and explained diagnostic criteria for plant analysis of the type presented in this manual will ensure its success and international recognition. The challenge now is to use the information wisely for both individual and community benefit. In conclusion and for their relevance, I recall Professor Jack Loneragen's final sentence in his Foreword to the inaugural edition: 'We are all very much in their debt'.

George E. Rayment
ASPAC Chairperson 1995–1996

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CONTENTS

Contributors v

Sponsors vi

Foreword vii

Preface to the Second Edition xi

1 Interpretation of Plant Analysis: Concepts and Principles

F.W. Smith and J.F. Loneragan 1

A. Background 3

A.1 Historical introduction 3

A.2 Uses of plant analysis 3

A.3 Nutrient behaviour in plants 4

A.3.1 Regulation of nutrient concentrations in plants 4

A.3.2 Nutrient uptake 4

A.3.3 Partitioning and remobilization of nutrients 5

A.3.3.1 Partitioning between root and shoot 5

A.3.3.2 Remobilization 6

B. Diagnosis of nutrient status from nutrient concentrations 8

B.1 Nutrient concentrations and yield 8

B.2 Critical nutrient concentrations 10

B.2.1 Principles 10

B.2.2 Derivation of critical nutrient concentrations 10

B.3 Factors affecting critical concentrations 11

B.3.1 Culture systems and sensitivity of plant response 11

B.3.2 Plant age and part 12

B.3.3 Environmental interactions 14

B.3.4 Genotype 15

B.4 Nutrient surveys 16

C. Prediction of nutrient responses from nutrient concentrations

C.1 Principles 16

C.1.1 Yield criteria 17

C.1.2 Plant nutrient reserves 17

C.1.3 Soil nutrient supply after sampling 17

C.1.4 Nutrient requirement 18

C.2 Procedures 18

C.2.1 Seed analysis 18

C.2.2 Prediction during crop growth 19

D. Monitoring crop nutrient status from nutrient concentrations 19

E. Diagnosis, prediction and monitoring from other measures of nutrient status 20

E.1 Nutrients in relation to fresh weight 21

E.2 Form of nutrient 21

E.3 Nutrient and metabolite ratios 23

E.4 Organic compounds 23

E.5 Biochemical, molecular and physiological assays 24

E.6 Interaction with radiant energy 25

F. Conclusions 26

Acknowledgments 27

References 27

2 Nutrient Deficiency and Toxicity Symptoms

N.J. Grundon, A.D. Robson, M.J. Lambert and K.A. Snowball 35

A. Introduction 37

B. Symptoms in relation to the function of nutrients 38

C. Symptoms in relation to the mobility of nutrients 39

D. Description of symptoms 42

Acknowledgments 42

References 46

Appendix 1: References to symptom descriptions 47

3 Guidelines for Collecting, Handling and Analysing Plant Material

D.J. Reuter, J.B. Robinson, K.I. Peverill, G.H. Price and M.J. Lambert 53

A. Introduction 55
B. Purposes and methods of plant testing 55
C. Documenting site and crop information 56
C.1 Discussions with the landholder 56
C.2 Description of plant symptoms 56
D. Collecting representative samples 58
D.1 Concepts and strategies 58
D.1.1 Diagnostic sampling 58
D.1.2 Sampling for monitoring 58
D.2 Sampling appropriate plant parts 61
D.3 Other factors to consider 61
E. Sample handling and preparation 63
E.1 Sample transport 63
E.2 Sample handling and decontamination 63
E.3 Sample drying 66
E.4 Grinding and storage 66
E.5 Sap analysis 66
F. Laboratory analysis 66
G. Conclusion 68
References 68

4 Definition of Terms and Abbreviations Used in the Manual 71

5 Temperate and Tropical Crops
D.J. Reuter, D.G. Edwards and N.S. Wilhelm 81
Tables 84
References 254
Summarised interpretation guidelines for diagnosing nutrient disorders in agronomic crops 279

6 Pasture Species
A. Pinkerton, F.W. Smith and D.C. Lewis 285
Tables 288
References 338
Summarised guidelines for diagnosing nutrient deficiencies in pasture species 343

7 Fruits, Vines and Nuts
J.B. Robinson, M. Treeby and R.A. Stephenson 347
Tables 350
References 379

8 Vegetable Crops
D.O. Huett, N.A. Maier, L.A. Sparrow and T.J. Piggott 383
Tables 386
References 379
Summarised guidelines for diagnosing nutrient disorders in selected vegetable crops 461

9 Ornamentals.
G.H. Price, G.C. Cresswell and K.A. Handreck 465
Tables 468
References 501

10 Forest Plantations
R. Boardman, M.J. Lambert, M. Webb and R.N. Cromer 503
Tables 507
References 562

Species in Tables
A. Scientific names 567
B. Common names 570

PREFACE TO THE SECOND EDITION

In 1981, a national Workshop on Plant Analysis was held at Goolwa in South Australia. At that meeting, Dr W. Cox of the Western Australian Department of Agriculture proposed that all available information on the interpretation of plant analysis for agricultural and horticultural species should be reviewed and consolidated into an Australian manual to support the emergence of plant testing services nationally. This vision was subsequently accomplished in 1986 with the publication by Inkata Press of *Plant Analysis: an Interpretation Manual*. Through rural industry sponsorship, the Manual was distributed widely within Australia. It was also sold overseas by the publisher.

From all accounts the Manual served a useful purpose. It laid a foundation for establishing commercial plant testing services within Australia by government and private sector agencies. Thus, plant testing was advanced as a 'new' tool for monitoring and diagnosing the nutritional status of plants, and particularly annual species. The compiled interpretation criteria also exposed many knowledge gaps for a host of crops important to Australia. These needed to be addressed through research initiatives if reliable, scientifically valid tests were to be offered to farmers, orchardists and foresters by commercial testing services with multi-element analytical capabilities.

Then, in March 1993, the newly established Australian Soil and Plant Analysis Council (ASPAC) hosted the First National Workshop on Soil and Plant Analysis in Ballarat, Victoria. At this meeting, ten reviews were presented by Australian specialists on major issues confronting soil and plant testing in Australia. These reviews were published subsequently in a special issue of the *Australian Journal of Experimental Agriculture* (Volume 33: issue 8). Delegates at the Workshop recommended that ASPAC commission the publication of a revised, second edition of 1986 Plant Analysis Manual. After two years of dedicated work by 25 Australian specialists, the second edition has now been published by CSIRO Publishing. It comprises a comprehensive and modern basis for the use of plant analysis, which the authors hope will further the use by primary producers of this powerful diagnostic procedure.

Readers who compare the first and second editions will find that the new edition provides some important innovations. Firstly, the volume and scope of the information accessed from both Australian and overseas literature has expanded several-fold. Interpretation criteria for 294 species have been compiled in the tables, from more than 1800 published papers. Secondly, a new chapter has been prepared documenting criteria for forest species, with particular emphasis being placed on plantation species grown in Australia and south-east Asia. Thirdly, chapter authors have carefully distilled from assembled data, sets of interpretation guidelines for plant tests which they judge may be most useful for diagnosing the nutrient status of major crop species. We and the authors collectively emphasise that the guideline ranges for the tests advocated should be used prudently, and with the full knowledge that the values may not apply universally. Indeed, they are guides, which may need to be modified for local conditions.

As co-editors it is a pleasure to acknowledge the exceptional input made by the 25 authors of the revised edition. With their enthusiastic support and advice the revision process proceeded smoothly to its scheduled conclusion. We also thank Laurie Martinelli, Kevin Jeans amd Marta Veroni of CSIRO Publishing for their professional assistance and advice on all publication matters.

The authors of the Manual especially express their sincere gratitude to Ms Cecilia Dutkiewicz, Assistant Editor, for her dedication, patience and good will. Her assistance with database searches is also acknowledged. Special thanks are also due to Ms Tracey Rohrsheim for photography.

We especially acknowledge the skill and effort made by external referees who provided excellent comments sometimes on more than one chapter of the Manual. These include Professor Colin Asher (University of Queensland), Dr Patrick Brown (Department of Pomology, University of California, Davis USA), Mr David Campbell (Pivot Ltd), Associate Professor David Edwards (University of Queensland), Mr Barry Goldspink (Agriculture Western Australia), Mr Ian Grant (Hifert Pty Ltd), Dr Peter Hopmann (The Centre for Tree Technology, Victoria), Mr Brian Leach (CSBP and Farmers Ltd),

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Finally, and most importantly, we acknowledge the financial support provided by:

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- Grape and Wine Research and Development Corporation,
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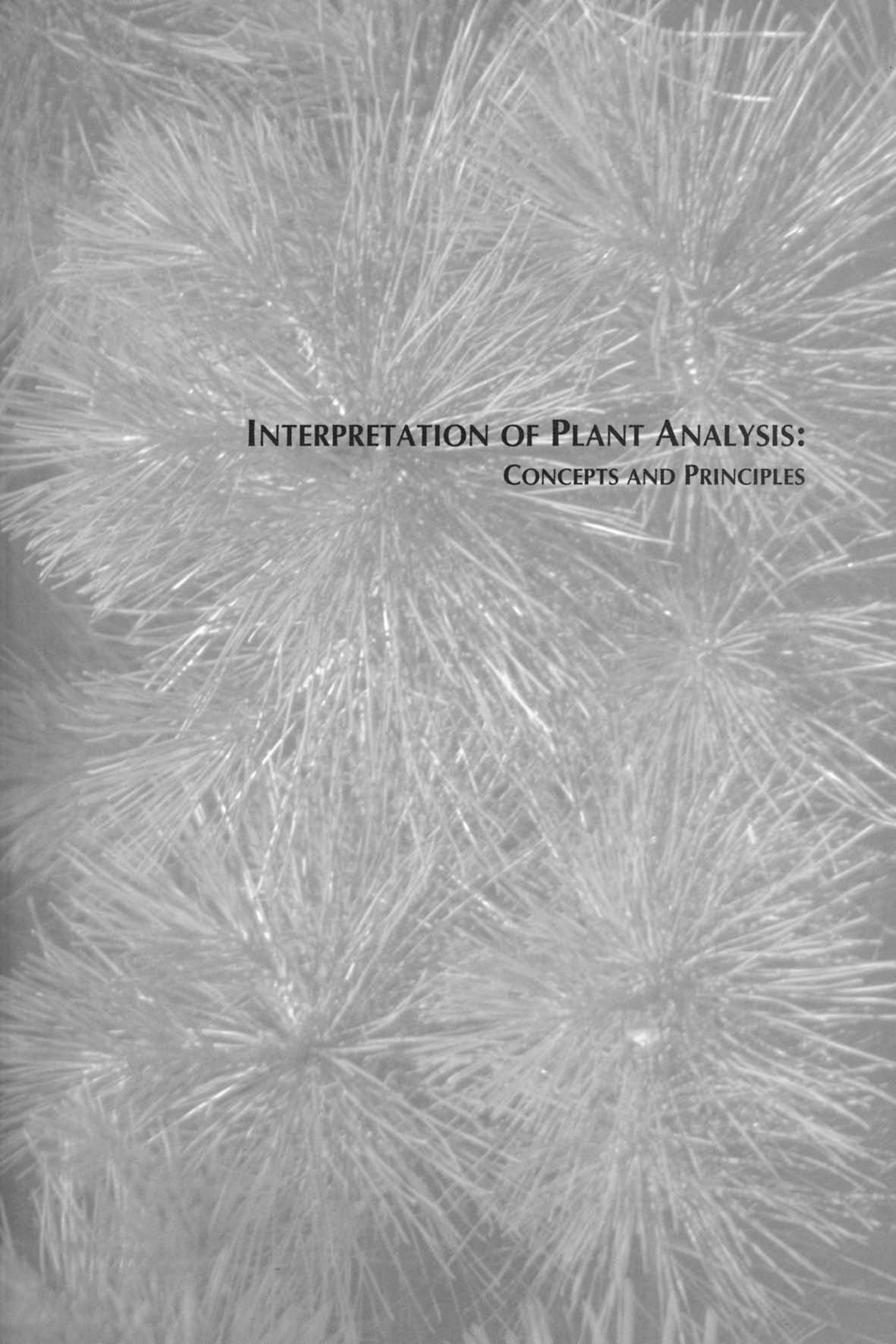
- International Wool Secretariat,
- Rural Industries Research and Development Corporation, and
- Sugar Research and Development Corporation.

D.J. Reuter

J.B. Robinson

Manual Editors



Interpretation of Plant Analysis:
Concepts and Principles

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1. Interpretation of Plant Analysis: Concepts and Principles

F.W. Smith and J.F. Loneragan

A. Background

A.1 Historical introduction

The use of plant analysis as a diagnostic tool has a history dating back to studies of plant ash content in the early 1800s. Chemists working on the composition of plant ash recognized that relationships existed between yield and the nutrient concentrations in plant tissues. Quantitative methods for interpreting these relationships in a manner that could be used for assessing plant nutrient status arose from the work of Macy (1936). Since then, much effort has been directed towards refining plant analysis as a diagnostic tool. Readers interested in following these developments are referred to the articles of Goodall and Gregory (1947), Ulrich (1952), Ulrich *et al.* (1959), Ulrich and Hills (1967), Bates (1971), Bouma (1983), Martin-Prevel *et al.* (1987), Munson and Nelson (1990), Jones (1991) and Bergmann (1992).

Advances in the capabilities of modern instruments have widened the scope for plant analysis, made more sensitive analytical techniques available, and simplified procedures. Atomic absorption spectroscopy, for example, has made routine analysis of micronutrient elements in plant tissues readily available. Various chromatographic and electrophoretic instruments that permit separation and quantitative analysis of organic constituents, together with the availability of rapid enzyme assay procedures, molecular probes and immunological techniques have opened up the possibility of using biochemical and molecular techniques in plant nutrient diagnosis. In recent years, the adoption of plasma source spectroscopic techniques such as inductively coupled plasma–optical emission (ICP–OES) and mass spectrometry (ICP–MS) has enabled many laboratories to perform analysis for a variety of applications in agricultural and environmental chemistry (Watson and Isaac 1990). Other spectroscopic techniques such as X-ray fluorescence (XRF) and near infrared spectrometry (NIR) have broadened the scope of measured parameters. Whilst advances in classical approaches such as Kjeldahl digestions and colorimetric analyses have been minimal by comparison, these techniques still provide valuable plant analysis information and are widely used. Information provided by such instruments on the concentrations of a range of nutrient elements in plant tissues, together with computerized processing of data (Donahue and Gettier 1990), bring new dimensions to the interpretation of plant analyses.

There has also been renewed interest in the development of tests which can be done *in situ,* such as colorimetric analysis of expressed sap and leaf colour measurements using transmission and reflectance meters, thus providing information for immediate remedial action.

A.2 Uses of plant analysis

Plant analysis has been developed primarily to provide information on the nutrient status of plants as a guide to nutrient management for optimal plant production. Increasingly, it is being used to protect the environment from over-fertilization of crops and pastures. Other uses include assessment of the quality of plant products, the estimation of the overall nutritional status of regions, districts, or soil types, of nutrient levels in diets available to livestock and for human nutrition, and as an indicator of environmental toxicities.

For nutrient management of crops, analytical data are used in various tests designed to:

- diagnose existing nutrient problems — trouble shooting,
- predict nutrient problems likely to affect crop production between sampling and harvest, or
- monitor crop nutrient status for optimal crop production.

Some diagnostic tests, such as those which have been calibrated against yield at sampling, reflect the history of the plant's nutrition and growth to the time of sampling (Figure 1.1). Others, such as some enzymic assays, reflect the plant's current nutrient status and its immediate potential to respond to added nutrients. Predictive tests project from current nutrient status to likely nutrient problems under conditions yet to come. Monitoring tests combine a record of the plant's nutrient history with both diagnostic and predictive procedures.

The most widely used of all tests are those based on the concentration or ratio of total chemical element to dry matter in plant parts. We prefer the term concentration over content, which some authors use (e.g. Marschner 1995), in order to avoid confusion

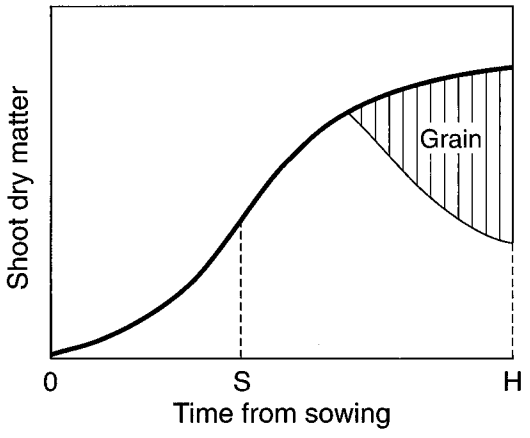

Figure 1.1 Relationship of time of sampling (S) for plant nutrient analysis to growth before and after sampling and to grain yield at harvest (H). Shoot dry matter at S reflects nutrient history from sowing (0) to S. Grain yield at H reflects plant nutrient status at S subjected to the operation of unknown environmental factors from S to H.

with the use of content in the sense of the amount of chemical element in a plant part. We will discuss the tests based on nutrient concentrations before considering tests based on other measures of nutrient status.

However, as the development and effective use of plant nutrient tests require an understanding of nutrient behaviour in plants, this topic will be presented briefly before considering the tests in detail.

A.3 Nutrient behaviour in plants

A.3.1 Regulation of nutrient concentrations in plants

Concentrations of most nutrients in plant tissues are restricted to quite a narrow range. Generally speaking, plants appear to have a remarkable ability to tune the rate at which they absorb nutrients from their rooting medium to the demand established by their growth rate. Thus, very large changes in concentrations of nutrients around plant roots often result in relatively small changes in tissue concentrations. For example, in their work with dilute flowing culture techniques, Asher and Loneragan (1967) used a 625-fold range of phosphorus concentrations continuously maintained at the root surface. In spite of this, there was only a 10-fold range in phosphorus concentrations of the shoots of plants growing in these solutions. In similar work with potassium, a 16000-fold range in the potassium concentration maintained at the root surface resulted in only 7-fold to 13-fold ranges in potassium concentrations in shoots of cassava, maize or sunflower (Spear *et al.* 1978). For plants in which growth was not restricted by either phosphorus or potassium deficiencies, the range of nutrient concentrations in their shoots was even less. Further, the internal nutrient concentration in some tissues is restricted to narrower limits than in other tissues; for example, the range in seeds is often much narrower than in the plant as a whole.

An understanding of the mechanisms plants use to regulate the nutrient concentrations in their tissues is important when interpreting results of plant analysis. Fortunately, this aspect of plant nutrition is receiving increased attention. Useful studies with whole plants on the influence of nutrient stress on nutrient absorption by plant roots, ion transport within the plant, remobilization of nutrients, nutrient solubilization in the rhizosphere, and relationships between plant growth and nutrient absorption are being reported. From these studies, an understanding of the active role that plants play in regulating the nutrient concentrations in their tissues is emerging.

A.3.2 Nutrient uptake

The uptake of nutrients into plant roots is mediated by membrane transport proteins embedded in the plasmalemma. The functioning of many of these specific nutrient transporters is linked to proton pumps through cotransporter or antiporter activities. The specificity of these transporter proteins, or permeases, and the mechanisms by which they are regulated, control the entry of inorganic ions into the symplasm of plant roots. A great deal of physiological information related to the functioning and regulation of ion transport systems has accumulated in recent years (see review by Clarkson and Lüttge 1991). Some of the genes encoding the transporter proteins from plant roots have been cloned recently (Schachtman and Schroeder 1994; Smith *et al.* 1995; Smith *et al.* 1997) and others are being eagerly sought. These clones provide powerful new tools for elucidating the complex regulatory systems that govern the nutrient content of plants.

Many of the 'high affinity' permeases associated with the uptake of major nutrients in field grown plants are subject to feedback regulation. Thus, the ion transport function is repressed in plants supplied with a normal or supra-optimal nutrient supply and de-repressed when the supply of that nutrient becomes deficient. Rates of sulfate uptake are very tightly controlled, increasing by as much as 15-fold within 48 hours after removal of the external sulfate supply, and returning to the low rate characteristic of sulfur-adequate plants within 24 hours of resupplying sulfate to sulfur-starved plants (Clarkson *et al.* 1983; Lass and Ulrich-Eberius 1984; Clarkson and Saker 1989). Phosphorus uptake exhibits similar feedback regulation, although it does not appear to be as tightly controlled as slfate transport (Clarkson and Scattergood 1982; Lefebvre and Glass 1982; Cogliatti and Clarkson 1983; McPharlin and Bieleski 1987). The uptake of potassium is also subject to regulatory mechanisms that respond to the potassium status of the plant. The complexity of the mechanisms related to potassium accumulation can be gleaned from the reviews of Jensen *et al.* (1987) and Lüttge and Clarkson (1989). Regulation of the uptake and reduction of nitrate is also very complex. It appears that uptake of nitrate *via* a constitutive transporter is required to trigger induction of a regulated nitrate transporter and a nitrate reductase.

Accumulation of nitrogenous compounds then serves to repress excessive nitrate uptake and reduction (Crawford and Arst 1993).

Among the micronutrients, the mechanisms of iron transport have been studied best (Romheld 1987; Welch 1995). Grass roots excrete phytosiderophores that chelate and solubilize iron from the soil (Romheld and Marschner 1986), resulting in grasses being considerably more efficient in acquiring iron than dicotyledons. In dicotyledons under iron deficient conditions, H^+ efflux is increased and an iron reductase is induced aiding the solubilization, reduction and uptake of iron compounds from the soil.

Studies on the expression of cloned transporters reveal that the feedback regulation of ion uptake is controlled primarily by transcription of the genes that encode these transporters. Thus, withdrawal of the external sulfur supply elicited a large increase in the level of mRNA associated with the root high affinity sulfate transporters (Smith *et al.* 1995), increasing the number of sulfate transporter proteins in the roots of sulfur-stressed plants: it declined rapidly upon resupply of external sulfate, indicating that the transporter proteins turn over quite quickly (Hawkesford and Smith 1996). Further evidence for this rapid turnover of sulfate transporters arises from studies using inhibitors of protein synthesis (Clarkson *et al.* 1992). Similar expression studies with a specific phosphate transporter in roots show that it is also subject to transcriptional control by signals that ultimately respond to the external phosphate supply (Smith *et al.* 1997).

Allosteric regulation may also modify the activity of ion transporters (Glass 1983). Regulation in this way would enable rapid fine tuning of nutrient transporters in response to nutrient supply and demand and other environmental factors.

The compounds responsible for feedback regulation of ion transport have not been identified. However, their identity should be revealed by current studies with the promoters associated with the genes encoding these transporters. Such molecular studies are also beginning to unravel the complex mechanisms that coordinately regulate nutrient transport and assimilation, and link these key processes to the other processes that govern plant growth and development. The study of plant mutants (Delhaize and Randall 1995) is also providing insights into the regulation of uptake and homeostasis of nutrients in plants.

A.3.3 Partitioning and remobilization of nutrients

During absorption by roots and translocation in the xylem sap to shoots, nutrients may be transferred to phloem sap or withdrawn and deposited in root, stem, and leaf cells (Pate 1975; Jeschke *et al.* 1985; Jeschke and Pate 1991a, 1991b). Nutrients absorbed in excess of the plant's immediate requirements are held at various sites within the plant or lost by guttation from shoots, excretion from roots, or by death and abscission of plant parts. For each nutrient, the pattern of distribution and the rate and extent of cycling and remobilization varies widely with the nutrient, environmental conditions, and plant nutrient status, species, and stage of development.

In annual species, partitioning and remobilization of nutrients are closely involved in the rapid developmental changes occurring during the plant's life cycle. For example, at some levels of nutrient supply, retranslocation from vegetative organs after flowering could account for up to 85% of the phosphorus in the grain of oat plants (Williams 1955) and most of the copper in the grain of wheat (Loneragan *et al.* 1980).

In perennial species too, nutrient uptake, partitioning, storage and mobilization are often related to particular phenological stages. For example, nitrogen taken up by grapevines after crop removal and before leaf fall is stored in the roots and permanent wood during dormancy but mobilized in spring to support shoot growth prior to uptake becoming significant at around flowering (Conradie 1991). In this situation, tissue analysis at flowering would provide a picture of the interaction between nitrogen supply during the previous growing season and growing conditions during the current growing season. Experiments with conifers have indicated that nutrient uptake and growth rate are primary determinants of the amount and rate of retranslocation of nutrients rather than only senescence as previously thought (Nambiar and Fife 1991). In these experiments, rapid growth associated with high soil fertility and rapid nutrient uptake increased the retranslocation of nutrients and there was competition among parts of the shoots for internal nutrient reserves. Switzer and Nelson (1972) estimated that, in a 20 year old plantation of loblolly pine, internal recycling accounted for 20–30% of the trees' requirements for nitrogen, phosphorus and potassium, about 16% for magnesium and sulfur, and 7% for calcium. Estimates of retranslocation of nitrogen and potassium in *Alnus rubra* (Miller 1986) and of phosphorus in *Pinus radiata* (Turner and Lambert 1986) suggest even greater contributions of 50–60% of the trees' requirements within 5–10 years from planting.

With such massive movement of nutrients in plants, it is not surprising that partitioning and remobilization play central roles in relations between nutrient concentration and plant growth. An understanding of how they influence nutrient levels in plant tissues greatly enhances the interpretation of plant analyses.

A.3.3.1 Partitioning between root and shoot

During periods of nutrient stress, plant shoots can call upon stores of mobile nutrients accumulated in roots, thus buffering nutrient concentrations in shoot tissues to some extent. Rapid transport of sulfur out of root systems to plant shoots has been measured in sulfur-stressed plants (Clarkson *et al.* 1983). Upon resupplying sulfur to sulfur-deficient plants there were rapid increases in sulfate concentrations to levels in excess of those in plants

that had been maintained on an adequate sulfur supply. The partitioning of this newly acquired sulfur was such that the greatest increases in tissue sulfate concentrations occurred in old leaves. However, roots and young leaves accumulated amino acid sulfur rapidly following relief of sulfur stress.

In experiments with the tropical forage legume *Stylosanthes hamata* (Smith *et al.* 1990), there was rapid partitioning of previously accumulated phosphorus from roots to shoots during the initial stages of phosphate stress. As stress became more severe, this partitioning was reversed and there was a net transfer of phosphorus from shoots back to roots. These studies also showed that the partitioning of phosphorus between root and shoot was such that roots retained the smallest proportion of the plant's total phosphorus when the external phosphorus concentration was just adequate to support maximum plant growth. At higher external phosphorus concentrations, roots retained a greater proportion of the plant's phosphorus and acted as a storage organ. At lower external phosphorus concentrations, roots were a strong sink for phosphorus and photosynthate, the root systems being expanded at the expense of shoots (with a resulting increase in root:shoot ratios). The complexity of fluxes such as these and the speed at which they can occur have considerable bearing on the concentrations of nutrients observed in plant tissues.

A.3.3.2 Remobilization

Nutrients deposited in tissues and organs may be remobilized and transported to other plant parts. Remobilization from older to younger parts during plant development and during nutrient stress may lead to rapid changes in concentrations of nutrients in particular leaves or organs and impacts strongly on the expression of deficiency symptoms and on the relationship of plant nutrient concentrations to growth and yield.

While all nutrients move readily in the xylem, they vary widely in the extent to which they move in the phloem. Nutrients have been characterized as having high, low or intermediate phloem mobility on the basis of several criteria including nutrient concentrations in the phloem sap, movement of isotopes, development of deficiency symptoms, and changing nutrient contents of organs (e.g. Marschner 1995). For diagnosis and prediction of nutrient deficiencies, a slightly different grouping based on the internal movement of nutrients from older leaves to young leaves and other developing organs during the onset of deficiencies has been suggested and will be used here; on this basis, nutrients have been characterized as phloem mobile, phloem immobile, and variably phloem mobile from leaves (Loneragan *et al.* 1976; see also Table 2 .2).

(i) The nutrients that are phloem mobile from leaves, nitrogen, phosphorus, and potassium, are present in high concentrations in the phloem sap and cycle rapidly throughout the plant; as their supply becomes limiting, young leaves and other developing organs retain the cycling nutrients at the expense of older leaves in which their contents decline (Marschner 1995). Consequently, during the development of their deficiencies, the concentrations of these nutrients remain high in young leaves while they decline in older leaves.

The decline in the content of these nutrients may occur in relatively young leaves, independently of senescence. For example, while maintaining its chlorophyll content constant from 11 to 28 days after sowing, the oldest leaf of young wheat plants lost 75% of its phosphorus and 50% of its potassium (Figure 1.2a; Hill *et al.* 1979c). Relatively young needles of conifers have also been found to lose appreciable amounts of nitrogen and phosphorus to new shoots during periods of rapid shoot growth (Nambiar and Fife 1991). Further losses occur during senescence. In nitrogen-deficient plants, the deficiency itself induces premature senescence with protein hydrolysis and chloroplast disintegration resulting in an early, rapid and massive loss of nitrogen from older leaves (Figure 1.2d).

Magnesium behaves in some respects like these nutrients which are phloem mobile from leaves. Its

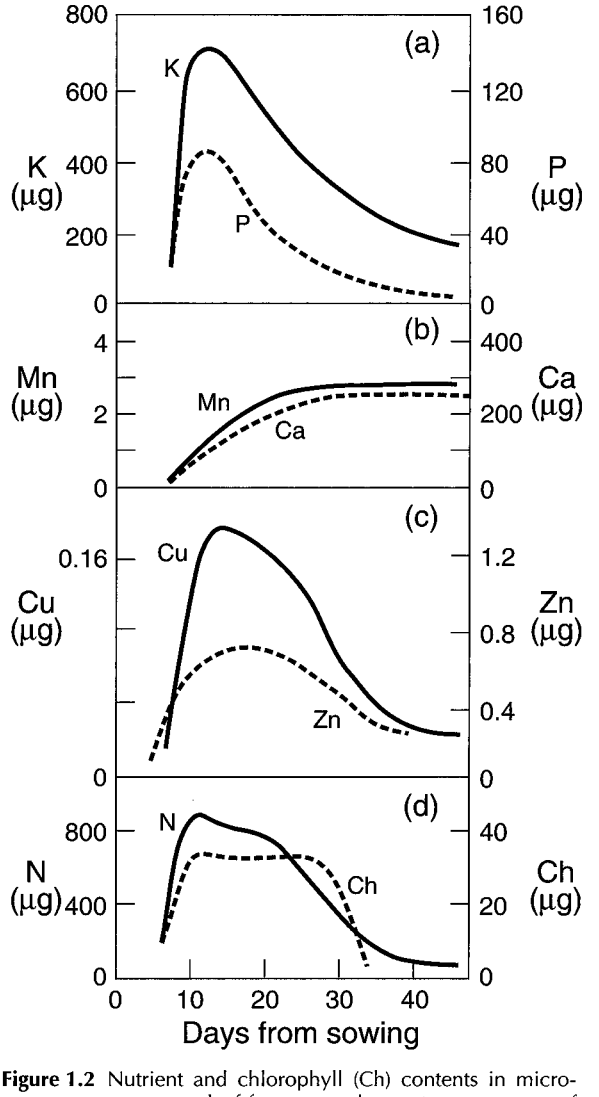

Figure 1.2 Nutrient and chlorophyll (Ch) contents in micrograms per leaf from an early age to senescence of the oldest leaf of wheat plants grown with adequate nutrients (from data of Hill *et al.* 1979c).

concentration in phloem sap is high relative to calcium (Pate 1975; Jeschke *et al.* 1985), it is retranslocated from green leaves to young organs (Scott and Robson 1990) and magnesium-deficiency symptoms frequently develop first in the oldest leaves (Embleton 1968). But in some species and under some conditions, deficiency symptoms appear earlier in young leaves than in older leaves, indicating that the rate of movement of magnesium from leaves in the phloem is relatively slow. For example, when transferred from solutions with magnesium to solutions without, subterranean clover plants developed their earliest magnesium-deficiency symptoms in young leaves; but when deficiency developed more slowly in solutions containing a low and constant magnesium concentration, the symptoms appeared first in the old leaves (Scott and Robson 1990). In wheat, the symptoms appeared first in young leaves under both conditions of magnesium supply (Scott and Robson 1991).

(ii) The nutrients that are phloem immobile from leaves, calcium, boron, manganese and iron, are characterized by their failure to move rapidly enough from leaves in which they have been deposited to prevent the onset of their deficiencies in young leaves, roots, or other developing organs when their supply from the roots becomes inadequate (Figure 1.2b). Leaves may lose appreciable quantities of these nutrients in guttation fluid and leachate but little, if any, moves to other plant organs. During the development of their deficiencies, concentrations of these nutrients remain high in older leaves even when senescent, while they decline rapidly in young leaves. To avoid deficiencies of the nutrients in this group, plants must have a continuous supply in the external medium or be able to tap reserves stored in organs other than leaves, as discussed later for manganese. Roots, young leaves, buds, seeds and fruits may fail to develop normally when the external supply of these nutrients becomes inadequate, even in plants with high total contents of them. Such cases can lead to misinterpretation of plant analyses unless special sampling procedures are adopted.

The failure of calcium to move from old leaves has been attributed to its low concentration in the phloem sap (Pate 1975). As a result, plant organs can grow only if they receive a continuous supply of calcium from the external medium or from the transpiration stream, as shown in elegant experiments with split roots (Haynes and Robbins 1947) and developing underground fruits of peanuts (Wiersum 1951, 1966) and subterranean clover (Ozanne and Howes 1973). Calcium deficiency thus develops in young leaves and other organs and is largely independent of the total amount of calcium in the plant, in many cases developing as soon as the external supply of nutrient becomes inadequate, regardless of how much excess calcium may be stored in older leaves; even *Lupinus albus,* which has an unusually high concentration of calcium in the phloem sap (Jeschke *et al.* 1985), showed this characteristic behaviour when deprived of calcium (Loneragan and Snowball 1969). But while they do not remobilize calcium from leaves, plants can remobilize calcium from stems as, for example, in apple trees that lost some 40% of their calcium from trunk bark during the spring flush of shoot growth (Mason and Whitfield 1960) and in kiwifruit vines which lost enough calcium from their canes to provide 13% of the next season's leaf requirements (Smith *et al.* 1987).

In most plant species which have been studied, boron resembles calcium in its failure to move from old leaves to developing organs and its requirement in the immediate environment for root growth (Haynes and Robbins 1947). Thus, when transferred from culture solutions with high boron to solutions without boron, tomato plants rapidly developed boron-deficiency symptoms in their young leaves but lost none of their boron from old leaves with high boron concentrations and symptoms of boron toxicity (Oertli 1993). But, while excess boron in old leaves is not exported in the phloem, appreciable amounts may be lost in guttation fluid and washed from leaves (Kohl and Oertli 1961; Nable *et al.* 1990): the boron retained by plant cells appears to be confined to and tightly bound to pectic compounds of the cell wall (Brown and Hu 1993; Hu and Brown 1994).

In contrast to its immobility in most species, boron appears to be phloem mobile from leaves of some stone fruit trees of the genera *Malus, Prunus* and *Pyrus.* The patterns of boron distribution and symptoms of toxicity in these trees have been observed to differ markedly from those so indicative of phloem immobility in other species (see Brown and Hu 1996). Moreover, application of boron to the leaves of several trees of these genera in the autumn increased the boron contents of flower buds in the same season and fruit set in the following season (Hanson 1991a, 1991b). Brown and Hu (1996) have postulated that the phloem mobility from leaves of these stone fruit trees is related to sorbitol being their primary translocated photosynthate, the boron being transported as boron–sorbitol complexes.

Manganese also resembles calcium in its failure to move from old leaves to developing organs and in the poor growth of roots in environments from which it is absent (Nable and Loneragan 1984a, 1984b). In addition, applications of manganese to plant leaves are effective only in the short term (Gettier *et al.* 1985). But unlike calcium, manganese has been reported to be present in phloem sap at concentrations which are high relative to tissue requirements (Shelp 1987, 1988, 1993). Although manganese is not mobilized from leaf blades, it may be remobilized rapidly from the stems and even petioles of some species, as evidenced by its loss from petioles and stems but not from leaf blades of *Lupinus angustifolius* following anthesis and during seed development (Hannam *et al.* 1985a; Figure 1.7).

While no definitive studies on the mobility of iron from leaves are available, the rapid development of symptoms in young leaves and root tips and their absence from old leaves during the onset of iron

deficiency suggests that iron in old leaves is not mobile. Yet there are several reports of iron concentrations in the phloem sap (e.g. Hocking 1980) which seem high relative to cellular requirements.

(iii) The nutrients that are variably phloem mobile from leaves, sulfur, copper and zinc, remain in old green leaves as their supply becomes deficient but may move rapidly from them during senescence (Figure 1.2c,d). As a result, the concentrations of these nutrients in old green leaves do not respond as rapidly to declining nutrient supply as they do in young leaves, which are generally first to show deficiency symptoms. Even plants which had accumulated inorganic sulfate in the vacuoles of their old green leaves before transfer to sulfate-free solutions exported it too slowly to prevent sulfur deficiency developing in their young leaves (Bouma *et al.* 1972; Clarkson *et al.* 1983), a surprising result in view of information that sulfate concentrations may be quite high in the phloem (Smith and Lang 1988; Van Beusichem *et al.* 1988).

The retention in and movement of copper, zinc and organic sulfur from leaves is closely related to the movement of nitrogen (Ergle 1954; Hill *et al.* 1979a, 1979c; Figure 1.2c,d; Figure 1.3). But unlike nitrogen deficiency, deficiencies of these nutrients do not trigger senescence and may even delay it, sometimes producing unexpected results. For example, during the development of copper deficiency in wheat, copper concentrations in young leaves fell while those of older green leaves remained relatively high. In the same experiment, leaves of plants supplied with adequate copper lost so much copper during senescence that their copper concentrations dropped below those of leaves of severely copper-deficient plants whose senescence was delayed (Loneragan *et al.* 1976, 1980). By contrast, although leaves of subterranean clover given adequate copper lost most of their copper during senescence, they retained sufficient to reflect their levels of copper supply, remaining higher than those of copper-deficient plants. This greater retention of copper in the senescent leaves of this pasture legume may be related to its retention of relatively high protein concentrations (Reuter *et al.* 1981a, 1981b).

Nitrogen supply would also be expected to have a major impact on the redistribution of variably mobile nutrients from leaves through its effects on leaf senescence, as has been shown for copper (Hill *et al.* 1978). Clearly, the behaviour of the variably mobile nutrients is complex, requiring that experimental results be interpreted carefully with due consideration of interacting factors.

The phloem mobilities from leaves of molybdenum, cobalt and nickel have received insufficient study to place them confidently in any group. Molybdenum and cobalt have been classified as phloem mobile since their radioisotopes painted on leaves were readily translocated from them (Bukovac and Wittwer 1957; Handreck and Riceman 1969). Such evidence is not definitive as seen from the contrast

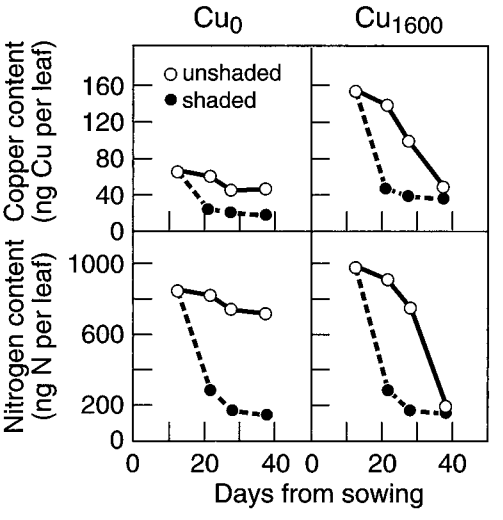

Figure 1.3 Effect of shading the oldest leaf of a copper deficient (Cu_0) and a copper adequate (Cu_{1600}) wheat plant on their export of copper and nitrogen (Hill *et al.* 1979a)

between the rapid export of painted radioisotopes of sulfur, manganese and zinc (Bukovac and Wittwer 1957) and the retention of these nutrients in green leaves when imported *via* xylem sap. However, foliar application of molybdenum has corrected molybdenum deficiency in many species (Gupta and Lipsett 1981), and in peanuts it also increased molybdenum concentrations in nodules and seeds (Rebafka cited by Marschner 1995). Recent experiments with black gram have confirmed that molybdenum may have high phloem mobility from leaves but that it varies with molybdenum supply; plants given an adequate supply of molybdenum lost a high proportion of their molybdenum from trifoliate leaves after flowering, but none from leaves of deficient plants. This variable phloem mobility of molybdenum from leaves differed from the behaviour of copper, sulfur and zinc in that senescence did not promote the movement of molybdenum from leaves of molybdenum-deficient plants (Jongruaysup *et al.* 1994). Further experiments, including some with non-legumes, are required to elucidate the factors governing the phloem mobility of molybdenum from leaves.

B. Diagnosis of Nutrient Status from Nutrient Concentrations

B.1 Nutrient concentrations and yield

The relationship between nutrient concentration and yield of a plant or plant part forms the basis of most schemes for using plant analysis to assess plant nutrient status. Some common forms of relationship that have been observed are shown in Figure 1.4. The most common form is that in Figure 1.4a. It comprises three parts: an ascending portion where yield increases with increasing nutrient concentration, a plateau where yield is not limited by nutrient concentration, and a descending portion in which yield declines with further increase in nutrient

concentration. Whether or not the complete curve is obtained in any one experiment depends on the particular nutrient being studied, its initial level in the soil, the range of treatment levels applied, the plant part sampled, the time of sampling, and the sampling procedure adopted. Nutrient concentrations of plants in many soil experiments do not extend into the toxicity range, and sometimes their plateau is very short, even over a wide range of fertilizer applications, as in the relationship of phosphorus concentrations to yield in leaves and shoots of wheat (Elliott *et al.* 1997b). It is also found for some nutrients in seed where the range of nutrient concentrations is narrower than in leaves and there is little 'luxury' accumulation (Randall *et al.* 1981).

Figures 1.4b, c and d depict three variations on this relationship. In Figure 1.4b, the absence of an appreciable plateau where yield is not affected by nutrient concentration has been observed for potassium concentration in the youngest leaf of tomato, but sampling of older leaves revealed the common relationship with a more extended plateau (Figure 12.4 in Marschner 1995). Lack of an appreciable plateau in relationships between yield and nitrogen concentration in the youngest fully expanded leaf of zucchini squash has also been reported (Huett and White 1991). The sigmoidal relationship in the ascending portion of the curve in Figure 1.4c has been noted for young plants growing in very deficient soils; as these plants grew older, the relationshipchanged to the more common form shown in Figure 1.4a (Smith 1975; Bolan *et al.* 1983).

The relationship shown in Figure 1.4d, in which initial increases in yield are associated with decreases in nutrient concentration, was first noted in studies of copper nutrition by Piper (1942) and Steenbjerg (1951). This relationship is commonly referred to as the Piper-Steenbjerg effect or C-shaped curvature

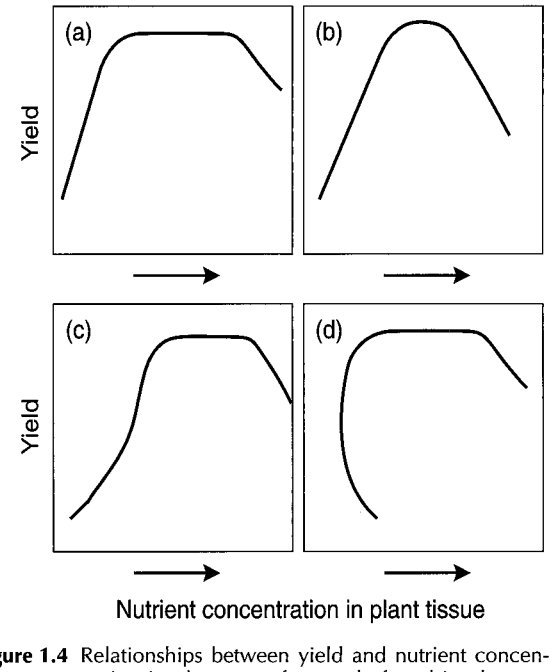

Figure 1.4 Relationships between yield and nutrient concentration in plant parts frequently found in plants as nutrient supply increases from deficient to toxic.

(Bates 1971) and has since been reported for a number of elements. For plants with no characteristic nutrient-deficiency symptoms it presents problems in the interpretation of the results of plant analyses.

For copper in wheat, a Piper-Steenbjerg effect has been attributed to the loss of copper from senescing leaves of copper-adequate plants to concentrations below those of old leaves of copper-deficient plants whose senescence and export of copper was delayed, as discussed earlier (Loneragan *et al.* 1976, 1980; Hill 1980; Hill *et al.* 1978, 1979a, 1979b). In subterranean clover, a Piper-Steenbjerg effect arose from variations in the distribution of both copper and dry matter between leaf blades, petioles and stems (Reuter *et al.* 1981a, 1981b). During severe copper deficiency, the amount of dry matter in leaf blades relative to that in stems plus petioles increased, and stems and petioles had higher copper concentrations than leaf blades. When copper was adequate, however, plants had higher copper concentrations in young leaf blades than in petioles. The multiplicative effects of these changes in the partitioning of dry matter and copper between leaf blades or petioles and stems in copper-deficient subterranean clover resulted in higher copper concentrations in shoots with severe deficiency than in those with only marginal copper deficiency.

In copper-deficient cereals (Hill *et al.* 1978, 1979a, 1979b; Loneragan *et al.* 1980), subterranean clover (Reuter *et al.* 1981a, 1981b), and peanut (Nualsri 1977), it has been possible to avoid the problems associated with the Piper-Steenbjerg effect by sampling tissues such as young leaves that do not exhibit the effect. However, problems remain with some nutrients. For example, Piper-Steenbjerg curves that have been observed in the relationship of yield to zinc concentrations in corn tops (Hiatt and Massey 1958) and young leaf blades of sugar beets (Rosell and Ulrich 1964) remain unexplained. Plants with such anomalously high concentrations usually show marked symptoms of deficiency, as is the case with zinc, so that careful observations at sampling may avoid errors of interpretation. In these situations too, Ulrich and Hills (1967) have recommended sampling as soon as symptoms appear rather than waiting until marked yield reductions occur.

In establishing standards of nutrient concentration for the diagnosis of the nutrient status of plants, two main procedures have been used. The first uses nutrient addition experiments to provide response curves to define those plant nutrient concentrations which limit growth through deficiency or toxicity. These concentrations can then be used for trouble shooting — diagnosing existing nutrient problems in unproductive crops. At the same time, by defining the nutrient concentrations for both deficiency and toxicity, the procedure also defines the sufficiency range.

The second procedure uses nutrient concentrations in samples from surveys of crops in the field. A third procedure, 'Vector Analysis', which has recently been suggested for diagnosing nutrient deficiencies

in forest trees (Timmer and Armstrong 1987; Haase and Rose 1995), is not of itself a diagnostic procedure but is simply an aid to the interpretation of responses to fertilizer or other treatments. The term should not be confused with the statistical procedure of vector analysis. It is much simpler, and involves graphical representation of the relative changes in dry weight and nutrient concentrations and contents of leaves or shoots in response to nutrient treatments.

B.2 Critical nutrient concentrations

The standard concentrations used for diagnosing nutrient deficiency or toxicity are based upon the concept of 'critical nutrient concentrations' that forms the basis of most methods of using plant analysis to assess plant nutrient status.

B.2.1 Principles

Ulrich (1952) gave three formal definitions of the critical nutrient deficiency concentration:

- the nutrient concentration that is just deficient for maximum growth, or
- that which is just adequate for maximum growth, or
- the concentration separating the zone of deficiency from the zone of adequacy.

These definitions are implied in most modern diagnostic schemes.

In proposing three definitions of the critical nutrient concentration, each one emphasising a different viewpoint, Ulrich (1952) pointed out that this usually did not cause problems in practice. The reason is that, when determined experimentally, the critical concentration is not a single value but a narrow range of nutrient concentrations, above which the plant is adequately supplied with nutrients, and below which the plant is deficient. Such a range would, therefore, cover the different critical values derived by strict application of different definitions. This view of the critical concentration being a range rather than a single value is often overlooked when critical concentrations are reported or used to interpret plant analyses. Too often, critical concentrations are regarded as single values and rigid boundaries between deficient plants and those adequately supplied with nutrients. Perusal of the data and methodology used to derive a critical nutrient concentration will reveal how inappropriate it is to attempt to use critical concentrations in this way. The effects of the numerous physical, environmental and biological factors that influence nutrient levels in plant tissues is a further persuasive argument for regarding critical nutrient concentrations as ranges rather than single values. In practice, most authors do not report ranges for critical nutrient concentrations, as users of the tables in this manual will note; it is important to bear the above comments in mind when using these tables.

One means of highlighting the fact that a critical concentration is a range is to provide estimates of the errors involved in its derivation. Selection of a defined point on a rather arbitrarily hand-fitted curve has been a common method for deriving critical nutrient concentrations. The simple Cate-Nelson procedure (Cate and Nelson 1971) has also been widely used. However, computer techniques for fitting non-linear regression models are now available which permit objective derivation of critical nutrient concentrations and their associated errors. Models are available that provide direct estimates of maximum yield and the errors associated with determination of maximum yield from the relationship between yield and nutrient concentration. Some models also include parameters that enable the critical concentration and its associated error to be estimated (Griffiths and Miller 1973; Smith and Dolby 1977; Johansen 1976, 1978).

The fact that a single definition of the critical nutrient concentration would not suffice reflects the empirical approach to plant analysis that has evolved. This empiricism is necessitated by a lack of knowledge regarding the functions of nutrient elements in the plant and lack of a means of measuring the effective concentration of nutrients at sites of reaction within plant cells. Problems arise particularly with those nutrient elements with restricted mobility, such as calcium (Loneragan and Snowball 1969). An attempt to address the problem has been made with the introduction of the concept of a 'functional nutrient requirement' (Loneragan 1968) defined as 'the minimal concentration of nutrient within the organism which can sustain its metabolic function at a rate which does not limit growth'. Experimental determination of the functional nutrient requirement of a whole plant would be difficult, if not impossible, and would probably not be useful. But some success has been achieved in determining the functional nutrient requirement of leaves for specific activities by relating their nutrient concentrations to enzymic activity, physiological response, or growth (see below). It has been suggested that these values might be used as critical values for diagnosis of nutrient deficiency in the plant (Ohki 1982; Nable *et al.* 1984; Kirk and Loneragan 1988).

B.2.2 Derivation of critical nutrient concentrations

Derivation of a critical nutrient concentration for diagnosis requires that a well-defined curve be established between nutrient concentration in a plant part and the current nutrient status of the plant. The standard measure of a plant's current nutrient status is generally taken as the response of its shoot dry matter yield to nutrient supply and is commonly expressed relative to the maximum shoot yield; nutrient concentrations are generally expressed as the ratio of the total nutrient content to dry matter (DM) of a plant part — macronutrients as % DM and micronutrients as mg kg^{-1} DM.

The critical concentration for deficiency diagnosis can be obtained from water culture, sand culture, glasshouse, or field experiments in which increasing levels of nutrient are supplied to a deficient growing

medium. Levels must be chosen so that, at sampling time, the desired portion of the relationship between nutrient concentration and yield is fully defined. An accurate measure of maximum yield is particularly important. Precautions must be taken during the experimental phase to avoid rapid nutrient depletion of the growing medium (see B.3.1) and to ensure that growth is not limited by factors other than supply of the nutrient being studied. Following harvest of the appropriate plant part and analysis of its nutrient content, a relationship between nutrient concentration and shoot yield is derived (Figure 1.5). An appropriate yield is then selected (often 90% of maximum yield) and the nutrient concentration in the selected plant part at this yield is accepted as the critical nutrient concentration. When the slope of the curve of yield to nutrient concentration is too steep to define an accurate critical concentration, an alternative two stage approach may be used by firstly estimating the level of nutrient application corresponding with 90% maximum yield, and then using the relationship of plant nutrient concentration to nutrient application to estimate the critical nutrient concentration (Pinkerton *et al.* 1989).

A similar approach is generally used for defining the critical concentration for a nutrient toxicity. This concentration may be more appropriately considered a threshold of toxicity rather than a critical value. For many nutrient toxicities, these values may vary so widely with environmental conditions that they are restricted to specific situations.

While response of dry matter yield to nutrient supply has generally been accepted as the standard measure of plant nutrient status against which to calibrate indices of nutrient status such as nutrient concentration in plant parts, other criteria have occasionally been used. For example, critical concentrations in plant leaves have been derived from relationships of nutrient concentrations in leaves to fresh weight, water content, leaf symptoms, photosynthetic oxygen evolution (Ohki 1982) and the rate of leaf blade elongation (Kirk and Loneragan 1988). Sometimes too, criteria other than total nutrient concentration have provided better or more convenient indices for use as critical diagnostic values; they are discussed in Section E.

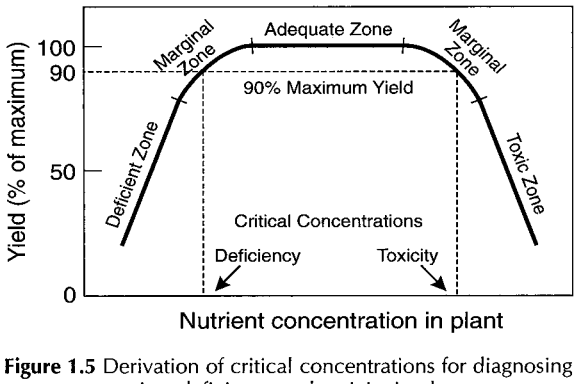

Figure 1.5 Derivation of critical concentrations for diagnosing nutrient deficiency and toxicity in plants.

B.3 Factors affecting critical concentrations

In concept, the critical concentration for a nutrient deficiency or toxicity is pictured as a constant value which defines a unique physiological state of a plant. In practice, experimentally determined values for critical concentrations vary widely, due to a number of factors and these need to be taken into account when interpreting plant test data.

B.3.1 Culture systems and sensitivity of plant response

Problems in calibrating a plant nutrient test for diagnosing a nutrient deficiency can arise from the slow response of shoot dry matter to developing nutrient stress. During the time for a deficiency to depress dry matter by 5–10%, the plant may continue to absorb and redistribute nutrients. As a result, the rate of nutrient depletion in the culture system in which the deficiency develops has a major impact on the critical concentration determined by calibration with shoot dry matter, as Spear *et al.* (1978) have so clearly shown in experiments on potassium deficiency in cassava. They found that the youngest fully expanded leaf of cassava had a critical potassium concentration of 1.1% when plants were grown in flowing culture solution with a constant, sub-optimal concentration of potassium, but dropped progressively to 0.5% in a series of non-renewed solutions of decreasing volume. They considered that all values determined by depletion of nutrients from restricted volumes of solution or soil would be erroneously low and that values would only represent a constant characteristic of a plant genotype when obtained by growing plants in culture solutions with low and continuously maintained concentrations of the test nutrient or in a large volume of a soil with a high buffer capacity (Spear *et al.* 1978; Asher and Edwards 1983).

Precautions against rapid nutrient depletion during the onset of nutrient deficiency would also need to be taken when using other criteria of nutrient status which respond slowly to the onset of deficiency. For example, a relatively slow rate of response in symptoms to magnesium deficiency may explain the much lower magnesium concentrations in young leaves of subterranean clover grown with an interrupted magnesium supply compared with plants grown with a constant suboptimal supply (Scott and Robson 1990).

For young leaves, the effects of culture systems on the experimental values for critical concentrations of the immobile nutrients would be expected to be similar to those for potassium. But for old leaves, they might be opposite, resulting from greater accumulation of excess nutrient in old leaves during its depletion from the initially higher concentrations of non-renewed solutions compared with solutions of constant composition, as suggested from studies with calcium (Loneragan 1968).

An alternative procedure for setting critical concentrations correlates nutrient concentrations with criteria of nutrient status which respond more rapidly than dry matter to the disorder. In culture systems where deficiencies were induced rapidly by

transferring plants from solutions with adequate nutrients to solutions with all except the nutrient under study, photosynthetic oxygen evolution in subterranean clover leaves responded much more quickly than shoot dry matter to manganese deficiency (Nable *et al.* 1984), as did the rate of leaf blade elongation in soybean to boron deficiency (Figure 1.6; Kirk and Loneragan 1988). As a result, when determined by calibration against these more responsive physiological criteria, critical concentrations of manganese and boron in young leaves were much higher than those determined by calibration against shoot dry matter. Similarly, using the more sensitive relative growth rate rather than total dry matter as a measure of response gave higher critical concentrations for diagnosis of deficiencies of nitrogen, phosphorus and potassium induced in lettuce by transfer from adequate to deficient solutions (Burns 1992).

B.3.2 Plant age and part

Growth and development cause marked changes in nutrient concentrations in plant parts and tissues as the growing season progresses. In whole shoots of annuals, the concentrations of all except the leaf immobile nutrients decline steadily with age (Smith 1962), probably as the combined result of a declining nutrient supply and an increasing proportion of structural tissues and storage substances. For the same reasons, critical deficiency concentrations in whole shoots also decline with age, as for example for phosphorus in stylo (Moody and Edwards 1978), subterranean clover (Lewis 1992) and wheat (Bolland and Paynter 1994; Elliott *et al.* 1997b). In perennials, the concentration of nutrients in leaves and other organs fluctuates with seasonal flushes of shoot growth and fruit development; they also vary between leaves of vegetative and fruiting shoots (Smith 1962; Leece 1976; Bouma 1983). Therefore, for interpreting nutrient concentrations in plant samples, the growth stage at sampling needs to be defined. Three approaches have been taken.

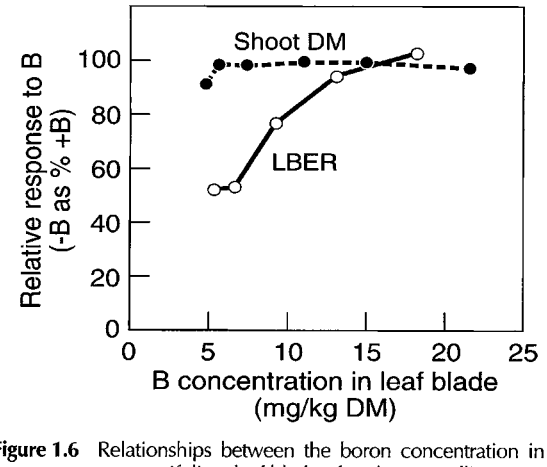

Figure 1.6 Relationships between the boron concentration in a young trifoliate leaf blade of soybean seedlings grown in nutrient solution without boron (–B) and the relative response to boron of (a) the elongation rate of the same leaf blade (LBER), and (b) the seedling shoot dry matter (shoot DM). The LBER and shoot DM of the –B seedlings are reported as a percentage of those of control seedlings grown with added boron (+B). (Kirk and Loneragan 1988).

The first approach has been rigid standardization of the stage of growth at which the whole plant above ground (i.e. the whole shoot) is sampled and analysed. This has been used for deriving diagnostic criteria for deficiencies of sulfur and phosphorus in tropical pasture species (Andrew and Robins 1969; Andrew 1977; Moody and Edwards 1978) and phosphorus in wheat (Elliott *et al.* 1997b). Mixing of plant parts of different physiological age and type results in some loss of sensitivity, but it does minimize the problem of ensuring that the correct plant part has been sampled. This approach is best suited to elements that move readily in both deficient and adequately supplied plants, but it is unsuitable for elements of limited or variable mobility.

The second approach also samples and analyses the whole shoot but uses its dry weight to adjust for variations in nutrient concentrations with the stage of growth (Moller Nielsen and Friis-Nielsen 1976; Moller Nielsen 1979). Southern (1985) has established critical deficiency concentrations for a series of dry weight classes and has used them successfully for diagnosis of nutrient deficiencies in cereals and subterranean clover in Western Australia.

The third approach has been to sample tissue of standard physiological age. Thus, in the same plants in which the critical concentration of phosphorus in whole shoots declined from early vegetative growth to flowering, it remained constant in the apical tissue and leaves of stylo (Moody and Edwards 1978) and in young leaves of the same physiological age in subterranean clover (Lewis 1992). Similar results have been reported for critical concentrations of copper in wheat, peanut and subterranean clover (Robson *et al.* 1980, 1984; Reuter *et al.* 1981b).

As critical concentrations vary with age of plant parts, it is essential that parts of the same physiological age be used, irrespective of the degree of deficiency, and that they be sampled carefully. The critical concentration for zinc is especially sensitive to leaf age as seen in subterranean clover where it declined from 25 mg kg^{-1} DM in the apical leaf to 18 and then 10 mg kg^{-1} DM in successively older leaves (Reuter *et al.* 1982). A technique commonly used to standardize physiological age is to sample petioles and/or blades of leaves at well defined stages of development, such as the most recently mature leaf blade, the youngest emerged leaf blade, or the youngest open leaf blade (see Figure 3.3 in Chapter 3).

The best plant part to sample depends upon the nutrient; young immature parts are generally the most sensitive for nutrients that are immobile or variably mobile from leaves, while older parts are the most sensitive for those which are phloem-mobile. However, apart from samplings of wood or storage tissues of perennial species, where they provide a means of assessing nutrient 'reserves', older parts are not commonly used for plant analysis, probably because of the difficulties in interpreting the results

and the practical problems of sampling them reliably. Interpretation is hampered by the rapid and often variable movement of mobile nutrients from old leaves as they mature and senesce. Growing at the base of many herbaceous plant species, old leaves suffer frequently from insect and pathogen damage, and are often difficult to identify accurately in the field. Consequently, sampling procedures that use younger parts are often adopted for the readily mobile nutrients; but the very young parts which may be preferred for immobile and variably mobile nutrients are generally not satisfactory. This is demonstrated in the youngest leaf of tomato, which had a very narrow range between the critical potassium concentrations of 3.0% for deficiency and 3.5% for toxicity compared with a broad plateau from 1.5 to 5.5% for a mature green leaf (Marschner 1995). To simplify the collection of samples and minimize the number analysed in commercial laboratories, compromises are usually made by selecting a plant part whose concentrations give useful information for many nutrients, as seen in the 'best bets' recommendations of this manual and elsewhere (e.g. Weir and Creswell 1993a, 1993b, 1994, 1995). The youngest fully expanded leaf suggested some time ago by Ulrich (1952) has been used successfully for many nutrients in many plant species.

Unfortunately, there are many reports that critical concentrations in plant parts of apparently identical physiological age vary with the age of the whole shoot. Some of these reports are not relevant to diagnosis, as the studies are predictive, relating nutrient concentration to subsequent rather than current yield. But other studies using current yield data have encountered the same problem. In some cases the decline in critical concentration may result from plants of increasing size rapidly depleting the test nutrient from a restricted supply of nutrient in a small volume of solution or soil in pots, as already discussed.

Whilst artifacts of experimental systems may be the reason for some reports that, with increasing age of the shoot, critical nutrient concentrations decline in leaves of the same physiological age, other reports appear to be soundly based. Two causal factors have been suggested (Smith 1978). Firstly, some nutrient deficiencies delay phenological development of plants (Williams 1955). If the requirement for a particular nutrient varies with the stage of plant development, then critical nutrient concentrations in tissues of apparently similar physiological age may also vary. Secondly, as leaves become more distal on the stem of grasses (i.e. their level of insertion on the stem increases), their cell wall characteristics change (Wilson 1976): these morphological changes could change the nutrient requirement of successive leaves at the same physiological age. This second explanation is consistent with observations on wheat leaves of the same physiological age in which the critical deficiency concentration range of phosphorus fell with increasing shoot age. Elliott and colleagues (Elliott *et al.* 1997b) observed that, as the number of leaves on the stem increased with shoot age, the weight of the young, terminal leaves increased, probably due to an increasing proportion of structural tissue. Over the same time, as the level of insertion of the youngest emerged leaf increased from 1 to 7, the critical concentration in its blade decreased from 0.48–0.55% to 0.22–0.25%. Elliott and colleagues have proposed that the level of insertion of the youngest emerged leaf on the stem provides a simple index of the stage of growth which must be specified for diagnosis of phosphorus deficiency in wheat, even for leaf blade samples of the same physiological age. In other cases, the problem of variation of critical concentrations with plant age has been overcome by expressing the concentrations in a manner that takes the moisture content of the tissue into account, as discussed in Section E.1.

Perennial plants often pose additional problems. In fruit trees, sampling of plant parts for analysis needs to be related to the location and stage of fruit development. Sometimes too, as in *Hevea brasiliensis*, it is difficult to sample leaves of standard age during the sampling season; in this species, the problem was resolved by relating leaf calcium to leaf age and using the calcium concentration of sampled leaves to adjust concentrations of other nutrients to accord with leaves of standard age (Lau and Wong 1993). In *Eucalyptus marginata*, living bark from stems of defined age appeared more useful than leaves for diagnosing the phosphorus status of the tree (Dell *et al.* 1987).

Mature seeds, which can be collected and analysed conveniently in many crop species, provide samples of defined physiological age. Seed analysis has been used to diagnose nutrient deficiencies in crops at harvest and in the seed itself. It has also been used to predict nutrient problems in future crops (C.2.1).

The nutrient concentrations in seeds might be expected to be relatively insensitive to nutrient status, being buffered by retranslocation of elements from vegetative tissues as plants mature. Moreover, the uneven distribution of inorganic nutrients between embryo and storage tissues and the effect of seasonal conditions on the proportional weights of these components is likely to cause wide variation in critical concentrations from year to year. Such variation could be especially troublesome with cereal grains in which the endosperm has much lower concentrations of most nutrients than the embryo (e.g. Hill *et al.* 1979b).

Nevertheless, seed analysis has proved useful in diagnosing sulfur and nitrogen deficiencies in wheat crops (Randall *et al.* 1981; Moss *et al.* 1982). Information on phosphorus and sulfur concentrations in mature seed of the tropical legume *Stylosanthes humilis* (Robinson and Jones 1972) also suggests that there is potential for using seed of pasture species for diagnostic purposes. But experience with diagnosis of copper deficiency in wheat from grain analysis suggests caution — the concentrations of copper defined as critical for deficiency in Europe and South Australia exceed those in the grain of most wheat crops in Western Australia, including

crops which failed to respond to increasing copper supply (Robson and Reuter 1981).

Seed analysis has also been used to diagnose seed quality for a number of nutrients and crops. For example, critical concentrations have been defined for deficiencies in seeds of calcium in peanuts (Cox *et al.* 1976), manganese in peas (Glasscock and Wain 1940) and sweet lupin (Hannam *et al.* 1984) and boron in black gram (Bell *et al.* 1989).

In some situations, critical concentrations in above ground plant parts do not reflect nutrient problems existing in roots. Thus, leaf analysis may indicate an adequacy of the phloem-immobile nutrients calcium, boron and possibly manganese for plants growing in soils with adequate supplies in surface horizons, but fail to indicate a deficiency restricting root growth in deeper horizons which depresses plant growth by limiting nutrient and water acquisition from subsoils as, for example, for calcium deficiency in cotton (Howard and Adams 1965).

Critical nutrient concentrations in shoot parts may also fail to diagnose nutrient problems in root systems arising from toxicities of heavy metals, acidity, and aluminium. Smith (1962) cites an example in citrus of leaf analysis indicating normal copper and iron deficiency; the iron deficiency was found to result from copper toxicity damaging the root system. While leaf analysis can diagnose copper deficiency, it is not sensitive to copper toxicity; root analysis is far better (Rahimi and Bussler 1974, cited by Marschner 1995).

B.3.3 Environmental interactions

There are many reports that critical concentrations for diagnosis of nutrient deficiencies vary as the result of interactions with other nutrients and climate (e.g. Munson and Nelson 1990). Most of these reports arise from effects of environmental interactions on plant growth subsequent to sampling and hence relate to prediction rather than diagnosis; they will be discussed in Section C.1.4. But there is clear evidence that, in some species, the plant's internal requirement for some nutrients, and hence its critical concentration for deficiency diagnosis, varies with the supply of other nutrients (Robson and Pitman 1983) and with environmental factors such as light, temperature, carbon dioxide concentration and disease organisms. Critical concentrations for nutrient toxicities may also vary with environmental factors.

In a number of species, sodium can substitute for some functions of potassium, so that critical concentrations of potassium for diagnosis of potassium deficiency vary widely with the sodium supply. For example, in the grass *Chloris gayana,* the critical potassium concentration in shoots can be reduced from 2.1% to 0.4% by the addition of sodium (Smith 1974). But the ability of sodium to substitute for potassium varies widely with species and cultivars from substantial to nil (Smith 1972; Marschner *et al.* 1981). Where it occurs, the extent of substitution also varies widely among individual organs, with age of organs, and within cells. In cells it is limited in the cytoplasm and large in vacuoles where sodium substitutes for potassium as an osmoticum (Leigh *et al.* 1986). In tomato, most of the sodium which replaces potassium is located in the petioles of expanded leaves (Besford 1978) and in sugar beet, sodium can replace most of the potassium in old leaves but relatively little of it in expanding leaves which have a higher proportion of cytoplasm (Lindhauer *et al.* 1990). Such variability creates problems for sampling of plant parts and for the setting and interpretation of critical concentrations for diagnosis of potassium deficiency, leading to suggestions that the concentration of total cations or of all osmotically active solutes might be a better indicator of plant growth than potassium concentration alone (Dijkshoorn 1962; Smith 1972; Leigh and Wyn Jones 1984; Barraclough and Leigh 1993).

Nitrogen supply affects the critical deficiency concentrations for cobalt and molybdenum in legumes and some other plants as it impacts on their requirements for these nutrients. The literature has been reviewed recently by Marschner (1995), supporting the conclusions that legumes require cobalt only for nitrogen fixation, and not at all when given an adequate supply of fixed nitrogen. They also require appreciably more molybdenum when fixing nitrogen than when supplied with fixed nitrogen. Plants which do not fix nitrogen require molybdenum primarily for nitrate reduction; they require very much less when supplied with ammonium salts.

Increasing nitrogen supply also depresses the calcium and copper requirements of legumes fixing nitrogen (Robson and Pitman 1983). By contrast, increasing nitrogen supply increases the internal requirement and the critical concentrations of copper in whole shoots of oats and barley (Thiel and Finck 1973). This increase appears to have resulted from nitrogen delaying the senescence of old leaves and the export of copper from them, thus maintaining the copper concentrations of shoots above those of plants of lower nitrogen status. Sampling of young leaves should eliminate the problems of deficiency diagnosis since their critical concentrations of copper remain constant with varying nitrogen supply (Hill *et al.* 1978, 1979a; Loneragan *et al.* 1980). In other cases where nutrient interactions arise from one nutrient affecting the transport of another to functional sites within the plant, the sampling of specific tissues could also be expected to minimize problems of interpretation.

Very high, near toxic, concentrations of phosphorus in leaves may decrease the physiological availability of zinc (Cakmak and Marschner 1987), giving problems for diagnosis of zinc deficiency under these unusual conditions. Less specific interactions among nutrients have been reported but have not been clearly demonstrated for diagnosis, although they are common for prediction; they probably arise from effects of limiting nutrients on plant growth as discussed for the interaction between nitrogen and

phosphorus in *Araucaria cunninghamii* in Section C.1.4. When analytical and growth data were collected at the same time in wheat, increasing nitrogen fertilizer had little or no effect on the critical concentration for diagnosing phosphorus deficiency even though it promoted growth substantially (Elliott *et al.* 1997a).

Critical concentrations for diagnosis of nutrient toxicities may fluctuate strongly with the concentrations of other inorganic elements. Thus for manganese toxicity, the addition of silicon to the nutrient solution increased the critical concentration in leaves of bean from 100 to 1000 mg manganese kg^{-1} (Horst and Marschner 1978).

A low concentration of many nutrients in plants often increases their susceptibility to disease. For example, barley plants deficient in zinc or manganese are susceptible to root diseases (Thongbai *et al.* 1993; Graham and Rovira 1984). If, as Graham (1983) has suggested, effects of low nutrient supply on disease occur in the deficiency range only, the likely incidence of disease would not affect critical concentrations for deficiency diagnosis. By contrast, a high concentration of nitrogen in plants increases their susceptibility to some disease organisms which, by depressing plant growth, could depress the critical concentration for nitrogen toxicity. But the interaction between nitrogen and disease infection is complex (Marschner 1995) and has not been related to critical concentrations.

There is also some evidence that mycorrhizal infection of roots might affect critical concentrations for phosphorus in plant shoots since, at similar concentrations of phosphorus in their shoots, mycorrhizal subterranean clover plants had higher shoot dry matter than non-mycorrhizal plants (Pairunan *et al.* 1980).

The effects of temperature, light and carbon dioxide on critical concentrations of nutrients have received little study. Temperature had a marked effect on the concentration of manganese in leaf blades of tobacco at which symptoms of manganese toxicity first appeared, increasing them 7–fold when day/night temperatures were increased from 22/18 to 30/26°C (Rufty *et al.* 1979). High light intensity has long been suspected to enhance deficiency symptoms and plant requirements for zinc and boron; it has now been shown to enhance chlorosis and necrosis in zinc, potassium, and magnesium deficient leaves (Marschner and Cakmak 1989), but its impact on their critical concentrations has yet to be assessed. Shading of black gram plants depressed the critical levels of boron for expansion of young leaves from 15 to 10 mg boron kg^{-1} dry matter (Noppakoonwong *et al.* 1993). Increasing the concentration of carbon dioxide also depressed the critical concentration for deficiency of nitrogen and enhanced that of phosphorus in both cotton and wheat (Hocking and Meyer 1991; Rogers *et al.* 1993).

B.3.4 Genotype

A cursory examination of the diagnostic tables in this manual suggests considerable diversity among critical nutrient concentrations of different plant genotypes. However, when values from similar tissues and plants of similar physiological age are examined, this diversity is reduced considerably. In many cases, it then becomes feasible to construct major groupings of related plant species that have reasonably similar ranges of critical nutrient concentrations. Such groupings enable an experienced nutritionist to extend published diagnostic criteria for a particular species to related species. However, this must be done with considerable caution; only tentative conclusions can be drawn until they can be confirmed from more reliable assessments.

With the notable exception of potassium, and on the basis of somewhat limited research, species of the same genus and cultivars of the same species appear to differ little in their internal nutrient requirements. For example, three lupin species which differed widely in their responses to external iron supply, had similar critical iron concentrations for maximum chlorophyll synthesis (Tang and Robson 1993). Several cultivars of wheat, barley and oats which showed genotypic differences in copper concentrations in whole shoots and old leaves, had similar critical copper concentrations of approximately 1.0 mg kg^{-1} when young leaves of all genotypes were sampled (Nambiar 1976). Similarly, no substantial difference in critical nitrate-N levels could be found among several genotypes of wheat, barley, triticale and rye (Papastylianou and Puckridge 1981). In three cultivars of subterranean clover, no difference in the critical concentrations of copper in the youngest open leaves was measured in spite of substantial differences in the level of copper fertilizer they required in the root zone for maximum yield (Reuter *et al.* 1983).

The wide variation among species and cultivars in their critical concentrations for diagnosis of potassium deficiency has been mentioned in Section B.3.3. Four broad groups of species have been recognised on the basis of their ability to substitute sodium for potassium in osmotic functions; the proportion of substitution varies from nil in many temperate agricultural species such as maize and soybean to over 80% in many C_4 grasses and members of the Chenopodiaceae (Smith 1974; Marschner 1995).

Some broad groupings of species according to their requirements for other nutrients have also been recognised and attributed to differences in biochemical mechanisms and cell wall constituents. Marschner (1995) has suggested that C_4 plants will generally have lower critical concentrations for nitrogen deficiency than C_3 plants, because of differences in their photosynthetic mechanisms. The sulfur requirements of crop plants in Gramineae are less than in Leguminosae, which are less than in Cruciferae (Deloch 1960, cited by Marschner 1995). Differences in the composition of their cell walls where a high proportion of plant calcium and boron are located (Loomis and Durst 1992) are probably responsible for the much higher concentrations of calcium and boron in most dicotyledons than

monocotyledons, and for their usually much higher critical concentrations as indicated in the diagnostic tables of this manual. For calcium, the estimated internal requirements of young shoots of 18 annual legumes and herbs grown in flowing culture solutions with a range of low but constant calcium concentrations were double those of 11 cereals and other grasses (Loneragan 1968; Loneragan and Snowball 1969). The estimated calcium requirements varied little among the species within each group. The greater variation in other published critical concentrations probably arises from differences among species in the age and vegetative composition of the samples analysed and in nutrient supply during the calibration experiments.

In contrast to critical concentrations for deficiency, critical concentrations for toxicity may vary widely among species and cultivars. For example, for manganese toxicity the critical concentration in young shoots varied from 200 mg Mn kg^{-1} in maize to 5300 in sunflower grown under identical conditions (Edwards and Asher 1982).

B.4 Nutrient surveys

Surveys of nutrient concentrations in samples from crops at specified growth stages have been correlated with crop yields to establish standard, desirable nutrient concentrations for some species. This approach has been the primary method used for large perennial species where it is costly and difficult to set up traditional experiments to measure nutrient responses as in fruit trees (Leece 1968, 1976), vines (Robinson and McCarthy 1985; Smith *et al.* 1987; Creswell 1989) and plantation forest trees (Bevege 1978; Lambert 1984). It has also been used for corn, soybean and other annual crops (Munson and Nelson 1990).

A study aimed at developing nutrient concentrations standards for kiwifruit in New South Wales illustrates the approach (Creswell 1989). Preliminary experiments were undertaken on leaf samples collected from a commercial orchard to determine the best leaf for sampling. The best time in the year for sampling was chosen after following the variation in the concentration of seven nutrients at monthly intervals during three growing seasons: at the time recommended, the rate of change in concentration of most nutrients was minimal. After establishing that the sampling procedure gave a reasonably accurate picture of the nutritional status of the vines in an orchard block, 40 commercial plantings throughout the kiwifruit growing areas of New South Wales were sampled in three successive seasons. The results for leaf samples from the 10 most productive, best managed and healthiest plantings were taken as the nutrient concentration ranges for healthy vines. A set of leaf analysis standards for kiwifruit in New South Wales was then constructed by combining these data with values recommended from similar surveys of commercial kiwifruit orchards in New Zealand (Smith *et al.* 1987).

Standards derived in this way may be supplemented and refined by the accumulation of data from other sources such as commercial plant analytical services. They may also incorporate analytical values for deficiency and toxicity derived from a synthesis of data from sand culture experiments, field observations, and field fertilizer trials. This approach is even more empirical than that based on the critical concentration approach, making it advisable to interpret data cautiously. It is important too, to recognise that nutrient concentration standards set from surveys are not truly diagnostic but predictive since they are generally derived from relationships of nutrient concentrations at a favoured sampling time during vegetative growth with production data collected some time later. Hence they suffer from problems inherent in predictive techniques discussed in the next section. Provided this fact is recognised by restricting their use to appropriate situations, nutrient standards derived from surveys of commercial crops can be useful aids in nutrient management of crops.

C. Prediction of Nutrient Responses from Nutrient Concentrations

C.1 Principles

Diagnosis of plant nutrient status has little value unless aimed at correcting existing nutrient problems or preventing their development in the future. Such prediction is especially important in long lived perennial fruit and nut crops where nutrient problems in the current season may affect not only the yield and quality of the current season's crop but also the yield potential of next season's.

But whereas plant analysis alone may provide a definitive diagnosis of the nutrient status of the plant at the time of sampling, it can provide information only on the first of the three factors which determine nutrient response between sampling and final harvest:

- nutrient stores available for redistribution within the plant
- nutrient supply from the soil
- nutrient requirement for growth and yield.

Hence, the relationship of plant nutrient concentrations at sampling to subsequent yield must be regarded as variable and dependent upon factors governing the plant's uptake of nutrients from the soil and its requirements after sampling.

The relationship of nutrient concentration to predicted yield also differs from diagnosis in that, while diagnosis concerns the nutrient status of the plant as a whole, prediction usually concerns the relationship of nutrients to the production of selected components, such as seed. Moreover, predictive plant analysis is increasingly concerned with nutrient management to prevent pollution from excessive fertilizer use.

Additional problems may arise in the interpretation of plant nutrient concentrations when some other factor is limiting plant growth at the time of sampling.

The importance of this cannot be overemphasized since it is probably the most frequent cause of error. Unfortunately, the complexities of the field environment mean that sampling for plant analysis often occurs when growth is limited by water stress, temperature, light, disease, insect attack, abnormal root development, poor irrigation management, or deficiencies of nutrients such as nitrogen. Applying standards derived under 'ideal' conditions to analyses of such samples clearly opens the possibility for erroneous interpretation of the results. Environmental factors may also induce intermittent symptoms of nutrient disorders which further confuse interpretation of plant analyses.

C.1.1 Yield criteria

Dry weight of shoots or harvested plant parts (seed, fruit, root, tuber, etc.) most commonly measures nutrient response when calibrating plant analysis data for diagnosis or prediction. But it is not the most appropriate measure for many crops. For cereals used for some forms of processing, grain yield may be secondary to protein concentration or amino acid composition. For legumes, the amount of nitrogen fixed may be as important as dry matter yield. For sugar cane and sugar beet, sugar concentration is as important as stem or beet weight. Choosing a measure of plant response is often even more difficult in grazed pastures, where herbage yield may be less important than a range of indices related to long-term pasture stability and animal production. In the horticultural industries, quality criteria such as texture, aroma, flavour, and sometimes also long storage are important considerations for fruit, vegetables and tobacco (Embleton *et al.* 1975; Marcelle 1995).

To date, dry matter yield has remained the major criterion for the calibration of plant tests. Apart from horticultural crops, very little has been done to base interpretive information on the more complex, commercially relevant criteria.

C.1.2 Plant nutrient reserves

Plant analysis can measure the plant's internal reserves which contribute to its nutrient requirements between sampling and harvest. But few predictive studies have consciously examined the location and contribution of nutrient reserves to final yield. With the notable exception of a careful study of the location and redistribution of manganese in the shoots of lupins (Hannam *et al.* 1985a,1985b), most studies have simply extended diagnostic data to predictive applications through empirical relationships between nutrient concentrations at sampling and yield at harvest to produce critical concentrations for prediction. This is not a problem if the plant part selected for diagnostic plant analysis also happens to contain or reflect the plant's nutrient reserves. But it may be if the available nutrient reserves are stored in other plant parts, as shown in the lupin study above. In that study, manganese concentrations in leaves or whole shoots at anthesis correlated well with dry matter production at sampling but poorly with seed yield at harvest; none of the large amounts of manganese accumulated in leaf blades was redistributed to seeds whereas manganese moved readily from roots, stems, and petioles (Figure 1.7; Hannam *et al.* 1985a). The study provided a sound physiological rationale for the prediction of manganese deficiency in seeds based on manganese concentrations in the stem (Hannam *et al.* 1985b).

The inorganic ions, nitrate, sulfate, orthophosphate, and potassium, and some organic molecules accumulate in storage pools in various plant tissues when supplied in excess (Barraclough 1993).

Therefore, they should be sensitive indicators of plant nutrient status and should be especially valuable indicators of over-fertilization with its problems of wastage and pollution. In providing an estimate of nutrient storage, they should also be especially pertinent to the prediction of future nutrient needs. Conductive plant parts, such as petioles and stems, would probably be more sensitive to nutrient status than leaves in which the concentrations of nutrients required for metabolism are likely to be higher.

C.1.3 Soil nutrient supply after sampling

Nutrient concentrations in the plant at sampling reflect nutrient supply from the soil up to the time of sampling. They give no indication of the plant's ability to obtain nutrients from the soil following sampling. Yet nutrient uptake from the soil may make a substantial contribution to meeting the crop's nutrient requirements for its final yield.

Soil properties, such as clay type and content, organic matter and water contents, and physical characteristics, affect nutrient supply to the plant. Plant genome, mycorrhizae, and soil temperature, water, and pH affect nutrient uptake by the plant.

Plant species vary widely in their ability to obtain nutrients from soils. Even genotypes with similar critical concentrations for a nutrient deficiency may vary so widely that the same nutrient concentrations in the plant can lead to quite different fertilizer recommendations. The work referred to above (B.3.4)

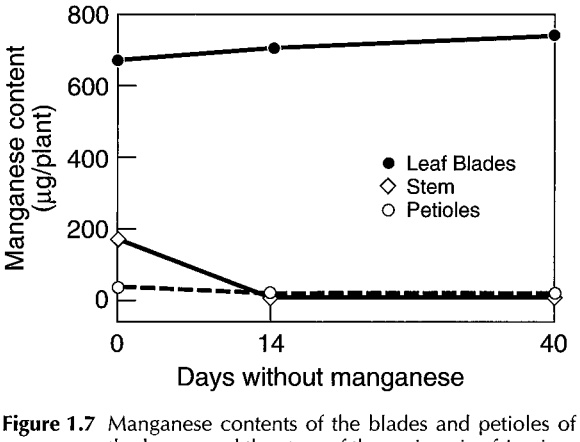

Figure 1.7 Manganese contents of the blades and petioles of the leaves and the stem of the main axis of *Lupinus angustifolius* during seed development and after termination of external manganese supply. (Data of Hannam *et al.* 1985a).

on copper nutrition of subterranean clover illustrates this point, as does that with manganese reviewed by Graham (1988). The presence and activity of mycorrhizae also modifies the ability of plant roots to absorb phosphorus and other nutrients from soils. In horticultural and floricultural species, the nutrient content of the scion is strongly affected by the rootstock genotype, which often will be a different species. The scientific literature is replete with descriptions of the effect of the perennial crop rootstocks on scion nutrient status (e.g. apples (Poling and Oberly 1979); grapevines (Downton 1985); oranges (Taylor and Dimsey 1993); pistachio (Brown *et al.* 1994)). The differences in the ability of particular rootstocks to supply scions with nutrients may be related not only to root morphology and/or uptake and transport characteristics, but also to relative mycorrhizal dependence. The salt exclusion characteristics of both citrus (Walker 1986) and grapevine rootstocks (Sykes 1987) suggest control of uptake and transport at the root level. These differences in nutrient uptake and transport may be reflected in the nutrient requirements of scions on different rootstocks: for example, exclusion of sodium and chloride ions by salt tolerant grapevine rootstock Ramsay (*Vitis champini* cv. Plancheon) may possibly mean that higher levels of compatible solutes such as potassium and nitrate are needed in the scion for subcellular osmotic adjustment. The propensity of a rootstock to absorb and transport nutrients must be considered in conjunction with knowledge of the effect of high or low levels of particular nutrients on scion performance. The efficiency of the rootstock must then be considered when plant nutrient concentrations are being interpreted and recommendations made.

Soil water is especially important to the availability from soils of phosphorus, boron, zinc and manganese, and impacts strongly on the interpretation of plant analysis for prediction. Two studies serve to illustrate the problems that interactions with soil water, a factor that commonly restricts plant growth, pose for those interpreting plant analyses. In work on phosphorus nutrition of *Stylosanthes humilis* at Katherine in the Northern Territory, Fisher (1980) found that phosphorus concentrations in shoots were reduced from 0.20% to as low as 0.08% by water stress during early vegetative growth and from 0.22% to 0.15% during late vegetative growth. When water stress was relieved, phosphorus concentrations recovered to levels similar to those in plants maintained on adequate moisture. Fisher suggested that a period of at least 6 weeks without water stress was needed prior to sampling if reliable estimates of the phosphorus status of *Stylosanthes* were to be obtained in that environment. In another study with *Macroptilium atropurpureum* grown at 18 sites in south-eastern Queensland, White and Haydock (1970) found that critical phosphorus concentrations in young runners harvested immediately prior to flowering varied from 0.16% to 0.29%. The most important factor associated with this variation was rainfall in the 28 days prior to sampling.

Temperature also has a strong influence on the rate of nutrient absorption by roots and the rate of mineralization of nitrogen, phosphorus and sulfur from soil organic matter.

C.1.4 Nutrient requirement

The plant's nutrient requirement following sampling is determined by the yield finally achieved, a parameter which is sensitive to environmental conditions. For example, in plants with indeterminate yield potential such as wheat, the productivity of late tillers is strongly affected by factors such as water and nitrogen supply. In addition, other factors, such as other nutrients, pests, disease, light, and temperature, may limit final yield. Interactions between two or more limiting nutrients may also affect the interpretation of plant analytical data. For example, increasing nitrogen supply increased the critical deficiency concentration of phosphorus in *Araucaria cunninghamii* and, in the same experiment, increasing phosphorus supply increased the critical deficiency concentration of nitrogen (Richards and Bevege 1969); in this experiment, the critical concentrations were reported as diagnostic values but were in fact predictive since the analytical samples were collected midway in the year over which growth rates of the trees were measured. The literature contains many other reports of nutrient interactions affecting critical concentrations for prediction (Munson and Nelson 1990).

The plant's nutrient requirements for vegetative production may also differ from those for its commercial product. This is especially true for nitrogen which, for optimal yield and quality of plant products, needs to be low or even deficient in the plant prior to harvest, as has been well documented for sugar production from sugar beet (Ulrich and Hills 1990).

C.2 Procedures

Two types of predictive tests based on nutrient concentrations are commonly used as an aid to nutrient management following sampling:

- seed analysis as a measure of seed viability or nutrient reserves for growth on deficient soils
- analysis of vegetative plant parts at a particular growth stage to forecast nutrient problems likely to be encountered.

For the special case of predicting storage quality of fruit, the fruit itself is analysed (Marcelle 1995).

C.2.1 Seed analysis

As discussed earlier (B.3.2), critical concentrations in seeds have been used for diagnosis of nutrient deficiency in parent crops and the seeds themselves. As the seed disorders affect seed viability and seedling establishment, the critical values also serve to predict seed performance in crop establishment. These problems cannot be corrected by addition of the deficient nutrient when the seed is sown.

Seed analysis is used to predict nutrient response in two other ways. Firstly, it can indicate the need for early nutrient addition if sown on a low nutrient soil. Thus, in maize, molybdenum concentrations in

the seed are important to early seedling growth when sown on low molybdenum soils (Weir and Hudson 1966). In lupins too, the cobalt concentration of the seed has been related to its ability to provide the plant's requirements to maturity when planted on soils low in available cobalt (Robson and Snowball 1987). Low calcium (Cox *et al.* 1976), manganese (Marcar and Graham 1986), boron (Bell *et al.* 1989), phosphorus (Bolland and Baker 1988, 1989; Thomson *et al.* 1991) and zinc (Rengel and Graham 1995) concentrations in the seed have all been shown to depress seedling growth and often dry matter production at maturity when sown on soils low in these nutrients. In most cases, and in contrast to seed damaged by nutrient deficiencies, early nutrient addition eliminates the responses.

Secondly, seed analysis can provide information on the nutrient status of the soil on which crops are grown, assisting nutrient management for succeeding crops. In South Australia and north-western Victoria, the concentration of 10 nutrients in barley grain has been mapped from intensive collection of samples over a wide area. The information has been used to define the areas of soil with high levels of boron as a guide for the sowing of boron tolerant cultivars. It could also be used in fertilizer management and in the animal feed industry (Spouncer *et al.* 1992).

C.2.2 Prediction during crop growth

The procedures adopted for using plant analysis to predict nutrient responses following sampling and to guide nutrient management prior to harvest vary widely. They range from simple correlations between nutrient concentration in a plant part at a particular stage of growth and yield at maturity, to sophisticated models simulating the likely climatic conditions and their impact on nutrient release from soils, uptake by the crop and requirement of the commercial crop product.

The most common procedure involves the setting of nutrient predictive standards in the same way as for diagnostic standards but correlating nutrient concentrations with final rather than current yield. As for diagnosis, predictive standards are derived from plants grown in experimental pots or field plots or from field survey data. Standards derived from crop survey data have been widely used in corn, soybean and other crops in the USA (Munson and Nelson 1990).

Where predictive standards have been set from field data, plant analysis can provide reasonable estimates of the likely nutrient responses for crops grown on similar soils under similar environmental conditions. For example, the values determined for the critical phosphorus concentration in wheat leaves from field experiments at five sites over two seasons in South Australia (Elliott *et al.* 1997b) were in such good agreement that they appear promising for a wide area of southern Australia. But prediction of yield from critical concentrations alone is unlikely to be accurate in atypical seasons or in areas which differ markedly in soils and climates from those in which the critical concentrations were set (Righetti *et al.* 1990).

Where dressings of fertilizers or ameliorants are required, information is needed from field trials on desirable rates of soil addition in relation to crop value, seasonal conditions and pollution problems. Where sufficient data have been accumulated, recommendations for fertilizer or ameliorant applications have been refined by integrating nutrient information with other factors such as climatic risks and soil properties into static or dynamic simulation computer models (Angus *et al.* 1993). Australian examples of models used for making fertilizer recommendations for a farmer's next crop are WHEATMAN (Woodruff 1992), DECIDE (Bennett and Bowden 1976), NPDECIDE (Burgess 1988) and MANAGE RICE (Angus *et al.* 1996). DECIDE and NPDECIDE predict the yield response curves in an empirical fashion and are not dynamic simulation models, though they do endeavour to account for changes in nutrient availability due to environmental factors such as the leaching of nitrogen when heavy rainfall follows fertilizer application. MANAGE RICE uses the nitrogen concentration of the plant, together with other information, to predict benefits that might be obtained from top-dressing a rice crop with nitrogen fertilizer.

Complex dynamic simulation models that consider crop growth processes in response to climatic conditions and the soil environment are able to deal with water and nitrogen limitations to crop growth, but as yet do not include phosphorus or other nutrient constraints. Such models are powerful tools for investigating the risks associated with use of fertilizer nitrogen which arise from seasonal variability in rainfall. The application of such a model in a very variable rainfall environment in Kenya made accurate predictions of crop yield by integrating information on the effects of a range of water, nitrogen and management regimes on maize grain yields (Keating *et al.* 1991).

D. Monitoring Crop Nutrient Status from Nutrient Concentrations

In its application to plant nutrition, the term 'monitoring' has been used to cover a wide range of procedures. At its simplest, it includes the collection of plant samples at a specified stage of development for comparison of their nutrient concentrations with established standards for defining nutrient status. In annual crops such as cereals, this may involve the collection of only one sample in the life of the crop (Westfall *et al.* 1990). Such a procedure is identical with the diagnostic and predictive procedures already discussed.

More generally and as used here, monitoring procedures involve periodic sampling of a crop to provide a continuous assessment and record of its nutrient status. It is this record of nutrient status and the use made of it which distinguishes monitoring procedures from other diagnostic and predictive procedures. In all other aspects, monitoring combines

diagnosis and prediction and introduces no new principles.

In following nutrient concentrations throughout the life of a crop, monitoring procedures aim to provide information on its nutrient status so that adjustments in nutrient management may be made and followed in order to keep nutrient concentrations within limits set to prevent nutrient problems arising and to optimize crop production. The frequency of sampling varies widely with the crop and the level of nutrient management required.

In perennial crops such as plantation timber trees, monitoring is usually confined to a single sample per year, allowing adjustments in fertilizers to be made for the following season. As nutrient concentrations in plant parts fluctuate widely throughout the year, samples are usually collected at a time when they are most stable and with the same care in attention to the selection of the plant part and its age as already discussed (Weetman and Wells 1990). A similar procedure is adopted for many fruit and nut tree and vine crops. In these horticultural and forestry tree crops, standards for assessment of nutrient status have frequently been set from crop surveys as previously described (B.4). The use of such standards for interpreting analytical data from specific orchards of forest sites must be done cautiously, taking into account differences in soil and other site characteristics: indeed, foresters recommend that the interpretation of plant analysis be related to soil/site classification systems (Lambert 1984; Turner and Lambert 1986). For horticultural crops the interpretation of plant nutrient concentrations also needs to take account of variations in seasons and crop characteristics such as fruit load and pruning intensity; it may be further complicated when the nutrient concentrations required for good fruit quality or storage differ from those for yield (Righetti *et al.* 1990; Marcelle 1995). Given such complexities, it is not surprising to find that, in considering plant analysis in the management of orchard nutrition, researchers recommend limiting its role to that of a useful tool, and stress the need to understand the factors affecting the interpretation of analytical data (Righetti *et al.* 1990).

For effective monitoring of nutrient status in annual crops, nutrient concentration standards need to be set for a series of growth stages during plant growth. This has usually been done with plants grown in glasshouse or field experiments with multiple fertilizer treatments. Using this approach, Ulrich and Hills (1967), plotted plant nutrient concentration against growth stage for each nutrient treatment; they observed that plant nutrient concentrations in each treatment fell progressively with time and proposed that, at each growth stage, the concentration in the lowest fertilizer treatment giving maximum yield be regarded as a 'safe level'. For maximum yield, nutrient concentrations should not be allowed to fall below the 'safe level' at any time. Subsequent workers have refined this approach by defining at a number of growth stages a 'critical nutrient range' with its limits as the critical nutrient deficiency concentrations for 90 or 95 and 100% of maximum yield at harvest; management techniques should aim to keep plant nutrient concentrations within the critical nutrient range of each growth stage at all times (Dow and Roberts 1982; Roberts and Dow 1982).

Monitoring procedures are especially valuable in the management of the nitrogen nutrition of crops in which nitrogen impacts strongly on the quality of plant products or in which leaching of nitrogen fertilizers creates environmental problems. For example, the conditions for optimal commercial sugar production require that sugar beets be nitrogen sufficient during early vegetative growth but nitrogen deficient for at least 4 weeks before harvest (Ulrich and Hills 1990). These conditions may be achieved by judicious use of nitrogen fertilizers and irrigation water in response to data obtained from the monitoring of nitrate concentrations in sugar beet petioles. Other examples of successful nitrogen monitoring procedures using total nitrate, sap nitrate, or radiant energy are presented in Figure 1.8 and Sections E.2 and E.6.

Frequent sampling in monitoring procedures minimizes errors such as those encountered in other predictive procedures when environmental events affect nutrient supply or requirement following sampling. As with those procedures, modelling of likely environmental conditions yet to be encountered, may also improve the efficiency of monitoring procedures. One of the earliest and best known examples of such monitoring approaches to nutrient management is the practice known as 'crop logging' of sugar cane in Hawaii where Clements (1964, 1980) has set critical concentrations of nutrients in relation to climate and physiology for sugar production in a 24-month crop cycle (Bowen 1990). Other models suitable for use in monitoring procedures have been mentioned in the preceding discussion of predictive models (C.2.2).

E. Diagnosis, Prediction and Monitoring from Other Measures of Nutrient Status

In diagnostic work, plant analysis generally refers to the total amount of chemical element in a plant part in relation to its dry weight and is reported as its concentration in % or mg kg^{-1} dry matter. In some cases, workers prefer to express nutrient content as a ratio of fresh weight, as already mentioned, or of total plant nitrogen. Many criteria other than total nutrient concentration are also used, including visual symptoms (see Chapter 2), concentrations or ratios of particular inorganic or organic forms of a nutrient, organic compounds, enzyme activities and concentrations, and physiological behaviour.

Like nutrient concentrations, all of these additional measures of plant nutrient status must be correlated with plant response to the test nutrient; many also use the concept of a critical deficiency level. While

valuable in specific cases, none of them is yet as readily applicable for general use by commercial analytical laboratories as is total nutrient concentration in dried plant parts which has the advantages of providing information on a wide range of nutrients in a single, easily collected, preserved and transported plant sample.

E.1 Nutrients in relation to fresh weight

Many authors have argued that, for water soluble nutrients such as potassium, it is more rational to express concentrations in relation to cell water rather than dry weight (Clements 1964; Cassidy 1966; Leigh and Wyn Jones 1984). For potassium, expressing concentrations on a tissue water basis is more physiologically relevant because of its role in plant–water relations. Potassium concentrations expressed on a tissue water basis remained constant at around 200 mM in leaves of all ages during plant development of barley grown with an adequate supply of potassium in water culture (Ahmed and Wyn Jones 1982) and in the shoots of barley crops with a good supply of potassium; moreover, it was not affected by nitrogen and phosphorus supplies (Leigh and Johnston 1983). However, in barley, sodium can substitute for potassium requirements and its concentration would modify critical concentrations of potassium. Leigh and Wyn Jones (1984) have postulated that such substitution is limited to the turgor functions of potassium in cell vacuoles and that potassium is not replaceable in its cytoplamic functions. In an attempt to define more precisely the specific potassium requirements of ryegrass, Barraclough and Leigh (1993) have related potassium functions to concentrations of potassium in tissue water.

Occasionally, concentrations of other nutrients in plant parts have also given better relationships when expressed on a fresh weight, rather than a dry weight, basis. For example, the critical concentration of phosphorus in shoots of *Stylosanthes humilis* and in young leaves of *Desmodium intortum* remained constant with plant age when expressed on a fresh weight basis but declined on a dry weight basis (Moody and Edwards 1978; Johansen 1978). In other studies, reporting the critical concentration of nutrients on a fresh weight or tissue water basis has not prevented a decline with age. Such declines may be artefacts of experimental systems in which the ratio of plant mass to volume of the nutrient medium declines progressively with plant age, as discussed earlier (B.3.1.) and suggested to explain the decline in the critical concentration of potassium in the tissue water of the youngest fully expanded leaf of soybean from 65 mM at pod set to 29 mM at pod filling (Bell *et al.* 1987).

Despite its advantages in particular situations, expression of nutrient concentrations on a fresh weight basis has not been adopted widely, probably because of the inconvenience of determining fresh weight at sampling and the variability in estimation of water contents arising from fluctuations in the plant prior to sampling and losses afterwards. On the other hand, determination of critical concentrations of nutrient fractions in sap expressed from plant parts is becoming increasingly popular, as discussed below.

E.2 Form of nutrient

Sometimes a particular form of a nutrient gives a more sensitive indication of plant nutrient status than does the total nutrient. Most attention has been given to nitrogen but various forms or tissue extracts of iron, phosphorus, sulfur, potassium and zinc have also been studied.

The concentration of α-amino nitrogen gives a more sensitive measure of nitrogen stress in plants than does total nitrogen (Greenwood 1976). Total, acetic acid-extractable and sap nitrate have all been used for assessing nitrogen status and predicting nitrogen requirements. The total nitrate concentration of leaves, petioles or stems has been strongly recommended for diagnosis and prediction of nitrogen status in many plant species as, for example, in petioles of sugar beet (Ulrich 1952) and 'basal stems' (leaf sheaths and stems of the main culm) of barley (Papastylianou 1986; Elliott *et al.* 1993), wheat (Papastylianou and Puckeridge 1981; Elliott *et al.* 1987) and 'lower corn stalks' (basal stem sections) of maize (Binford *et al.* 1992). In wheat and barley, basal stem nitrate was appreciably more sensitive than nitrate and nitrogen concentrations of young leaves (Elliott *et al.* 1987, 1993). In the leaves of tomato (Huett and Rose 1988) and zucchini squash (Huett and White 1991), nitrate concentration was more sensitive than total nitrogen concentration, but was considered less reliable because of its greater variability.

In addition to its use for diagnosis and prediction of nitrogen deficiency, nitrate concentration has been used to monitor the nitrogen status of many crops and to manage nitrogen fertilizer applications. In maize, nitrate concentrations in stems after harvest provided a good indication of excessive application of nitrogen fertilizer to the crop (Binford *et al.* 1992). The measurement of nitrate concentrations in petioles to monitor the nitrogen status of sugar beet in order to optimize sugar production has already been mentioned (D). Similar nitrate monitoring procedures have been developed to optimize yield and quality of pumpkins (Swiader *et al.* 1988), economic return in cotton (Grimes *et al.* 1973) and yield of potatoes (Williams and Maier 1990a, 1990b). In potatoes, a critical concentration range for nitrate concentrations in the petioles of the youngest fully expanded leaf was derived from intensive sampling throughout growth of plants in extensive field experiments; maximum tuber yield was recorded when petiole nitrate concentrations fell within the critical range at all growth stages (Figure 1.8; Williams and Maier 1990a). As the critical concentration range fell steeply with plant development, correct interpretation of samples from field crops depends upon careful specification of the developmental stage at sampling.

Nitrate concentration in acetic acid extracts of fresh plant parts has been used for assessing the nitrogen

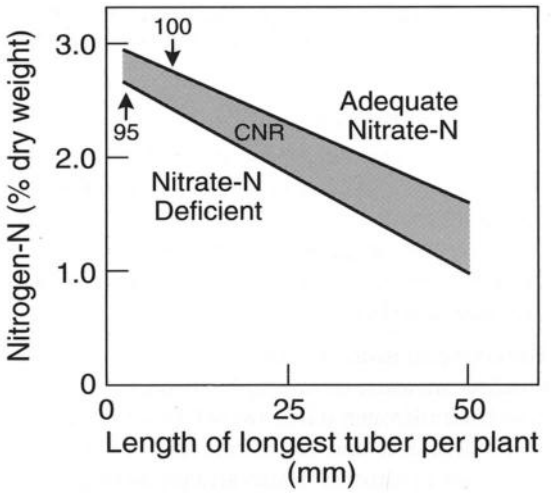

Figure 1.8 Change during tuber development of potato in the critical nutrient range for nitrate concentrations in petioles of the youngest fully expanded leaves for 95 and 100% maximum yield of tubers (after Williams and Maier 1990).

status of vegetable crops and grapes in California (Geraldson *et al.* 1983) and, when estimated with paper strips, correlated well with total nitrate in basal stems of wheat (e.g. Elliott *et al.* 1987).

Nitrate concentration in the sap expressed from fresh plant parts has long been regarded as a sensitive indicator of nitrogen status in many crops (Emmert 1934 cited by Scaife and Turner 1984) and has also been used as the basis of several rapid field tests (Irving and Bouma 1984b). The recent availability of paper test strips for determination of nitrate concentration in expressed sap has led to renewed interest in sap nitrate for rapid field tests of the nitrogen status of many crops. Nitrate concentrations in expressed sap determined by paper test strips have correlated well with determinations by more rigorous methods in a wide range of vegetable crops (Scaife and Stevens 1983; Lyons and Barnes 1987; Williams and Maier 1990b) and have been recommended for rapid field evaluation of crop nitrogen status particularly in monitoring programmes for prediction of fertilizer nitrogen management. Care must be taken in selection of plant parts and to avoid problems of variability in nitrate concentrations arising from fluctuations with time of day and water content of tissues at sampling (Scaife and Stevens 1983). Problems may also arise from variability among different batches of test paper in development of colour intensity (Elliott *et al.* 1987; Handson and Sheridan 1992) and in the presence of interfering substances in the sap of some species, as reported for sunflower (Schaeffer 1986). But there is general agreement that rapid field tests of sap nitrate concentration can provide a useful estimate of the nitrogen status of crops as a guide to nitrogen fertilizer management.

Rapid sap tests have also been devised for iron, potassium and phosphorus. Iron extracted from leaves and measured colorimetrically as the Fe^{2+}–phenanthroline complex has been suggested as a measure of iron deficiency chlorosis in rice plants (Katyal and Sharma 1980). The method was developed in an effort to provide a better measure of the iron status of plants than that given by total iron concentration, which is frequently unsatisfactory even when contamination from soil is removed. The suggestion that the method extracts only Fe^{2+} has been challenged; but despite ignorance of the form and location in the plant of this extracted 'active iron', the method has proved useful in some situations (Abadia 1992). For potassium, colour changes of paper test strips in contact with sap expressed from fresh plant parts has given a good indication of potassium status of several crop and pasture plants (Melsted 1950; Spencer and Govars 1982). But in lettuce they only gave good estimates of potassium concentration in sap expressed from marginally potassium deficient plants, due to interference from accumulation of pigments and amines in more deficient plants (Burns and Hutsby 1984). The test would be further limited in those species in which ammonia accumulates or sodium substitutes for potassium.

The concentrations of inorganic orthophosphate and sulfate in petioles have been recommended for the diagnosis of the phosphorus and sulfur status, respectively, of sugar beet plants (Ulrich and Hills 1990). Their concentrations in acid extracts or sap expressed from petioles and leaves have also been recommended for rapid field tests. Several studies have been done with phosphorus, but few data are available on sulfur (Handson and Sheridan 1992). Acetic acid extractable phosphorus in the leaf blades of grapevines at anthesis provided a sensitive measure of the phosphorus status of the vines for prediction of their berry weight and yield and pruning weight (Skinner *et al.* 1987). Inorganic phosphate extracted by sulfuric acid from green leaves and determined by a rapid colorimetric procedure provided a reasonable guide to the phosphorus status of subterranean clover (Bouma and Dowling 1982; Irving and Bouma 1984a) and wheat (Elliott *et al.* 1997b). The concentration of inorganic phosphate in sap expressed from petioles of the youngest mature leaf also indicated the phosphorus status of canola (Handson and Sheridan 1992) and, in a more comprehensive study, inorganic phosphorus concentration in young leaves correlated well with phosphorus status of subterranean clover (Lewis 1992). However, total phosphorus was preferred for diagnosis of phosphorus deficiency in subterranean clover because the critical concentration of inorganic phosphorus in young leaves fell rapidly with age, while that of total phosphorus in the same leaves remained stable; in addition, standard errors for inorganic phosphorus concentrations in leaves also tended to be larger than those for total phosphorus (Lewis 1992).

A suggestion has also been made that the concentration of metabolically active forms of phosphorus ('labile' phosphorus) would provide a better indication of plant phosphorus status than either inorganic or total phosphorus (Chisholm *et al.* 1981; Chisholm and Blair 1988). The suggestion was

based upon the greater stability of a lipid and residual phosphorus fraction compared with inorganic and total phosphorus. For diagnosis of phosphorus deficiency in wheat, total phosphorus was preferred over 'labile' phosphorus which is more difficult to determine, had a steeper diagnostic slope, and for which critical concentrations declined in a similar manner with leaf age (Elliott *et al.* 1990b).

In plant leaves with very high phosphorus concentrations, water soluble zinc concentration gives a better measure of zinc status than does total zinc (Cakmak and Marschner 1987).

E.3 Nutrient and metabolite ratios

Where a physiological basis for a nutrient ratio can be established, a ratio can be used to interpret plant analyses. Since protein content of plant parts probably gives a better estimate of the quantity of their metabolically active tissues than does dry matter, a case can be made for expressing, as a proportion of protein, the contents of those nutrients which are primarily involved in plant metabolism, i.e. all nutrients other than calcium and boron. But this concept seems to have not been explored, possibly because of the tedium of protein determinations compared with the ease of weighing.

However, the structural association of sulfur with nitrogen in protein has provided a rationale for using ratios of the total element contents of N/S for diagnosis of sulfur deficiency (Dijkshoorn and van Wijk 1967; Freney *et al.* 1977). This ratio has proved very valuable in the interpretation of sulfur analyses in pasture (Spencer *et al.* 1977) and cereal plants (Rasmussen *et al.* 1977) and cereal grain (Randall *et al.* 1981). Other workers have found the index of sulfate-S content as a percentage of the total-S content to be a better indicator of sulfur status than sulfate concentration alone (Smith and Dolby 1977; Spencer *et al.* 1978). The ratios of protein to non-protein nitrogen have also proved valuable in diagnosing sulfur deficiencies (Freney *et al.* 1982).

Other nutrient element ratios have been suggested at various times. But, without a sound physiological base they cannot be expected to provide diagnostic criteria that are valid beyond the confines of the particular conditions under which they were developed. The promulgation of P/Zn ratios for diagnosis of Zn deficiency provides a good example of wasted effort in uncritically chasing purely empirical relationships (Loneragan and Webb 1993). Unfortunately, the availability of multi-element analysers and high capacity computers has made it easy for researchers to relate plant growth and nutrient response to an almost unlimited number of elemental ratios, as the revival of the Beaufils' Diagnostic and Recommendation Integrated System (DRIS) (Walworth and Sumner 1988) has shown.

The rationale for DRIS is that the ratios of nutrients to dry matter (e.g. % DM) in plants either decline or increase progressively with age, but that ratios of those nutrients which decline (nitrogen, potassium, phosphorus) with those which increase (calcium, magnesium) *'are often less affected by aging processes and so present an opportunity to expand the usefulness and accuracy of foliar diagnosis'* (Walworth and Sumner 1988). For a given crop, an extensive data bank of nutrient concentrations is obtained from analyses of high and low yielding crops. Using these data in a complex series of nutrient ratios, a set of DRIS 'norms' are calculated. Deviations from these norms are used to assess plant nutrient status for fertilizer management and yield prediction.

In assessing the value of DRIS, it is important to recognize that, while purporting to diagnose deficiencies, it is a predictive technique and has relied for its validation on nutrient responses following sampling, usually at final harvest. As should have been expected from *'a priori'* considerations, early claims of a more general validity than other predictive techniques have not been sustained, and DRIS indices have been shown to vary with location and time of sampling (Jones 1993). Extensive data from field crops are required to establish DRIS indices and their predictive power has yet to be shown to be substantially better than traditional, less demanding procedures.

Compositional Nutrient Diagnosis (CND) is another approach which is based upon the relationships between the concentration of all nutrients and final yield in survey samples (Parent and Dafir 1992). CND uses a multivariate approach to establish indices that indicate whether a particular nutrient is insufficient, in balance or excess. Like DRIS, the system is empirical in nature, relying upon statistical manipulation of nutrient composition data to establish the indices for prediction of yield.

E.4 Organic compounds

A number of diagnostic techniques has been developed on the basis of changes in the concentrations of organic substances related to the status of specific nutrients. Most are only sensitive to deficiencies of nutrients and do not provide information on nutrient reserves. Many are related to nitrogen metabolism.

The use of α-amino nitrogen concentration as a sensitive measure of nitrogen stress in plants has already been mentioned (E.2). So has the ratio of protein to non-protein nitrogen as a measure of sulfur deficiency (E.3), which, through a shortage of sulfur amino acids, blocks protein synthesis, causing non-protein nitrogen to accumulate. But, while the shortage of sulfur amino acids decreases the protein content, it has little impact on the proportion of high sulfur to low sulfur proteins of vegetative plant parts. By contrast, in seeds of many species, sulfur deficiency depresses the proportion of high sulfur proteins to low-sulfur proteins as well as protein to non-protein nitrogen. In wheat grain, sulfur-rich albumins decrease while sulfur-poor gliadin proteins increase dramatically accompanied by a drastic depression in flour quality. The changes in grain composition have provided two simple tests for diagnosis of sulfur deficiency in wheat grain — a

colour reaction of whole grain with glutaraldehyde and a simple precipitation and turbidimetric test on suspended flour (Randall *et al.* 1981; see comprehensive review by Randall and Wrigley 1986).

Bussler (1981) has observed in several plant species that lignin synthesis is depressed by even mild copper deficiency and thus provides the basis for diagnosis in the field by a simple histochemical test. The test should be interpreted with caution as both manganese and boron deficiencies also depress lignin synthesis.

Putrescine accumulation has been recommended for diagnosis of potassium deficiency in lucerne (Smith *et al.* 1982); in other species, the original hope to use its accumulation as a diagnostic test has not been realized due to a lack of specificity.

E.5 Biochemical, molecular and physiological assays

A wide variety of enzyme assays has been developed for diagnosis of nutrient deficiencies. They depend upon specific changes in enzyme activities or concentrations resulting from nutrient deficiencies. Hence, like assays of organic compounds, enzyme assays give no information on nutrient reserves. However, many of them are highly specific and give positive identification of particular nutrient deficiencies.

Enzyme activities respond to a nutrient deficiency either because the nutrient concentration in the plant tissue is too low for their maximal activity or the deficiency affects the concentration of the enzyme itself. In the first case, the nutrient deficiency does not affect the concentration of apo-enzyme and addition of the deficient nutrient restores activity quickly, providing a very specific and positive diagnosis, as in the diagnosis of iron deficiency by the activation of peroxidase with the addition of iron (Bar-Akiva *et al.* 1978).

Where a nutrient deficiency affects the concentration of an apo-enzyme, the deficiency may be diagnosed by assaying either the activity or the concentration of the enzyme. In molybdenum deficient plants, nitrate reductase activity is depressed but may be restored rapidly by incubating leaves or roots with molybdenum (Mulder *et al.* 1959) forming the basis of specific tests for diagnosing molybdenum deficiency in citrus (Shaked and Bar-Akiva 1967) and wheat (Figure 1.9; Randall 1969). Ascorbic acid oxidase activity in young leaves, which correlated closely with their copper concentration and with shoot dry matter in subterranean clover, provided a simple and specific technique for diagnosis of copper deficiency (Loneragan *et al.* 1982; Delhaize *et al.* 1982). The enhancement of phosphatase activity in wheat (Barrett-Lennard and Greenway 1982; McLachlan 1982) and in *Eucalyptus* seedlings and young plants (O'Connell and Grove 1985) have also been suggested as diagnostic techniques for phosphorus deficiency. In wheat leaves, an isozyme which was not present in leaves of phosphorus adequate plants appeared in leaves of phosphorus deficient plants; unlike general phosphatase activity which increased with plant age, the appearance of the isozyme was independent of plant age at all stages of growth to anthesis, offering a simple diagnostic procedure for phosphorus deficiency (McLachlan *et al.* 1987) In *Eucalyptus*, acid phosphatase activity provided a more sensitive measure of phosphorus deficiency than phosphorus concentrations in leaves and stems: in maize, it was relatively insensitive (Elliott and Läuchli 1985).

Application of the tools of modern biology now offer exciting opportunities for developing new diagnostic techniques. The products of genes specifically expressed in response to a particular nutrient disorder can now be detected by a range of very sensitive techniques. Although not specifically targeted at diagnosis, the feasibility of using such techniques is illustrated by work on manganese in which a molecular probe is being developed to detect the expression of a gene that confers manganese efficiency to cereals (Graham, personal communication). Specific DNA probes can be developed to detect whether genes are being expressed, and antibodies to specific polypeptides can be used for similar purposes. Immunological techniques such as ELISA (enzyme-linked immunosorbent assay) have been used in the assay of phenolase for estimation of the copper nutritional status of wheat and cotton (Rao and Ownby 1993). Once developed, such techniques are simple, quick and relatively cheap. But the development and adequate testing of the assays is demanding, time consuming, and expensive. For plants, it is made especially demanding by the variation among species and cultivars of not only the sensitivity to a deficiency of the chosen enzyme, as in phosphatase above, but also of isozymes within the enzyme complex. Given these difficulties, it is not surprising that progress in the use of ELISA assays for

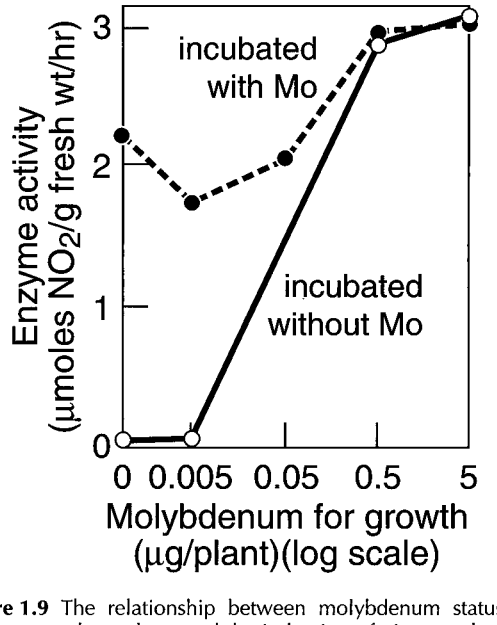

Figure 1.9 The relationship between molybdenum status of wheat plants and the induction of nitrate reductase activity in wheat leaf fragments. Fragments from the same leaf were incubated with (•) and without (o) molybdenum. Randall (1969).

diagnosing plant nutrient disorders has trailed far behind their widespread use for diagnosis in medical pathology laboratories.

Relatively little use is being made of the many excellent diagnostic tests which measure enzymic activity, despite their relatively high potential, especially in the horticultural industry (Leece 1976). Perhaps this is not surprising for those tests which are delicate require special conditions during transport of fresh samples to laboratories, or the use of special equipment. But even tests which have been simplified for field use with readily available chemicals such as the ascorbate oxidase test for copper in subterranean clover (Delhaize *et al.* 1982) are not available commercially.

Physiological tests do not involve plant analysis but are included here because they may offer another means of assessing plant nutrient status. Unfortunately, only a limited amount of work has been reported. Bouma and Dowling (1976) have devised a test for assessing the phosphorus status of subterranean clover. In this test, the weights of detached leaves are compared after they have been taking up either fructose 1,6-diphosphate (FDP) or distilled water for 8–12 hours followed by a period during which they are immersed in distilled water and allowed to photosynthesize. Under these conditions, detached leaves that are deficient in phosphorus resume normal levels of photosynthesis upon restoring their internal phosphorus supply. The weight of deficient leaves treated with FDP is therefore greater than that of corresponding leaves placed only in distilled water. In plants adequately supplied with phosphorus, there is no difference in weight between detached leaves treated with FDP or distilled water. The technique has the advantages of being simple, requiring little equipment, and not requiring prior establishment of standards.

A somewhat similar procedure has been proposed for assessing the nitrogen status of plants (Greenwood 1976). In this technique, carbon dioxide exchange rates were used to detect differences in growth rates of deficient plants and plants that received adequate nitrogen two days prior to measurement.

Finally, foliar application of a nutrient to identified leaves or sections of leaves can sometimes provide confirmation of a suspected deficiency. The procedure is used for micronutrients such as iron, manganese or zinc. In the case of iron, it is particularly useful as it avoids the analytical problems that often arise from contamination when chemical analysis is used to diagnose iron deficiency. However, users should be aware that, in some plants, aged leaves which show symptoms do not green up following foliar application of a nutrient.

E.6 Interaction with radiant energy

Leaf colour has long been used by physiologists in diagnosis of nutrient deficiencies and by farmers as a guide to nitrogen fertilization of crops. Recent technical developments have provided the means for quantifying these observations and for exploring other effects of nutrient deficiencies on the interaction between radiant energy and leaves. Transmission and reflectance of visible and infrared radiation and fluorescence of chlorophyll have all been studied.

The primary application of measurements of light transmission and reflectance has been in the prediction of the need to apply nitrogen fertilizer to achieve optimal grain yield of cereals at harvest. Successful predictions have been reported from measurements of transmission in corn (Piekielek and Fox 1992; Blackmer *et al.* 1994), rice (Turner and Jund 1994) and winter wheat (Follett *et al.* 1992; Fox *et al.* 1994) and reflectance in corn (Blackmer *et al.* 1994). Hand held 'chlorophyll meters' have been developed to estimate chlorophyll concentrations by measuring the transmission through leaves of radiation of one or two wavelengths related to chlorophyll activity. Readings on selected leaves in standing crops have been correlated with leaf nitrogen concentrations in rice (Turner and Jund 1991; Peng *et al.* 1995) and winter wheat (Fox *et al.* 1994), and with leaf nitrogen and chlorophyll concentrations in maize (Blackmer and Schapers 1995). In maize, both chlorophyll and nitrogen concentrations correlated more strongly with reflectance of 550 nm radiation than with the transmission readings (Blackmer *et al.* 1994). Chlorophyll and nitrogen concentrations in rice leaves have also correlated well with a 'green colour intensity' score calculated from measurements at 550 and 800 nm of reflectance of solar radiation from the leaf canopy of a rice crop; while measurements on canopies have obvious advantages over those on individual leaves, problems of instability during sunny or windy conditions need to be overcome before the technique can be applied generally (Takebe *et al.* 1990). In all these techniques, the interpretation of readings is specific to the stage of plant growth and the plant cultivar. Researchers also recommend that instrument readings be standardized against readings of a portion of the same crop which has received adequate fertilizer nitrogen. The techniques are further limited as diagnostic tools by their lack of specificity; any nutrient deficiency, other than nitrogen deficiency, or environmental factor affecting leaf colour introduce serious error.

Several workers have explored the possibility of using remote sensing of the reflectance of radiation from crop canopies as a technique for diagnosing nutrient disorders. The principles are the same as for laboratory or hand held instrumentation.

The technique of near infrared reflectance (NIR) spectroscopy is more specific and more accurate than the relatively simple measurements of transmission and reflectance of radiation discussed so far. NIR measures at a number of wavelengths the reflectance of monochromatic light directed at dried and ground plant samples. The reflectance depends upon the wavelength and the composition of the sample: its characteristics are then calibrated against chemical analyses of a range of samples. NIR-nitrogen has

correlated well with Kjeldahl-nitrogen in a wide range of crops (Watson and Isaac 1990; Blatt *et al.* 1995). Batten *et al.* (1993) have suggested that by determining non-structural carbohydrates as well as nitrogen, NIR could also identify wheat and rice crops suffering from stresses other than nitrogen. They have also developed procedures for estimating the stage of plant growth and sulfur, phosphorus and potassium status of rice crop samples; as with the simpler techniques, the interpretation of readings varies with the stage of plant growth and plant cultivar (Batten and Blakeney 1995). NIR estimation of the concentrations of potassium, magnesium, calcium and phosphorus in animal feeds have been more variable than that of nitrogen, suggesting caution in their application (Clark *et al.* 1987). NIR is being used widely for nitrogen fertilizer recommendations and for indication of sulfur, phosphorus and potassium deficiencies of rice crops in New South Wales (Batten and Blakeney 1995), although data relating NIR test results directly to field responses appear to have not yet been published. NIR has also been applied to other plant parameters such as fibre and cell wall characteristics and may provide an alternative to the traditional wet chemical approaches that are used by many laboratories. Its use is probably most advanced in the horticultural industry with on-line detectors being used to monitor parameters such as surface sugar levels, moisture and starch in a quality control mode. The technique is being recommended for a number of fruit and vegetable crops (Blatt *et al.* 1995).

Image processing of colour photographs has shown promise of identifying some nutrient deficiencies in forest trees as, for example, in diagnosing nitrogen and magnesium deficiencies in *Pinus radiata* (Thorn *et al.* 1995); problems of specificity and interference from water stress, disease and insect damage limit the application of the technique at this time. Similar problems also limit the application of chlorophyll fluorescence to the diagnosis of nutrient problems. The characteristics of chlorophyll fluorescence in response to excitation by light provide a sensitive indication of environmental stresses including nutrient deficiencies in plants. With the recent development of portable instruments capable of providing rapid measurements on attached leaves, they have been rated highly among tests for detection of stress in forestry applications (Mohammed *et al.* 1995). Unfortunately, the technique appears to be non-specific for most nutrients, being unable to distinguish nitrogen, phosphorus and potassium deficiencies from each other or from other physiological stresses (Sun *et al.* 1989). However, for manganese deficiency, which has a role in chloroplast structure, some characteristics of chlorophyll fluorescence in wheat and barley grass were distinct from those for copper deficiency, which also has a role in photosynthesis. In wheat, the changes occurred at manganese concentrations considered critical for diagnosis of manganese deficiency in field crops and could provide an index for early diagnosis (Kriedemann *et al.* 1985; Kriedemann and Anderson 1988).

F. Conclusions

Plant analysis is a valuable tool for managing the nutrition of crop, pasture, horticultural, floricultural and forest plants. It is being used to diagnose the nutrient status of plants at the time of sampling, to predict their yield and nutrient status when subsequently harvested, and to monitor and maintain their nutrient status at optimum levels throughout growth. For all purposes, the reliability of interpretation and recommendations is improved by an understanding of the physiology involved in nutrient acquisition, internal nutrient transport and the impact of these upon plant growth and development. Considerable progress has been made in the past two decades in understanding how nutrient uptake, partitioning and remobilization are regulated and how they respond to nutrient stress. These processes are key determinants of nutrient concentrations in plant tissues. These advances, combined with better information on the functional requirements for nutrients, continue to develop the sound physiological basis needed for reliable interpretation of plant analysis. However, there are many gaps in our knowledge of these processes, which result in many of the relationships that are commonly used for assessing plant nutrient status being somewhat empirical. This empiricism is reflected in a lot of the data contained on the diagnostic tables in this manual.

The limitations of using plant analysis alone for predictive purposes have become apparent as the plant, soil and environmental factors that influence plant growth in the period following sampling for plant analysis have been recognized. The value of using both soil and plant analysis when making recommendations for improving the nutrition of a crop cannot be overemphasized. Even with such a body of information, associated environmental factors often result in poor recommendations. Advances in computer technology in recent years are now enabling environmental risks and economic evaluations to be factored into the interpretation of plant analyses through the inclusion of information in both dynamic and static simulation models. As a result, schemes which enable users to evaluate the risks associated with particular fertilizer crop nutrition practices when making recommendations are becoming increasingly available and should be fostered.

The diagnostic, predictive and monitoring uses of plant analysis have primarily found their application in the past among agricultural researchers, extension agents, farm advisors and farm managers. However, as community concerns regarding use and fate of plant nutrients, particularly mineral fertilizers, continue to grow, environmentalists are also finding these tools valuable. Their proper use by both groups can only help in achieving the balance between productive agricultural and horticultural industries and protection of the environment.

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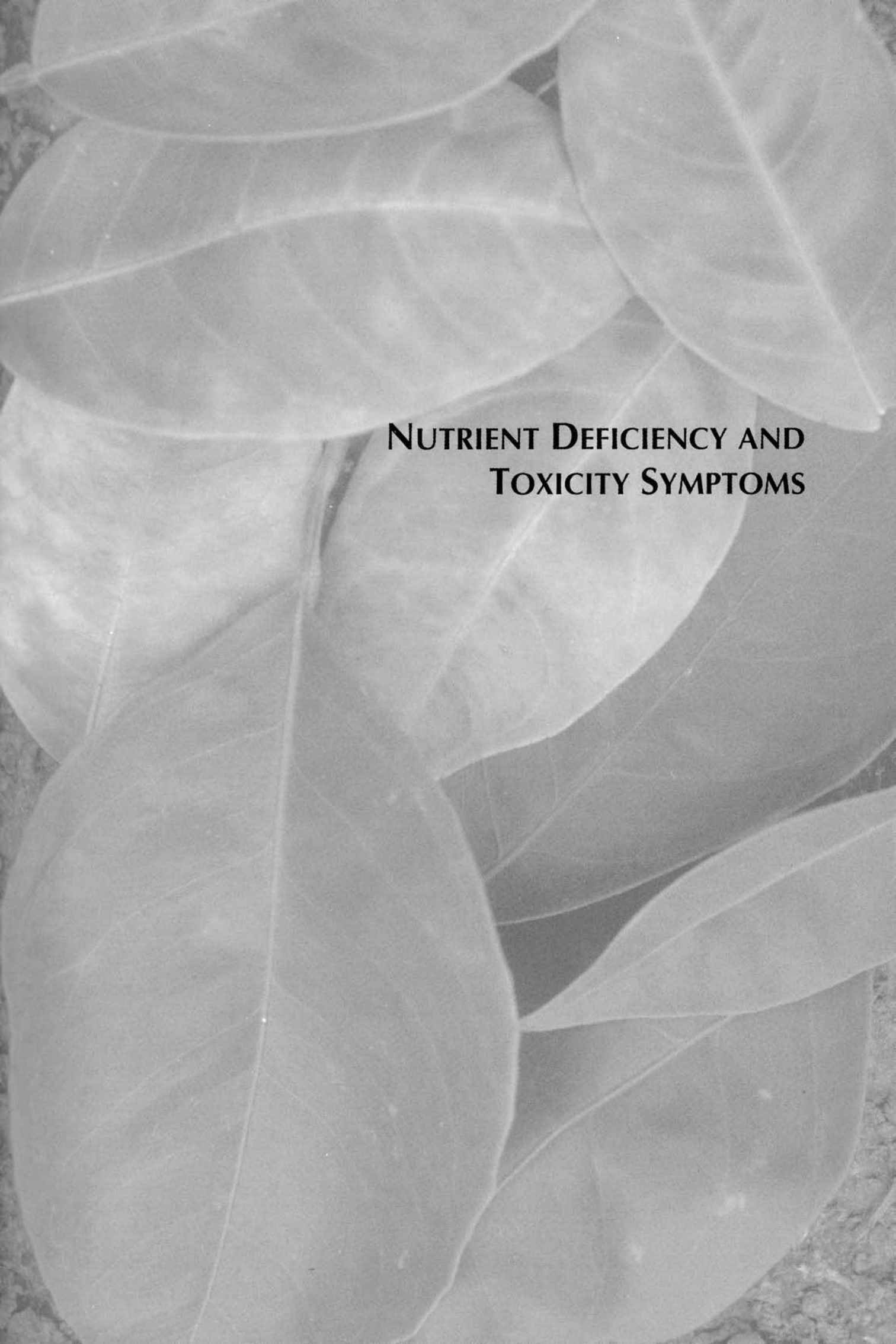

Nutrient Deficiency and Toxicity Symptoms

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2. Nutrient Deficiency and Toxicity Symptoms

N.J. Grundon, A.D. Robson, M.J. Lambert and K. Snowball

A. Introduction

Nutrient deficiencies and toxicities cause impaired metabolism within plants resulting in the appearance of visible symptoms. Many symptoms are sufficiently characteristic to permit identification of the disorder causing the impaired metabolism and reduced growth. Other symptoms are less characteristic, and their presence could indicate one of several possible stresses. For example, a general paleness of shoots with reddening and premature senescence of old leaves could indicate nitrogen, sulfur or molybdenum deficiency in legumes (Andrew and Pieters 1972; Smith and Pieters 1983; Smith *et al.* 1983; Snowball and Robson 1983), while in pines (Turner *et al.* 1979) and eucalypts (Will 1985), these symptoms could indicate nitrogen or sulfur deficiency. Failure of terminal spikelets in cereals to produce grain can be a symptom of moisture stress or frost damage at anthesis, root disease, mouse or insect attack, or copper deficiency (Graham 1975; Grundon 1987; King 1974; Snowball and Robson 1983). By contrast, a number of distinct symptoms may be produced by the one disorder. For example, boron deficiency generally causes death of growing points, but in pines it results also in buds failing to flush, and the main stem forking and becoming deformed (Turner *et al.* 1979).

The use of visual symptoms to diagnose nutrient disorders has distinct advantages for the extension worker, agronomist, farmer, or forest manager. Two great advantages are: (i) that the technique can be applied in the field; and (ii) that it is not dependent on laboratory support services.

However, there are a number of disadvantages in relying on visible symptoms as the sole diagnostic tool. One major disadvantage is that a disorder is diagnosed only after severe stress has occurred and yield may have been severely depressed. Another major disadvantage is that, by the time distinctive symptoms become evident, it is often too late to correct the problem in that growing season.

Even in the hands of experienced workers, the use of foliar symptoms as a diagnostic tool must be undertaken with care because a number of factors affect the form and appearance of visual symptoms and their usefulness as a diagnostic tool for nutrient disorders:

- Under certain conditions, different nutrient disorders can produce rather similar symptoms. At other times, the effects of insect pests or diseases may produce symptoms similar to those of specific nutrient disorders. Practitioners need to be able to distinguish between symptoms caused by nutrient disorders and those caused by pathological infection, insect damage, senescence, and management practices. As these facts have been recognized, some authors have included specific comments, sections or keys referring to the similarity of symptoms produced by different nutrient disorders, insect attack, or disease infection (Turner *et al.* 1979; Blamey *et al.* 1987; Grundon *et al.* 1987; O'Sullivan *et al.* 1995).
- When the disorder is mild or transient in nature, no foliar symptoms may be produced but seed production may still fail completely, as in copper deficiency in wheat (Graham 1975; Grundon 1987).
- With some crop species, there are considerable differences between cultivars in the form of expression of the symptoms; examples include magnesium deficiency in grain sorghum (Grundon *et al.* 1987), and nitrogen, phosphorus and magnesium deficiencies in sweet potato (O'Sullivan *et al.* 1995).
- For some micronutrient disorders, environmental factors such as light, temperature and soil moisture conditions may have a profound effect on the appearance or severity of the symptoms (Moraghan and Mascagni 1991). For example, in most field crops, iron, manganese and zinc deficiencies are increased in severity by a combination of low temperature and high soil moisture, while hot, dry summers intensify the severity of iron deficiency. However, in forest trees, zinc deficiency is more acute in summer than in winter (Boardman and McGuire 1990), and in both field crops and trees symptoms of zinc deficiency are more severe at high light intensities than in partial shade (e.g. Cakmak *et al.* 1995);
- There are significant differences between species, and even between cultivars or varieties within species, in their sensitivity to nutrient disorders. For example, Honduras Caribbean pine (*Pinus*

caribaea var. *hondurensis*) is much more sensitive to copper deficiency than slashpine (*Pinus elliotti*), and similar differences occur between individual trees of their F1 hybrids (Simpson and Osborne 1993). Then again, different provenances or families of Honduras Caribbean pine respond differently to fertilizers and have different sensitivity to copper deficiency in the presence or absence of nitrogen (Simpson *et al.* 1996).

- Plants may suffer also from multiple nutrient disorders on sites where more than one element may be deficient and/or toxic. However, the symptoms may not always be characteristic of one disorder, and may represent a combination of the more strongly expressed symptoms of individual disorders. In these instances, very complex symptoms can develop, and considerable skill and experience is required for a correct diagnosis. Then again, where multiple deficiencies exist, symptoms of the most limiting deficiency may be exhibited; when this nutrient is applied to the plant or soil, new symptoms develop that are characteristic of the second nutrient limiting growth. Specific symptoms may also occur where excessive levels of other nutrients depress either the uptake or transport of another nutrient to the shoots. For example, symptoms of iron deficiency often develop in the presence of high levels of manganese, zinc, aluminium, phosphorus and some non-essential heavy metals in the growing medium (Clark *et al.* 1981; Blamey *et al.* 1987; Grundon *et al.* 1987).

Despite any limitations to their usefulness, plant symptoms remain a valuable diagnostic tool, especially when applied by an experienced practitioner. However, few protocols for the successful application of the technique are given in the literature. Grundon (1987) lists some of the items to be considered, which include recording the history of the problem and the pattern of development of the symptoms. For forest species, Dell *et al.* (1995) list the distinctive characteristics of nutrient disorders that can be used to distinguish them from symptoms caused by other factors.

It is important to recognize that the use of visible symptoms provides a preliminary diagnosis. Confirmation by other methods such as plant and soil analyses, pot culture assays, field experiments, or test strips is an essential second step.

In this chapter, symptoms of nutrient stresses are considered in relation to function and distribution of nutrients within plants. A list of published descriptions of symptoms of nutrient deficiencies and toxicities is given in Appendix 1 to this Chapter.

B. Symptoms in Relation to the Function of Nutrients

There are several levels of knowledge of nutrient function. In ascending order these are: (i) the element is essential; (ii) the element plays a role in a physiological process; (iii) the element activates an enzyme or regulates the rate of an enzyme-mediated process; and (iv) the element is an integral constituent of an essential metabolite, complex or macromolecular assembly. Our knowledge of nutrient function varies for the essential nutrients (Table 2.1)

Essential elements may have non-specific roles in plant growth which may be additional to the specific functions listed. For example, many ions are important for the establishment of osmotic potentials within plants and for the maintenance of electrical neutrality. Another example is in maintenance of quality aspects of the harvested products: in fruits and vegetables, calcium deficiency often leads to reduced quality of storage tissues such as fruit (e.g. bitter pit of apples; blossom-end rot in tomato fruit).

It is clear that one nutrient may have several functions within the plant. The symptoms which are most characteristic for a particular nutrient are those in which one specific function dominates, causing a more visible symptom than those produced by the other functions. For example, zinc has been shown to be associated with auxin metabolism, nucleotide synthesis, and membrane integrity (Boardman and McGuire 1990; see Table 2.1), but it is impairment of auxin metabolism in zinc-deficient plants that leads to the characteristic symptoms of leaf distortion and internode shortening (rosetting).

When one nutrient is involved in the assimilation or metabolism of another nutrient, the symptoms may not clearly differentiate the causal element. For example, nitrogen and sulfur are biochemically related in plant proteins. Because there is no inorganic nitrogen in tree foliage, there is a constant ratio between organic (and total) nitrogen and organic sulfur, and the rate of nitrogen uptake is limited by the rate of sulfur accumulation (Turner and Lambert 1986). Thus, in many forest and horticultural tree species, protein formation is limited by the amount of sulfur available, and the symptoms of nitrogen and sulfur deficiency are very similar (Sprague 1964; Turner *et al.* 1979). Another example is in legumes, where molybdenum deficiency is indistinguishable from nitrogen deficiency because molybdenum is required most as a constituent of the enzyme involved in nitrogen fixation (nitrogenase). In plants other than legumes, symptoms of molybdenum deficiency depend on the level of nitrate supplied (see Snowball and Robson (1983) for wheat). At adequate but not luxury levels of nitrate, leaves of wheat plants deficient in molybdenum are paler and more flaccid than those on plants supplied with adequate molybdenum. When very high rates of nitrate are applied, tip scorch of old leaves may occur on molybdenum-deficient plants as a result of an excessive accumulation of nitrate. Molybdenum is a constituent of nitrate reductase, the enzyme involved in the first step of nitrate assimilation in leaf cells (see Table 2.1); nitrate reductase activity decreases the build-up of nitrate in leaves.

TABLE 2.1 Functions of essential elements in higher plants; for more detail see Epstein (1972), Mengel and Kirkby (1982), Marschner (1988), Asher (1991) and Tisdale *et al.* (1993)

Element	Physiological process	Activator of enzyme	Constituent of metabolite or cell component
Nitrogen			Amino acids, proteins, nucleic acids, nucleotides, chlorophyll
Phosphorus	Energy storage and transfer, membrane integrity		ATP, nucleotides, nucleic acids, phospholipids
Potassium	Translocation, water relations, energy relations, stomatal opening, regulation of cellular pH, osmoregulation, cation–anion balance	+	
Sulfur	Protein synthesis and function, energy transfer, structure		Amino acids, co-enzymes, ferredoxins, sulfolipids, proteins
Calcium	Membrane maintenance, cell division and elongation, cell wall stabilization, cation–anion balance, osmoregulation, second messenger in environmental signals	+	Calcium pectates
Magnesium	CO_2 assimilation, regulation of cellular pH, cation–anion balance, protein synthesis, carbohydrate partitioning	+	Chlorophyll, ribosomes
Chlorine	Maintenance of electrical neutrality, internal turgor		
Copper	Lignin synthesis, terminal oxidation in redox reactions, pollen formation and fertilization		Ascorbate oxidase, phenol oxidases, cytochrome oxidase, plastocyanin, CuZn superoxide dismutase
Zinc	Auxin metabolism, nucleotide synthesis, membrane integrity	+	Dehydrogenases, CuZn superoxide dismutase, carbonic anhydrase, RNA polymerase,alkaline phosphatase, phospholipase, carboxypeptidase
Manganese	Oxidation–reduction in electron transport, O_2 evolution in photosynthesis	+	Mn superoxide dismutase
Iron	Oxidation–reduction in electron transport		Iron porphyrins (leaves), ferredoxins
Boron	Nucleotide synthesis, assimilate translocation, cell wall biosynthesis and structure, plasma membrane integrity		
Nickel	Urea metabolism via urease	+	
Sodium	Conversion of pyruvate to phosphoenolpyruvate in C_4 photosynthetic pathway		
Molybdenum	Nitrogen fixation, nitrate reduction		Nitrogenase, nitrate reductase, xanthine oxidase/dehydrogenase

C. SYMPTOMS IN RELATION TO THE MOBILITY OF NUTRIENTS

The location of symptoms of nutrient deficiencies within plants depends on the extent and rate of retranslocation of nutrients within the plant. Nutrients differ markedly in their mobility within the plant (Table 2.2). Some nutrients, such as nitrogen, phosphorus and potassium, are readily retranslocated from old leaves to new growth. For these nutrients, the symptoms occur initially in the older leaves. Other nutrients, such as calcium and boron, have little or minimal mobility and do not appear to be retranslocated from old leaves to new growth. Hence, for these nutrients, deficiency symptoms occur generally in young growing areas of the plant.

Manganese does not appear to be retranslocated out of old leaves (Hill *et al.* 1979; Radjagukguk 1981; Nable and Loneragan 1984a, 1984b). Nevertheless, symptoms of manganese deficiency frequently occur in fully expanded young leaves rather than in new growth. This may reflect a greater internal requirement in these leaves than in new growth. Symptoms of manganese deficiency do not occur on old leaves.

TABLE 2.2 Mobility of nutrients within plants

Mobile	Variably mobile	Immobile
Nitrogen	Sulfur	Calcium
Phosphorus	Copper	Manganese
Potassium	Zinc	Boron
Magnesium	Molybdenum	Iron

Magnesium is considered to be a mobile nutrient, and thus it is expected that the symptoms of magnesium deficiency would appear first in older leaves. However, under certain conditions, the symptoms of magnesium deficiency occur initially in young leaves. For example, when magnesium supply to subterranean clover was constant but inadequate, symptoms of magnesium deficiency appeared, as expected, firstly in older leaves (Scott and Robson 1990). However, when magnesium supply to the roots was interrupted suddenly, the symptoms appeared first in young tissue. In young wheat seedlings, symptoms of magnesium deficiency appeared first in young leaves when the supply to the roots was interrupted suddenly, or when the supply was constant but inadequate (Scott and Robson 1991). In both species, the symptoms of yellowing and necrosis that characterize magnesium deficiency occurred when leaf concentrations of magnesium fell below 'critical' values. Although magnesium was retranslocated from older leaves when the supply was limiting, the symptoms presumably appeared first in young tissue when their concentrations were the first to fall below the 'critical' levels. Apparently, the rate of movement of magnesium from old leaves to new growth was not sufficient to meet the requirements of the new growth.

For many nutrients, the extent of retranslocation is variable and depends upon the degree of deficiency, the plant species, and either the nitrogen or phosphorus status of the plant. For example, there is little or no movement of copper, zinc and molybdenum out of old leaves of plants deficient in these elements, and symptoms occur mainly in young tissues. However, should nitrogen deficiency or some other physiological or environmental factor cause the older leaves to senesce, copper, zinc and molybdenum can be remobilized from older to younger leaves along with the retranslocation of nitrogen (Hill *et al.* 1978). For nutrients where nitrogen supply affects the movement of other nutrients from old leaves to new growth, the location of symptoms may vary with the supply of nitrogen. An example of this is the effect of nitrogen supply on the location of sulfur-deficiency symptoms. For example, in cashew seedlings receiving a luxury supply of nitrogen, symptoms of sulfur deficiency occur initially in young leaves, but in plants with a marginal nitrogen status, sulfur deficiency produces a general paleness with symptoms occurring initially in older leaves (N. Grundon, unpublished data).

Symptoms of nutrient toxicity occur more commonly in old leaves, at least partly because these elements have accumulated progressively in older leaves over a longer period of time than in younger tissues. Many toxicities result in chlorosis and necrosis of the margins of older leaves. For example, in dicotyledons such as subterranean clover, phosphorus toxicity causes a marginal necrosis of older leaves (Rossiter 1952). Similar symptoms of marginal chlorosis and necrosis in older leaves are seen in boron toxicity in sunflower (Blamey *et al.* 1987) and in salt (sodium chloride) injury in sunflower, navybean, soybean, and cotton (Grundon 1987). In gymnosperms and mono-cotyledons, the tips of the leaves are usually the first to display symptoms of toxicity. Thus, the symptoms of phosphorus toxicity in wheat (Bhatti and Loneragan 1970), salinity effects and toxicity of sodium, chloride and sulfate in sorghum (Grundon *et al.* 1987), and of boron toxicity in wheat and barley (Paull *et al.* 1988; Nable *et al.* 1990; Riley and Robson 1994) develop first and are more severe on the tips and distal margins of the leaves. In these instances, the location of the symptoms reflects the localized accumulation of the nutrients in those parts of the leaf most affected by evapotranspiration conditions. For example, increased water use by barley increased boron accumulation, with the boron being concentrated in the leaf tips where the symptoms of toxicity were the most severe (Nable *et al.* 1990).

For aluminium toxicity, seedling emergence, growth, and survival are affected, resulting in variable shoot growth and stand density (Blamey *et al.* 1987). On individual shoots, the symptoms are frequently similar to those of phosphorus deficiency, reflecting an impairment of phosphorus absorption and metabolism by high concentrations of aluminium (see Robson and Pitman (1983) for an account). However, the characteristic symptoms of aluminium toxicity are expressed more clearly on the roots than on the shoots: root growth is restricted, and roots are thick and stubby with many laterals, commonly with brown tips (Blamey *et al.* 1987; Grundon *et al.* 1987; O'Sullivan *et al.* 1995).

If the toxic nutrient interacts with the metabolism of a second nutrient, thereby inducing a deficiency of the second nutrient, symptoms of the toxicity occur on older leaves while symptoms of deficiency occur on those leaves characteristic for that nutrient. For example, on acidic soils, excessive levels of soluble manganese can induce iron deficiency in some plants, thereby causing the development of manganese toxicity symptoms on older leaves and iron deficiency symptoms on younger leaves (Grundon *et al.* 1987; O'Sullivan *et al.* 1995).

TABLE 2.3 General description of symptoms of nutrient deficiencies

Nutrient	Symptoms*
Nitrogen	In crop species, chlorosis of whole plant occurs, often with reddening in cold weather; older leaves usually affected first. Fine branching in pines. In eucalypts, yellowing occurs firstly on mature leaves; symptoms spread rapidly to young leaves in seedlings.
Phosphorus	Crop species have dark green foliage, reddening or purpling of leaves or petioles (similar to cold effects); older leaves affected first. In pines, trees lack vigour and needles may be short in length. In colder climates, the tips of needles turn yellow, and fascicles fused. In eucalypts, foliage has a purple discolouration.
Potassium	Older leaves of crop species may show chlorosis and necrosis near margin or marginal burn; younger leaves may develop red pigmentation or become interveinally chlorotic and show a shiny surface. In pines, chlorosis is rapid in spring in colder climates; in warmer climates there is a general chlorosis of the tree in spring with dark green new flush growth. Needles only last 1.5 to 2 years rather than 3 to 4 years, then yellow and fall. In eucalypts, old leaves show necrosis or scorching.
Calcium	Growing point dies in crop species. In fruit crops, disorders of fruits (e.g. bitter pit in pome fruit, blossom-end rot in tomato and *Capsicum*) In leaf crops, disorders such as leaf-tip burn. In pines, side branches sprout giving a hedged, flattened appearance to the top of the tree. There may be abundant cone production and copious resin bleeding near the terminal bud. In eucalypts, the growing shoot tip dies and falls off. Expanding leaves develop tip and marginal burns and the leaves appear distorted with rolled margins.
Magnesium	Marginal or interveinal chlorosis in older leaves in crop species; green area of leaf may form an 'arrow-head' in woody plants. Strong reddening may border the chlorotic zone. Usually on older tissue first. In pines, needles tips appear golden yellow as if dipped in paint. In some seasons yellowing occurs on stem needles.
Sulfur	In crop species there is a chlorosis of the whole plant, often younger leaves affected first and more severely. In severe cases, lesions and resin bleeding on stems of pines. In eucalypts, the interveinal areas of expanding leaves turn pale green. Under severe deficiency, the young leaves become pale red, the leaf tips die and shrivel, and the terminal bud aborts. Leaves which are uniformly yellow are indistinguishable from those suffering nitrogen deficiency. However, nitrogen deficiency symptoms first appear in mature leaves and the young leaves do not develop a red blush.
Copper	Death of young leaves, chlorosis, failure of fertilization and fruit set (S-shaped shoot growth and fruit gumming in citrus). In trees, the young growth is affected (e.g. weather-tip in pomefruits and pistachio). Often the first sign of deficiency is the pendulous habit of lateral branches due to impaired lignification of wood in the young stem. Expanding leaves become twisted and cupped, and the margins may be irregular in outline. In pines, there are distorted stems and branches and bushiness, and prostrate growth in extreme cases. Needles may develop distal necrosis.
Zinc	Little leaf, rosetting, chlorotic mottle in less severe cases. In eucalypts, deficient trees are stunted and the leaves are small and crowded.
Manganese	Interveinal chlorosis; when severe, necrotic spots or streaks may form. Often occurs first on middle leaves. In eucalypts, tip margins of juvenile and adult expanding leaves become pale green. Chlorosis extends between the lateral veins towards the midrib.
Iron	Interveinal chlorosis which in severe cases may mean total bleaching of young foliage followed by necrosis. Occurs first on young leaves. In eucalypts, there is distinct interveinal chlorosis, i.e. yellow leaves with narrow green veins.
Boron	Death of growing points. Axillary buds may burst giving a witches broom effect. Some species (e.g. grape) may show leaf distortion characteristic of impaired metabolism of auxin. Fruit may be distorted or show woody pits or cracking of the surface. Petiole cracking in celery and hollowness in some root vegetable species. In pines, yellowing of young needle tips, production of resin droplets, then needle necrosis and leader dieback with repeated dieback resulting in multiple leaders, lack of apical dominance, and a tree with bushy appearance. Pith is black or dark brown. In eucalypts, growth is severely impaired at the shoot tip. The first signs are leaf rolling and weeping branches.
Silicon	Growth reduction and leaf freckle in sugar cane; droopy growth and lodging in rice.
Nickel	In monocotyledons, interveinal chlorosis of leaves showing symptoms similar to deficiencies of Fe, Mn, Zn and Cu. In dicotyledons, leaf-tip necrosis.
Molybdenum	In legumes, general paleness. In nonlegumes, mottled pale appearance, marginal burn of mature leaves (rock melon, maize, sunflower) Whiptail in cauliflower.

***Caution**: Symptom expression can vary from crop to crop, and amongst cultivars within species. It is important to check the specific symptoms described for a particular crop — see reference list in Appendix 1.

TABLE 2.4 General description of symptoms of nutrient toxicities

Nutrient	Symptoms*
Nitrate-nitrogen	Edge burn may be followed by interveinal collapse.
Ammonium-nitrogen	Initial necrosis, blackening around tips and edges of leaves. Root death may occur.
Phosphorus	Interveinal chlorosis in younger leaves (may resemble iron deficiency), necrosis and tip die back may follow in susceptible species. Marginal scorch, interveinal necrosis, and shedding of older leaves.
Salt (sodium and chloride)	In Norfolk Island pines, bronzing of needles beginning at the tips. In eucalypts, tip and marginal scorching of foliage, discolouration and shedding of foliage, stunted growth and death.
Sodium	Marginal chlorosis and burn, more severe on older leaves.
Sulfate	Severe stunting. Marginal chlorosis or necrosis of older leaves.
Chlorine	Bronzing, chlorosis, marginal burn in older leaves; leaf drop may be premature. In some species, the marginal burn is accompanied by upward cupping.
Manganese	Yellowing, beginning at the leaf edge of older leaves, sometimes with upward cupping; brown necrotic peppering on older leaves. Interveinal bronze-yellow chlorosis in beans; orange-yellow marginal and interveinal chlorosis in lemons; brown 'tar spots' in orange leaves; necrosis in apple bark (i.e. bark measles).
Aluminium	Symptoms on shoots may resemble those of phosphorus deficiency. Roots frequently stunted, brown, with many short laterals.
Zinc	Interveinal chlorosis in younger leaves (may resemble iron deficiency) in mild cases. Severe symptoms develop on older leaves as an interveinal chlorosis and necrosis. In colder climates, pines and *Callitris* produce a general chlorosis.
Boron	Interveinal necrosis (often spotty at first) on older leaves. Leaf-tip and leaf margin necrosis and burn in older leaves of trees and grapevines.
Nickel	Interveinal chlorosis in younger leaves (may resemble iron deficiency); in grasses, a variation in intensity of the chlorosis produces transverse bands of light and dark colouring along the length of the leaf. In trees, interveinal chlorosis and necrosis, more severe on older leaves. In hoop pine, leaves become very bleached, almost white in colour.
Fluorine	Scorching of leaf tip and margin, extending into interveinal areas.

*__Caution__: Symptom expression can vary from crop to crop, and amongst cultivars within species. It is important to check the specific symptoms described for a particular crop — see reference list in Appendix 1.

D. DESCRIPTION OF SYMPTOMS

There are many published descriptions of symptoms of nutrient deficiencies in a wide range of plant species, but fewer descriptions of nutrient toxicities have been published (see Appendix 1). While symptoms vary from one plant species to another, and even between cultivars in some species, general symptoms of deficiency (Table 2.3) and toxicity (Table 2.4) can be summarized for each nutrient. Keys to distinguish between symptoms of deficiencies and toxicities of the various nutrients have been developed, and can take various forms; Table 2.5 shows a box type key used for subterranean clover (Snowball and Robson 1983), Table 2.6 shows a hierarchical text key for grain sorghum (Grundon *et al.* 1987), and Table 2.7 shows a text key for *Pinus radiata* that includes symptoms of diseases and insect pests (Turner *et al.* (1979)

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TABLE 2.5. Example of a diagnostic key to nutrient deficiencies in subterranean clover (Snowball and Robson 1983)

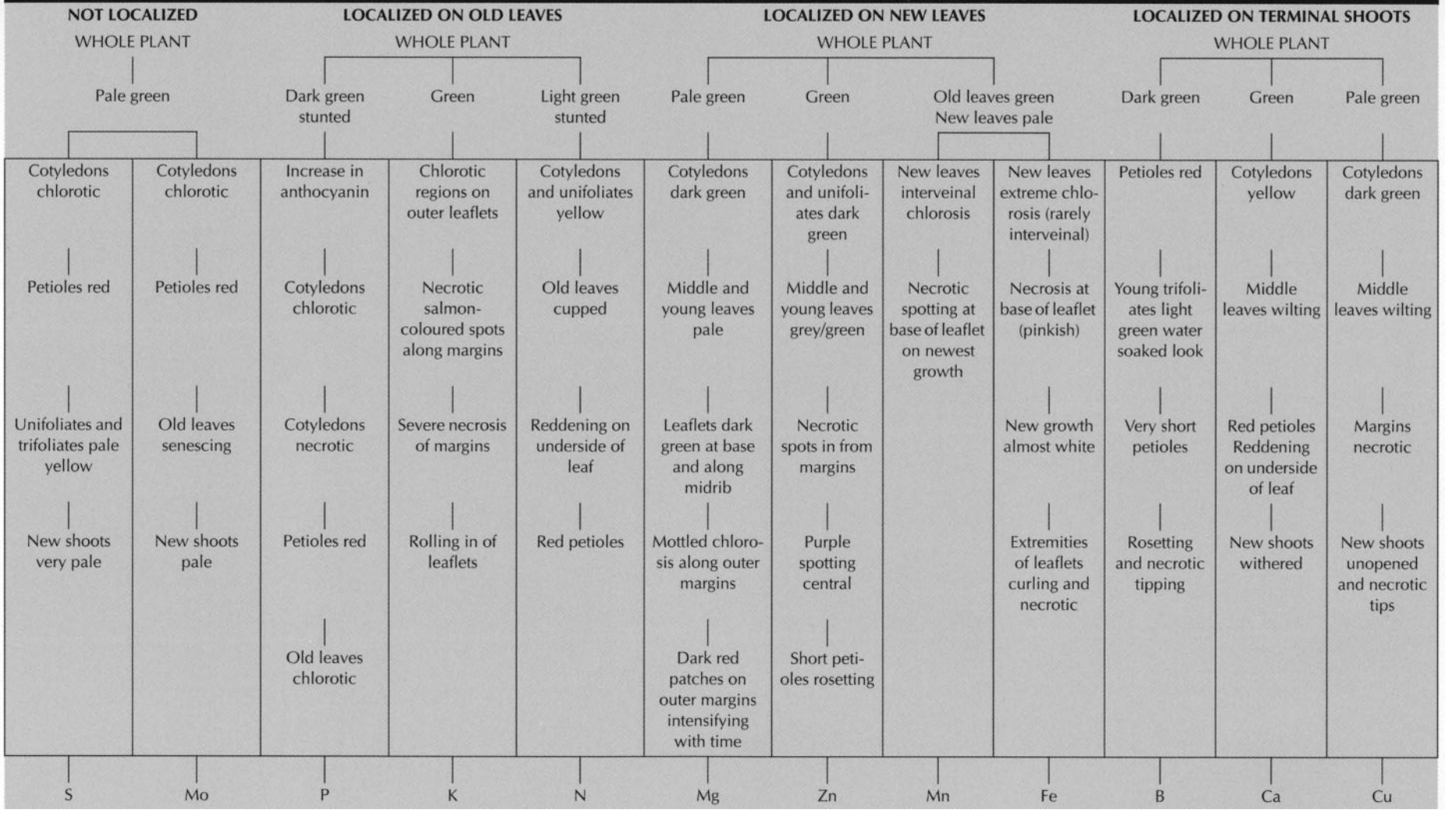

TABLE 2.6 An example of a hierarchical text key for diagnosis of nutrient deficiencies and toxicities of grain sorghum (Grundon *et al.* 1987)

A1	Symptoms begin or are more severe on older leaves	B
A2	Symptoms begin or are more severe on younger leaves	D
A3	Symptoms prominent on both old and young leaves	G
A4	No specific leaf symptoms but roots thickened and fail to elongate	Aluminium toxicity
B1	Older leaves mainly pale green with pale yellow chlorosis and pale brown necrosis	Nitrogen deficiency
B2	Older leaves mainly pale green with pale yellow interveinal chlorosis and sometimes brown, orange, and purple lesions	Magnesium deficiency
B3	Older leaves mainly dark green with or without dark yellow chlorosis but often with purple, red, or dark brown lesions or pigmentation	C
C1	Older leaves with small dark brown to red-purple lesions resembling spots	Manganese toxicity
C2	Older leaves with purple suffused pigmentation, no orange or brown spots	Phosphorus deficiency
C3	Older leaves with large orange, yellow, purple, or brown streaks and lesions	Zinc toxicity
C4	Older leaves with prominent red-purple lesions which have an irregular outline	Phosphorus toxicity
C5	Older leaves with marginal yellow chlorosis and brown necrosis, or older leaves with marginal brown lesions surrounded by red-purple halo with smooth outline, plants not wilted	Potassium deficiency
C6	Older leaves with yellow, white, or brown margins, plants often wilted	Toxicity of sulfur, sodium, or chlorine
C7	Older leaves with grey to white necrotic lesions and brown marginal necrosis, plants often appear wilted	Sodium toxicity
C8	Plants often appear wilted, yellow interveinal chlorosis and red-purple lesions on middle leaves	Chlorine toxicity
D1	Young leaves mainly pale green or pale yellow	E
D2	Young leaves mainly dark green	F
E1	Whorl of young leaves twisted to one side	Copper deficiency
E2	Prominent yellow or white interveinal chlorosis on young leaves	Iron deficiency
E3	Young leaves may develop faint yellow interveinal chlorosis but usually turn an even yellow colour	Sulfur deficiency
F1	Young leaves with brown twisted leaftips	Copper deficiency
F2	Young leaves with torn or serrated leaf margins and leaftips deformed, missing or joined together	Calcium deficiency
F3	Young leaves with broad yellow or white bands between margins and midvein in lower half of leaf	Zinc deficiency
F4	Young leaves with transparent white interveinal lesions	Boron deficiency
F5	Young leaves with yellow interveinal chlorosis and red-brown interveinal lesions	Manganese deficiency
G1	Older leaves mainly dark green with large purple or orange lesions, young leaves pale yellow	Zinc toxicity
G2	Older leaves mainly dark green with small brown or red-purple lesions, young leaves pale yellow	Manganese toxicity
G3	Older leaves and younger leaves mainly pale green or pale yellow, with or without nterveinal chlorosis	Deficiency of sulfur, or toxicity of aluminium inducing deficiencies of iron and/or magnesium

TABLE 2.7 An example of a hierarchical text key for diagnosis of nutrient deficiencies and toxicities and insect and fungal disorders in *Pinus radiata* (Turner *et al.* (1979)

	Primary symptom	Probable cause
A1	Brown or orange-red needles on a significant percentage of tree and/or dead topping (if not go to A2)	
	B1. Patches of stands with brown needles often from base up.	
	C1. Trees of all ages affected noticeably on dry ridges. Seasonal, usually after period of low rainfall.	Drought
	C2. Poorly drained areas, all age classes affected.	*Phytophthora* infection
	C3. Usually affecting suppressed trees in stand. Dead topping with needles retained.	Sirex wasp
	C4. Areas of stand turning orange red to red brown from base up, trees usually under 15 years old. Probably on basalts, poor granites or soils high in nitrogen (fertilized farmland) Related to low sulfur/boron situations. Brown needles have red bands.	*Dothistroma* infection
	B2. Scorching of needles	
	D1. Coastal situations with one side of tree affected — flagging.	Salt toxicity
	D2. Scorch from base up, groups of trees affected especially in hollows.	Frost
	D3. One side of tree affected, distortion may be present.	Herbicides
	B2. Dieback of patches of trees less than three years old, usually from top of tree down. Soils derived from basalts or highly weathered granites. At periphery of dieback, expect further zone of deformed trees with dead tips or side branches. Area most usually affected is in a gully and may be related in some instances to poor drainage. (*May expect secondary infection of *Diplodia* or *Dothistroma* on surviving trees.)	Sulfur/boron deficiencies*
	B3. Dieback of growing tips repeatedly giving rise to stunted bushes, rounded trees, and often, in otherwise highly productive stands, a high proportion of multiple leaders. Soils are basalts, weathered granites or eroded soils. Dead areas in stands (see B3) Dead topping may be spread through stand giving a pepper pot appearance.	
	E1. Black or dark brown pith near site of death. Shepherd's crook.	Boron deficiency
	E2. Resinosis with or without E1.	Sulfur/boron deficiencies
	E3. Wilting effect on side branch giving Shepherd's crook with or without E1 and E2.	*Diplodia* infection
A2.	Yellowing of needles (if not go to A3)	
	F1. Overall pale yellowing	
	G1. Thin crown, fine branches, generally slender trees. Yellowing or pale green appearance of all needle age classes, stand affected relatively uniformly. Coastal sands and some heavily weathered granites.	Nitrogen deficiency
	G2. Not finely branched, probably more patchy in stand. Usually very productive stands. Basalts and granites.	Sulfur deficiency (see also above)
	F2. Yellowing from base of tree up. Usually on deep sands. Seasonal. Rare in New South Wales.	Potassium deficiency
	F3. Yellowing of single needle age classes, starting with oldest. On inspection yellowing may be severe on distal half of needle.	
	H1. Older age classes and stem needles brown to yellow. Black shiny elliptical fruiting bodies, opening by central narrow slit.	*Lophodermium* infection
	H2. Older age classes and stem needles brown to yellow. Whitish waxy, rectangular shaped fruiting bodies.	*Naemocyclus*[A] infection
	H3. Bright yellow stem needles or younger needles, often appearance of needle ends dipped in paint. Probably seasonal, especially spring.	Magnesium deficiency

TABLE 2.7 An example of a hierarchical text key for diagnosis of nutrient deficiencies and toxicities and insect and fungal disorders in *Pinus radiata* (Turner *et al.* (1979)

	Primary symptom	Probable cause
	F4. Youngest needles yellow to white. Very sudden change. (A rare occurrence as usually found on alkaline soils)	Iron deficiency
	F5. Needles yellow to white as above — all soil types.	Triazine or Triazole herbicide spraying
A3.	Yellowing or brown needles not most obvious symptoms Trees generally remain green or grey green.	
	I1. Thin crowned trees causing stem and branches to be obvious especially in younger trees. Fused needles and rosetting on some trees. Poor and uneven growth. Generally on sedimentary rocks, poor granites or coastal sands. In less severe stages, may be yellowing on needle tips. Range of symptoms occurs in one stand. Most severe stage in older trees will be death of older needles and top of tree.	Phosphorus deficiency
	I2. Trees generally older than 15 years. Repeated dieback of trees leading to flattened appearance. High coning may occur. Soils usually similar to phosphorus deficiency sites.	Calcium deficiency
	I3. Rosetting — lateral branches short and at acute angle, with short needles. Only late-formed needles of current year retained. No recorded instances in New South Wales.	Zinc deficiency
	I4. Dark blue-green foliage, distorted branches and bushiness. No recorded instances in New South Wales.	Copper deficiency
	I5. Paleness of foliage, especially towards top of tree. No recorded instances in New South Wales.	Manganese deficiency

[A]*Naemocyclus* has been renamed *Cycloneusma*.

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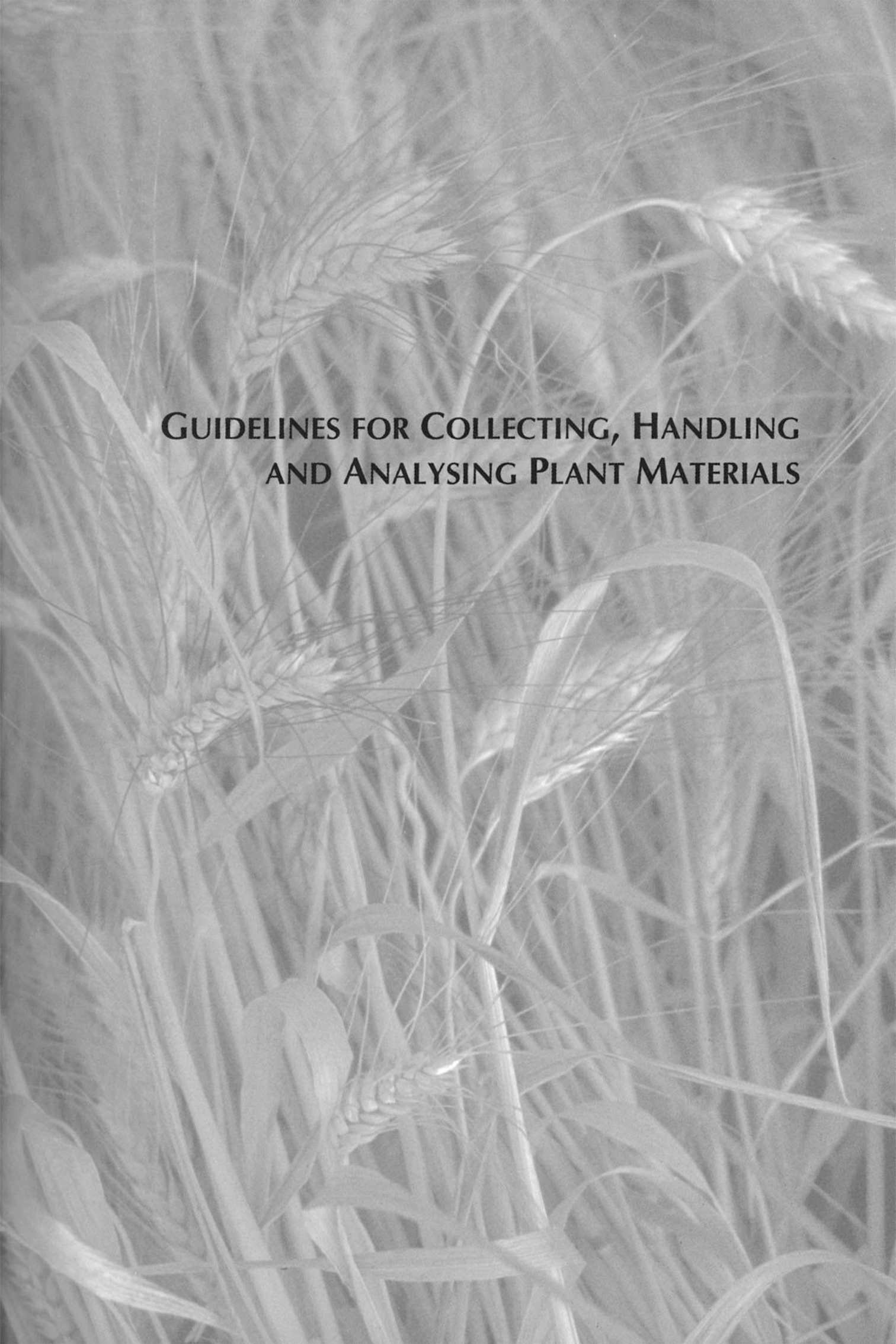

Guidelines for Collecting, Handling and Analysing Plant Materials

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3. Guidelines for Collecting, Handling and Analysing Plant Materials

D.J. Reuter, J.B. Robinson, K.I. Peverill, G.H. Price and M.J. Lambert

A. Introduction

The value of plant analysis for diagnosing and monitoring the nutritional status of plants hinges largely on the care that is taken in collecting, handling and analysing the gathered plant material. Unreliable and misleading interpretations will occur unless proper steps are taken to minimize errors in each of the above tasks. Procedures for sampling and handling plants should be standardized to ensure that the tests can be interpreted with confidence. While the specific requirements of the different tests may vary, samplers and testing laboratories should follow closely the procedure specified in the published account for each plant species and test, and laboratories should aim to provide a fast turn around service to their clients (Handson and Shelley 1993).

This chapter briefly reviews and indicates broad guidelines for sampling and preparing plants for chemical analysis. It is vital that those involved in plant testing become familiar with recommended practices and understand why these procedures have been adopted widely in Australia and overseas. The following discussion has been developed to promote a standardized approach for all users.

B. Purposes and Methods of Plant Testing

Distinction must be drawn between three purposes for plant testing: diagnostic testing, monitoring, and predictive testing (see Chapter 1). This is necessary because the intensity and pattern of sampling varies considerably for each method of testing (see Section 3.D). However, in all testing methods, there is a need to document details of site management and crop conditions, before and at the time of sampling.

Most farmers use plant analysis to diagnose a problem or to monitor nutrient status and thereby fine tune their fertilizer program. Forest managers and horticulturists mainly use the monitoring approach, although diagnostic testing is an important tool for identifying nutrient disorders in trees and other perennial species.

- *Diagnostic testing* (sometimes called *'trouble-shooting'*) is undertaken to diagnose the cause of poor crop vigour (e.g. patches of poor growth in an otherwise healthy crop, pasture or orchard) or to confirm a diagnosis made on the basis of plant symptoms or soil tests. Where no standards are available, comparing nutrient concentrations in samples from 'good' and 'poor' areas can be useful.

  Plant analysis has also been used to identify the causes of illthrift in grazing livestock (e.g. Beck 1962; Hogan *et al.* 1971; Langlands *et al.* 1981; Kubota 1983; Merry *et al.* 1983; Hosking *et al.* 1986), but this aspect will not be pursued further in this chapter.
- *Monitoring* samples are collected to assess the adequacy of current fertilizer practices and related management factors (e.g. irrigation practices). Monitoring can compare the nutritional status of crops, in successive years and allow fertilizer use to be adjusted according to trends revealed in the plant chemical composition. It can also be used to monitor the nutritional status of an individual crop or pasture during its development (i.e. crop logging) and thus ensure that its nutrient requirements are being met (see Clements 1961; Ulrich and Hills 1973; Gartrell *et al.* 1979).

  Time frames are considerably longer in forestry than in agricultural production systems (e.g. a forest rotation lasts for a minimum of 30 years). Hence for cost reasons, it is normally not practicable to under-take repeat samplings in successive years. The most common objectives for monitoring in forestry are:

  1. Prescription of the timing, amount, placement and type of fertilizer to be applied to forest stands to meet specific management objectives (for example, increased timber production and seed production, and alteration of wood properties);
  2. Assessment, after fertilizer treatment, of the relative efficiency of nutrient uptake and the possible inducement of nutrient imbalances; and
  3. Assessment of the rate of nutrient decline after fertilizer application and hence the necessity for additional fertilization in the future.
- *Predictive testing* is used in four ways.

  1. Analysis of samples collected during early crop development is used to predict the likelihood of nutrient deficiencies occurring before crop maturity is reached (Spencer *et al.* 1977; Freney *et al.* 1978; Gartrell *et al.* 1979; Spencer and Freney 1980; Spencer and Chan 1981; Rayment 1983; Hannam *et al.* 1985; Lambert and Turner 1988);

2. Analysis of fruit is used to predict its likely behaviour in storage (e.g. Perring 1976; Wills *et al.* 1976; Atkinson *et al.* 1980);
3. Analysis of seeds or grain is used to predict likely deficiencies in succeeding crops (e.g. Russell 1963; Walton 1978; Robson and Mead 1980; Randall *et al.* 1981; Moss *et al.* 1982), and to define attributes of product quality (e.g. grain protein or oil content); and
4. Analysis of plant sap for annual crops, primarily used in Australia for nitrogen scheduling (Williams and Maier 1990; Handson and Sheridan 1992).

Each form of testing may identify latent deficiencies (sometimes called 'hidden hunger') which limit crop production while the plants exhibit no obvious or distinctive symptoms.

Plant analysis will not be useful if the sampled crop is under stress for reasons other than nutritional stress (e.g. drought, soil waterlogging etc.). In such situations it should not be used.

C. Documenting Site and Crop Information

Successful testing and diagnosis requires a logical, investigative approach. Experience has shown that the precision of interpretation of both plant and soil tests is often enhanced substantially by considering relevant site and crop conditions recorded at the time of sampling. For diagnostic testing, and to a lesser extent for monitoring, two steps should be taken before sampling commences: discussion between the land manager and the adviser, and a description of any plant symptoms. Photographs are useful aids to memory.

Where land managers collect their own samples, they must provide relevant sample details to allow proper interpretation of the data (see Figure 3.1). It is important to note that recent market research suggests that sample collection (by farmers) is the 'single, biggest barrier' to the wide adoption of plant testing in Australia (Lewis *et al.* 1993). Training in all aspects of correct sampling is now considered essential if meaningful data are to be collected (Lewis *et al.* 1993; Robinson 1993).

Most soil and plant testing services supply site information forms with their sampling kits to assist users in the collection of relevant details of the site and plant symptoms (see an example in Figure 3.1). Such forms should be used as a check list when sampling and to record where the sampling took place. For modern GIS based mapping, site locators such as postcodes or map grid references are needed.

C.1 Discussion with the land manager

Initially, details of the site and crop or pasture should be discussed with the land manager to gain a perspective of the problem. Answers to the following questions should be supplied to assist with interpretation of results.

- What are the crop details (e.g. sowing date, cultivar, rootstock, crop condition)?
- In forestry, details of plantation stage (e.g. young planting, closed canopy, stocking and thinning levels) and the presence and status of competing vegetation should be recorded.
- Were any plant symptoms observed? When?
- What was the previous land use?
- Have these symptoms occurred in previous seasons and, if so, under what conditions?
- Are the symptoms associated with certain soils? Examine the profile and drainage characteristics of the soil, and the topographical features of the land form.
- Are soil tests available? What do the data suggest?
- Are plant analysis data from previous years available? What do they show?
- Has the system of land management (e.g. rotation sequence, method of cultivation, stubble handling, fertilizer use) changed recently?
- What has been the amount and type of fertilizer used previously and the frequency and method of application? Which nutrients, if any, have been applied as foliar sprays?
- Have seasonal conditions been abnormal?
- What is the type of irrigation, if any? Has it been altered recently (e.g. rate, frequency, water quality)?
- Are pests and diseases present? What are they, and what agricultural chemicals have been applied? Damage from pre-emergent and residual herbicides can produce symptoms similar to those of some plant nutrient disorders.
- Is the measurement of forest stand condition (growth, health) better or worse than expected for the site?

C.2 Description of plant symptoms

This is particularly important for diagnostic testing.

The *type* (e.g. chlorosis, necrosis, mottling, anthocyanin, plant stunting) and *location* on plants (e.g. terminal apices, young or old foliage) and on leaves (e.g veins, margins, interveinal) of symptoms on the shoots and roots should be recorded. In forestry, it is necessary to record stem form (straightness, speed wobbles, kinkiness), leaf retention, bud death, pith damage. These symptoms can be compared with those described or referred to in Chapter 2 (Appendix 1).

Although symptoms alone can often be misleading or non-specific, especially where more than one nutrient is limiting crop production (see Chapter 2), they can assist in eliminating certain nutrients that are adequately supplied. Characteristic symptoms focus the detection process on a small group of essential plant nutrient and plant and soil analysis can then be used to confirm or reject these preliminary diagnoses or suspicions.

It is extremely important to assess and record whether the affected plants are stressed by non-nutritional factors (e.g. weed competition, root and foliar diseases, nematodes, insects, drought, poor drainage, or poor physical condition of the soil). Root systems

PLANT ANALYSIS SAMPLE AND SITE DESCRIPTION

Laboratory No. ☐☐☐☐☐☐ Sample received ☐☐☐☐☐☐

Farmer's Name: .....

Address: Post Code: .....

Has this area/crop been sampled previously? Yes ☐ No ☐ When? ☐☐☐☐☐☐

Name of person who took the sample. .....

Name of this paddock/block .....

Nearest locality to paddock/block .....

Distance/direction from nearest locality (eg: 2 km NW of St Arnaud) .....

Grid reference: .....

A. Sample Description:

CROP: ..... VARIETY: .....

DATE SOWN: ☐☐☐☐☐☐ DATE SAMPLED: ☐☐☐☐☐☐ (DD MM YY format)

Paddock name/number: ..... Area: ..... Sample labelled as: .....

STAGE OF GROWTH: Seedling ☐ Early growth ☐ Tillering ☐ Flowering ☐ Fruit/Grain set ☐

(Tick) Mature ☐ Other: .....

PLANT PART SUBMITTED: Whole plants ☐ Leaf Blades ☐ Which?

(Tick) Stems ☐ Petioles ☐ Which? ..... Grain/Fruit ☐

Others ☐ Define: .....

DESCRIPTION OF CROP SYMPTOMS (If any, describe briefly): .....

Are symptoms on: Old leaves ☐ Young leaves ☐ Terminal new leaves ☐ ? (Tick)

When were the symptoms first observed? ..... Have they been observed in previous crops? .....

Which year? .....

How do you rate crop vigour? : Good ☐ Average ☐ Poor ☐ (Tick)

Has this crop been subjected to Drought ☐ Waterlogging ☐ Pests ☐ Diseases ☐ (Tick)

If yes, describe: .....

Has this crop been sprayed with Nutrients ☐ Pesticides ☐ Describe: .....

B. Site Description

SURFACE SOIL: Sand ☐ Sandy loam ☐ Loam ☐ Clay loam ☐ Clay ☐ Colour: ..... (Tick)

SUB SOIL: Sand ☐ Clay ☐ Limestone ☐ Other: . . . Colour: .....

Depth to subsoil: .....

Paddock/Block size (ha)		**Drainage**		**Topography**		**Rainfall (mm)**			
Under 1	☐	Poor	☐	Flat	☐	Under 400	☐	700-800	☐
1-5	☐	Average	☐	Slope	☐	400-500	☐	800-900	☐
6-20	☐	Good	☐	Hill top	☐	500-600	☐	Over 900	☐
Over 20	☐	Undulating	☐	600-700	☐	Irrigated	☐		

Crop rotation & fertilizer history for last 5 years:

Year	Rotation	Crop Yield (t/ha)	Fertilizer used	Rate of application (kg/ha)

When were trace elements last applied to this paddock? .....

Which trace elements? Copper ☐ Zinc ☐ Manganese ☐ Molybdenum ☐ Iron ☐ Boron ☐

IRRIGATION cm applied None ☐ Sprinkler ☐ Surface ☐

C. Site Sketch (Show where sample was taken in relation to known land marks)

Figure 3.1 An example of a form for recording the relevant information about the site and plant sample which is required for the nterpretation of plant analyses.

of affected plants should be inspected for abnormalities. The soil profile beneath the affected crop should be compared with that of the soil on which the surrounding healthy crop is growing. Where necessary, appropriate soil samples and additional plant samples should be taken for pathological examination.

It is also necessary to record the age and growth stages of affected and normal plants. Plant diagnostic criteria usually vary with plant age and stage of physiological development. Hence, chemical analyses need to be interpreted with reference to the stage of plant growth.

D. COLLECTING REPRESENTATIVE SAMPLES

Many plant tests have been developed and calibrated for use in agricultural, horticultural and forestry industries. The greatest opportunity for error in plant testing arises during sampling. Errors associated with sample preparation and analysis are often minor by comparison. Inaccurate or careless sampling invariably leads to inconsistent and erroneous interpretations and can ultimately discredit the value of plant testing itself. Thus the successful commercial adoption of plant analysis depends heavily on the development of sampling procedures which adequately cope with site and crop variability.

We refer the reader to publications by Martin-Prével *et al.* (1984), Jones *et al.* (1991) and Robinson (1993), which document further the principles and practices of correct sampling and the preservation of sample integrity.

D.1 Concepts and strategies

The principal objectives of any sampling program are to collect samples that satisfactorily represent the situation being examined and to provide sufficient material for the laboratory to analyse. The judgement and care taken by the sampler determines how well the total plant population is represented by the plant material collected. The sampler must be satisfied that the number of subsamples taken is sufficient to account for the variability existing within the area of crop that has been chosen for sampling.

The sampling strategy adopted for collecting representative diagnostic samples differs fundamentally from those required for monitoring samples, as often 'bad' samples will be drawn from a small population of plants.

In forestry, differences in the sampling strategies used for diagnostic and monitoring purposes are not so clear. In each case, sample stratification is required according to tree age class, soils or soil parent material, previous land use and topography.

D.1.1 Diagnostic sampling

With diagnostic samples, the collection must be confined within the area of crop for which an answer is sought (e.g. a patch of poor growth, a group of low-producing and/or slow growing trees). To minimize the effects of natural variability, each composite sample should be collected from within a small uniform area.

Where symptoms and plant size vary appreciably, a number of samples should be taken systematically, each from a uniform small area, which characterises the observed variability (e.g. severely deficient, mildly deficient and normal plants; or paired samples representing deficient and normal plants). Comparison of analyses of paired samples is sometimes helpful, especially where plant standards do not exist.

Where a crop is uniformly affected, or where a suspected disorder is being confirmed with the aid of plant analysis, it is necessary to collect only one composite sample.

If subsamples have been collected from small, uniformly affected areas of crop, which reflect the observed variations in plant vigour, actual sample size is dictated largely by the quantity of material necessary for the chemical determinations. Usually 30–100 appropriate shoots or plant parts are collected systematically and combined into a composite sample.

Composite subsamples from forests need to be made on the basis of an equal mass of foliage from each tree. Bias is introduced if compositing is done on the basis of equal numbers of leaves or needles.

Also, diagnostic sampling is best undertaken when symptoms of the disorder are first observed. Plants which have endured long periods of stress often develop unusual nutritional symptoms and secondary problems, such as disease. Each sample should contain shoots or plant parts of the same physiological age. Tissues of both deficient and healthy plants or tissues of varying chronological or physiological age should never be included in a single composite sample. However, in some cases, it may be difficult to satisfy the requirement of comparable physiological age (e.g. zinc deficiency which severely stunts growth). In such cases, the identity of parts sampled needs to be carefully recorded.

In forests, circular or rectangular sampling plots of at least 25 trees need to be established and marked permanently for future assessments of nutritional status. Where they exist, permanent inventory plots used to monitor tree growth can also be sampled to assess nutrient status and to determine fertilizer requirements of forests. Such reference plots are also used in orchards and vineyards, but the question of achieving adequate representation always exists.

D.1.2 Sampling for monitoring

Several approaches are possible for monitoring the nutritional status of field crops, pastures, forest species and orchards. The sampling strategy and intensity depends both on the observed uniformity in crop growth, soil type and topography. Some recommended sampling protocols estimate the variability in nutrient status for different parts of the area planted; at each sampling time more than one sample is collected and analysed from each crop or orchard. Such procedures can be justified for high value crops, and where the land manager is prepared to fertilize the crop according to deficiencies revealed

by plant analysis. Modern monitoring services allow land managers to receive and act upon tissue analysis data two or three times during the season.

The following examples show how sampling strategies for crop monitoring can vary.

- *Uniform crop*. Three approaches can be used:

1. Ulrich and Hills (1952, 1973), working with sugar beet, recommended that a minimum of two, and preferably four, composite samples should be taken from each field. The field is divided roughly into four equal parts, and a systematic sampling transect undertaken in each quadrant and preferably at right angles to the crop rows (Figure 3.2a). Each sample comprises from 25 to 50 plants or plant parts..
2. A variation of the above method, involves selecting a small uniform area (e.g. 0.4 hectare) in each quadrat of the field. A systematic sampling traverse similar to that described above is taken within each area and again four separate samples are obtained per field (Figure 3.2b).

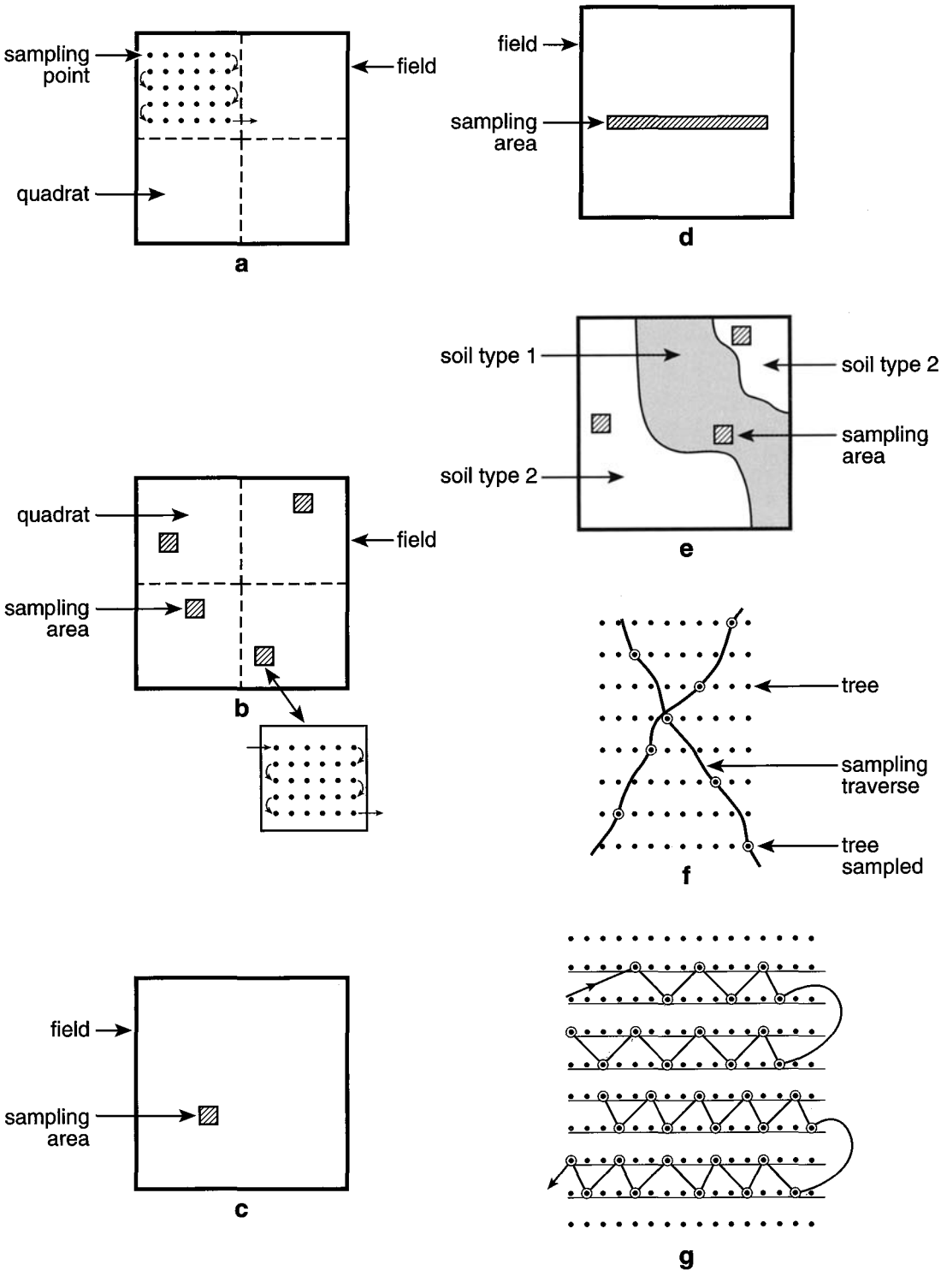


Figure 3.2 Strategies which may be used when collecting plant samples for analysis.

3. Frequently, just one sample is collected for analysis. A small area of crop (0.5–1.0 hectare), judged as representative of the average crop condition in the field, is selected. The crop within it is systematically sampled in the usual way (Figure 3.2c). Alternatively, a sampling transect can be undertaken across the whole crop (Figure 3.2d). The last approach is commonly used and is cheaper.

- *Variable crop.* Separate and more elaborate monitoring transects within small uniform areas of crop should be undertaken in fields or orchards where soil and topographical features are known to vary (e.g. loam *vs* clay loam; red soil vs black soil; sandy rise *vs* loamy flats), or where differences in crop growth are obvious. As with diagnostic sampling, each traverse requires a separate sample (Figure 3.2e)

- *Fruit trees and vines.* For most tree crops, it is important to sample leaves and/or petioles from all sides of trees. Typical sampling instructions might be: select a uniform area of orchard (soil, cultivar, age) and within this area select 20 trees along an X or zig-zag passage through the orchard (Figure 3.2f); collect four leaves per tree one from each of the north, south, east and west quarters of the tree. Select leaves from the outside of the canopy. Specific recommendations are given in detail for each fruit tree or vine crop later in this manual.

  In hedgerow orchards and in vineyards where it is not possible to cross rows easily, U or W type traverses through the planting offer a sensible compromise (Figure 3.2g). Samples can be taken at regular intervals (say five paces) alternately from both sides along each inter-row space.

- *Ornamentals.* As with the fruit tree crops, the sampling and analysis of leaves of shrubs and trees will be most beneficial after the second or third season of sampling. The analytical results, records of site management and estimates of production can provide a basis for assessing the health of the plant.

  With annual and herbaceous ornamentals, the grower has only a short time over which to assess the nutrient status of the plant during its growing season. Unless laboratory turn-around time is fast, any suggested changes to the fertilizer program are unlikely to benefit the current plants.

  When deficiency symptoms are observed on ornamentals, samples should be taken from affected plants and equivalent unaffected plants for diagnosis of the problem. The nutrient status of woody shrubs and tree species can be monitored by taking leaf samples regularly for analysis.

- *Forest Trees.* Standard sampling procedures as outlined below are provided in the *Field Methods Manual* of State Forests of NSW (Anon. 1995).

1. *Conifers*

   Foliage sampling is carried out after the onset of dormancy, usually in late May-June and should be completed usually by the end of July. The sample collected for chemical analysis must represent the full extension of the previous 12 months' growth and, for interpretative purposes, is directly applicable to analyses undertaken previously.

2. *Broad-leaved trees*

   For these species, depending on the size of the trees, foliage from either one or two of trees may be sampled per plot area. If trees are small and/or less than about 3 years of age, it is preferable to bulk leaves from 6–10 trees. For large trees, due to the time consuming nature of sampling (which is usually done by shooting branches from within the upper crown), only 1–2 typical trees are sampled in stands that are reasonably uniform.

   The sampling is undertaken in the middle of winter, except in the case of deciduous trees when sampling is undertaken at the end of summer. Leaves are selected from branches which are less than a year old and positioned in the top third of the tree crown. All recently matured leaves (which are not insect damaged or 'shot-holed') are collected from the branch, and mixed, and a subsample is taken for chemical analysis. The developing leaves at the tip of the branch are not included in the sample. At least 4 good handfuls of leaves are required per sample, producing a minimum sample size of 20 mature leaves.

If changes in nutrient concentrations with time are to be monitored reliably, it is essential that the boundaries of each sampling area are recorded precisely, and preferably pegged for future reference. In orchards, sampled trees should be tagged or marked; surveyor's tape is convenient and sufficiently durable for this purpose.

In recent years, more use has been made of analysing nutrient concentration in plant sap, as a monitoring tool for assessing plant nutrient status.

Tissues rich in conducting tissue, usually the petiole (dicots) or basal stem (monocots), are sampled at a specific stage of growth and thereafter regularly, say once per week or fortnight, to allow the trends in nutrient status to be tracked over time. When the standard ranges for the nutrients in healthy, high-yielding crops are known and the nutrients being monitored fall outside the desired range, fertilizer programs may be adjusted (i.e changed rates of injection of N or K through fertigation systems or applications of sidedressed fertilizer)

In any monitoring program the appropriate level of sampling intensity can be calculated approximately from the following equation (Steyn 1961; Leece 1972):

$$n = 2t^2d^2/D^2$$

where n = the number of plants or trees sampled

d = the average coefficient of variation for a given nutrient

D = the minimum % difference between the population and sample means which is significant ($P< 0.05$)

t = the Student's t value for the desired level of probability and with the degrees of freedom on which d was estimated.

In practice, average values for d are estimated for each nutrient from variability studies conducted at a range of sites for a given plant species. Australian studies with tree crops have also shown that n, for a given crop and location, varies for different nutrients and for different sampling dates (Leece 1972; Snowdon and Waring 1982). Thus, the estimate of sampling intensity (n) is only approximate for any given field or orchard (with unknown variance) and, for many species, recommendations for n are empirically based, being derived from wide experience in sampling field crops. A list of selected publications providing such data is given in Table 3.1.

D.2 Sampling appropriate plant parts

For many species, tests are available which specify the analysis of nutrients in nominated plant parts, such as the youngest mature leaf blades or petioles (see Chapter 1). These plant parts, of known physiological age, may be especially sensitive to variations in nutrient supply, and are usually preferred to the analysis of whole shoots. Samplers therefore need to gain experience in locating precisely the defined plant parts (see examples in Figure 3.3). The analysis of whole shoots is advocated by some commercial services

The relevant parts can be collected from plants in the field or they can be separated later from whole shoots. This is a matter of convenience but, if labile fractions such as nitrate are to be analysed, immediate separation of plant parts in the field is advisable (Knowles *et al.* 1989). Furthermore, it is essential that only clean, correctly identified plant parts are separated and dispatched for analysis.

D.3 Other factors to consider

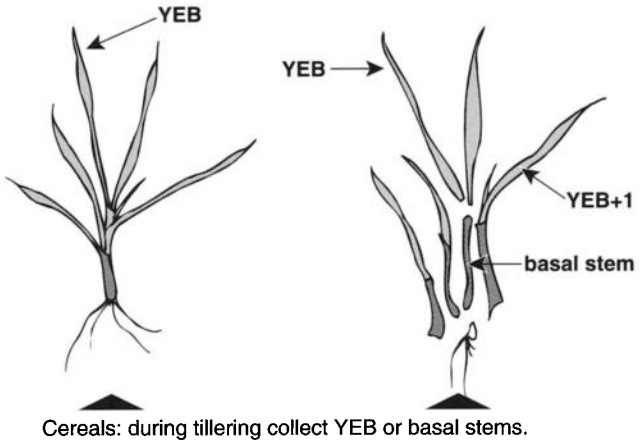
The following practices should be adopted for all sampling.

- Avoid soiled, diseased, insect- or mechanically-damaged plants, and exclude senescing and dead tissue from the gathered material.
- Avoid plants growing within areas which have unusual features (e.g rocky areas, poorly drained or salt affected areas and areas near water troughs, sheep camps, stock routes, rabbit burrows, crop edges, headlands, firebreaks and fertilizer depots).

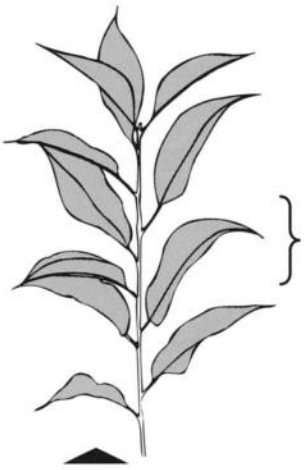
TABLE 3.1 Selected publications dealing with plant sampling methods and sampling intensities.

Plant species	Nutrients studied or reported	Reference
Apples	N, P, K, Ca, Mg	Holland *et al.* (1967)
Avocado	N	Lahav *et al.* (1990)
Cereals	Cu	Gartrell *et al.* (1979)†
Cocoa	N, P, K,Ca, Mg	Acquaye (1964)
Eucalyptus deglupta	N, P, K, Ca, Mg, Zn, Cu, Mn, Fe, B	Lamb (1976)†
Eucalyptus spp.	N, P, K, Ca, Mg	Bell and Ward (1984)
Ginger	N	Lee *et al.* (1981)†
Lupin and Wheat	P	Bolland (1995)†
Peaches	N, P, K, Ca, Mg, Na, Cl, Cu, Zn, Mn, B	Leece (1972)†
Pineapple, citrus	N, P, K, Ca, Mg, Na, Cu, Zn, Mn,Fe	Steyn (1961)
Pinus radiata	N, P, K, Ca, Mg, Al, Na, Mn, Fe, Cl, total S, sulfate-S	Humphreys *et al.* (1972)†
Pinus radiata	N, P, K, Ca, Mg, Zn, Mn, Fe	Snowdon and Waring (1982)†
Pinus radiata	N, P, K, Ca, Mg, Al, Na, Mn, Fe, Cu, Zn, Ni, B, Cl, total S	Raupach *et al.* (1972)
Sugar beet	NO_3, PO_4, K, Na	Ulrich and Hills (1952, 1973)
Sugar beet	General	Geng and Hills (1978)
Tropical grasses	N	Henzell and Oxenham (1973)†
Many species	General	Chapman (1964)*, Martin-Prével *et al.* (1984)*
Many tree crops	General	Kenworthy (1969)*
Many crops	General	Jones *et al.* (1971, 1991)*
Many crops	General	Jones and Steyn (1973)*
Many crops	General	Reisenauer (1976)*
Many crops	General	Cox (1978)

*Review publication; †Australian studies.

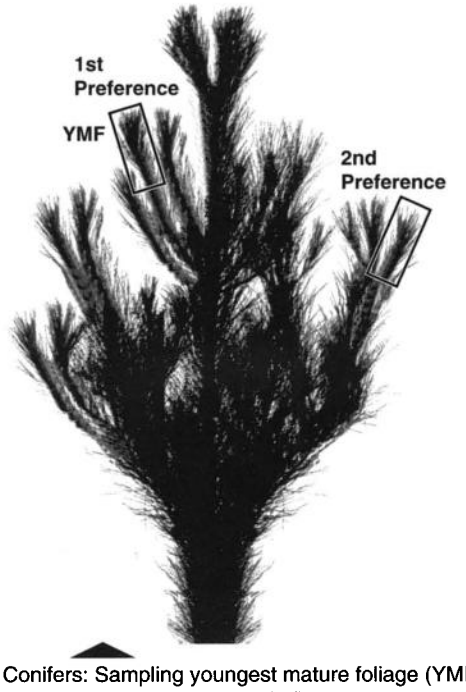


Cereals: during tillering collect YEB or basal stems.

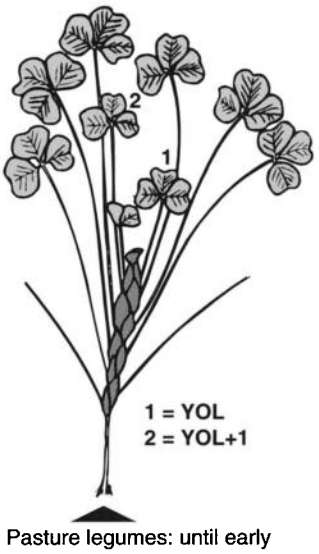


Deciduous fruits: in mid-summer collect a leaf from a mid-shoot position.

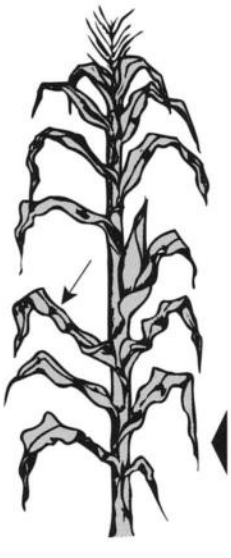
Grape vine: at flowering collect a petiole (leaf stalk) from a basal node opposite a bunch.



Conifers: Sampling youngest mature foliage (YMF). Preferred sampling location is first order lateral branch. Second preference is current seasonal growth on a second order lateral branch (as indicated).



Pasture legumes: until early flowering collect the youngest open leaf blades.



Corn: from tasselling to pollination collect leaf blades below and opposite the cob (BOBC).

Cotton: following first bloom collect the petiole or leaf blade of the youngest fully mature leaf.

Figure 3.3 Examples of plant parts to samples in a variety of crops.

- Avoid areas of crops and pastures in the immediate vicinity of trees.
- Do not sample plants that are under water or temperature stress; also avoid waterlogged plants. Sampling should be undertaken when plants are growing vigorously.
- For pasture and forage crops, avoid plants growing in dung and urine patches.
- Avoid vegetative organs after flowering in non-woody determinate species, since many nutrients are being redistributed to developing fruits and grain.
- Minimize contamination. Take particular care where trace element determinations are sought; use clean plastic gloves and stainless steel cutting implements when sampling, and avoid contact with soil, copper, and galvanized materials.
- Deionized water must be used to wash samples; do not use tank water.
- Standardize sample collection as much as possible during certain periods of the day for elements for which the concentration is known to vary diurnally (see Allen *et al.* 1961; Steyn 1961; Minotti and Stankey 1973; Teare *et al.* 1974; Papastylianou and Puckridge 1981; Papastylianou 1995).

E. SAMPLE HANDLING AND PREPARATION

Each step in sample handling and preparation can contribute errors which may have a cumulative effect on the final nutrient composition of a plant tissue sample. As far as possible, standard procedures should be employed to minimize or prevent such errors.

E.1 Sample transport

One of the most difficult logistic problems facing plant analytical services is the preservation of fresh material during transport from remote country areas to central processing laboratories. Delays and adverse conditions during shipment of fresh samples can cause substantial respiratory losses in weight (e.g. Steyn 1959) or enhanced enzymatic activity (e.g. Bieleski 1964; Handreck 1972), both of which produce corresponding errors in nutrient determinations (e.g. Bradfield and Bould 1963; Mayland 1968; Leece 1972). The apparent concentration of nutrient fractions may also change (Knowles *et al.* 1989). Erroneously high nutrient concentrations are measured in fresh samples which have decomposed during transport and storage (Lockman 1970). Such samples should not be analysed.

Thus delays in transport, sample handling and analysis should be avoided, and steps should be taken to minimize sample deterioration and respiratory losses.

Although no single handling system is likely to be accepted universally, the following guidelines should be followed:

- Undertake field sampling early in the week.
- Wash hands before collecting samples or use disposable gloves.
- Place tissue in labelled paper bags and transport to the laboratory with a minimum of delay. Do not seal samples in polythene bags (Steyn 1959) or grease-proof bags.
- Avoid storing samples unprotected in crushed ice, which melts and can contaminate the sample or leach out soluble fractions.
- Do not allow prolonged storage at ambient temperatures or in closed car compartments during warm weather.
- Store samples in refrigerators overnight at 5°C. Where possible, immediately oven dry in a forced draught oven at 65°C to minimize respiratory losses and plant spoilage.
- Before packaging, the plant surfaces should be free of excess moisture. If separating plant parts or shoots, the different plant parts should be placed in separate large, labelled paper bags.
- Place samples bags in a cardboard or paper container (often provided by the receiving laboratory) together with the completed site information form, and dispatch immediately by priority mail or air courier to the processing laboratory. Preferably, the laboratory should receive the samples within 24 hours of sampling.

Completely dried samples can be sent to the laboratory by ordinary mail. Small samples can be dried in a microwave oven for 10–20 minutes (see Section E.3). Drying fresh samples at ambient temperatures or at temperatures below 40°C or above 80°C is not recommended. At low temperatures respiratory losses can occur. At high temperatures volatile losses can occur.

E.2 Sample handling and decontamination

Upon receiving fresh samples, laboratory staff must first decide whether or not adhering contaminants or spray residues need to be removed from plant surfaces. Sample contamination arises principally from dust, rain splashed soil, deposits accumulated from pesticide or nutrient foliar sprays, or from inadvertent contamination during plant sampling and handling. The worst levels of contamination occur commonly in seedling crops and heavily grazed or sparse pastures (Healy *et al.* 1974), and in glasshouse crops (from soil and pesticide residues). Soil contamination is least in the uppermost foliage of erect terminal shoots.

The effects of surface contamination on plant nutrient concentrations vary with soil type, rainfall, plant type (whether glabrous or pubescent foliage), plant age, and management. Whereas soil contamination usually has little influence on concentrations of major nutrients in the plants, it can result in elevated concentrations of trace elements (see Tables 3.2 and 3.3). Soil deposits of iron, aluminium and silicon are especially troublesome, since their concentrations in soil are appreciably higher than

TABLE 3.2 Effects of washing techniques on mean nutrient concentrations in orange leaves (after Labanauskas 1966).*

Nutrient	Unwashed	Detergent wash	Detergent/acid wash
N(%)	2.53	2.56	2.55
P(%)	0.147	0.146	0.147
K(%)	1.07	1.08	1.07
Ca(%)	3.97	3.97	3.96
Mg(%)	*0.422*	0.407	0.416
Na(%)	0.061	*0.066*	*0.065*
Cl(%)	0.022	0.028	*0.064*
Cu(mg/kg)	*5.6*	5.1	5.0
Zn(mg/kg)	*123*	68	65
Mn(mg/kg)	*182*	94	92
Fe(mg/kg)	*186*	61	61
B(mg/kg)	367	368	369

* Each value is expressed on an oven-dried basis.

Mean values within each row that are in italic are statistically higher than other concentrations in the same rows ($P < 0.01$).

Detergent wash = hand washed in 0.1% detergent (Joy^R), then rinsed in deionised water.

Detergent/acid wash = washed in 0.1% detergent, rinsed, then dipped in 3% HCl for 2 minutes and washed again in deionised water.

TABLE 3.3 Effects of two washing techniques on iron and zinc concentrations in leaves of various glasshouse crops (after Sonneveld and van Diijk 1982).

Crop	Fe (mg/kg)			Zn (mg/kg)		
	A*	B	C	A*	B	C
Tomato	321	144	80	146	85	96
Cucumber	185	151	123	195	125	105
Sweet pepper	145	160	105	153	153	149
Eggplant	143	151	125	40	29	28
Lettuce	178	146	109	95	100	90

*Concentrations of NO_3, P, K, SO_4, Ca, Mg, Na, Cl, Mn and B were not affected by either washing treatment.

A,unwashed leaves;

B,leaves washed, twice (15 seconds) in deionized water;

C,leaves washed in 0.1% Teepol (15 seconds) and then rinsed in deionized water.

those normally found in plants. Their analytical values together with titanium concentrations (Cherney and Robinson 1982) can be used as an indicator of soil or dust contamination (Robinson *et al.* 1984; Jones *et al.* 1991).

Plants requiring iron analysis should certainly be washed (Nicholas *et al.* 1957). Foliage sprayed with fertilizer solutions or with pesticide formulations containing nutrients should preferably be washed or else avoided during sampling. Alternatively, the analytical value for that particular nutrient should be ignored. Normal washing procedures are unlikely to completely remove external spray deposits, dust or soil (Arkley *et al.* 1960).

Where pollutants or toxicities are being examined, washing procedures are inappropriate and may be unnecessary for the determination of major elements (e.g. Chapman 1964; Labanauskas 1966; Leece 1972; Jacques *et al.* 1974; Sonneveld and van Dijk 1982). For fluoride toxicity, leaves must first be washed to remove external or surface fluoride, since only internal fluoride affects leaf physiology (Mitchell 1986).

A number of washing procedures have been proposed (see selected examples in Table 3.4). Most comprise brisk, agitated rinsings in either a mild strength detergent (e.g. 0.1–0.3% Teepol) or dilute hydrochloric or acetic acid, followed by several brisk rinses in deionized water. Others involve rapid and thorough rinsings in deionized water or removal of adhering soil with a brush. Brisk agitation dislodges adhering dust and soil particles and minimizes leaching of soluble plant nutrients (e.g. NO_3, B, Na and K). Smith and Storey (1976) have shown that sample handling can be improved by placing the foliage to be washed within nylon nets. They and others also recommend that washing solutions be renewed frequently.

Whilst all of the above washing processes clearly reduce concentrations of some contaminants (e.g. Fe), it is not usually possible to assess how effective the decontamination has been, or if it has been excessive for some nutrients. Thus, definitive experiments using tracer techniques are still required if acceptable plant washing procedures are to be developed. Procedures using dilute HCl rinsings enhance plant chloride determinations (Table 3.2), and some detergents may contain trace elements and phosphorus.

Oven-dried samples or partly dead tissues should never be washed; nutrients are leached more easily from dried foliage.

In view of the possible inadequacies in the existing published washing techniques, we suggest that samples with visible soil or dust should be briefly washed under running deionized water, or passed rapidly through a series of deionized water volumes (e.g. 4×7 litres) which are renewed regularly. Where residues of foliar sprays are likely to be present, more complicated washing procedures can be adopted but they cannot be recommended. In such cases, the analytical values for the likely contaminants should be assessed with caution, or ignored. Certainly the washing procedure used should be stated in the analytical report.

TABLE 3.4 Selected washing procedures for decontaminating plant samples. (See text for a discussion on the limitations of washing prior to plant analysis.)

Plant species	Recommended washing procedure	Nutrients tested	Reference
Apple	Wipe with damp cheese cloth or agitate in 0.8% Alconox* + EDTA (15 seconds); immerse in distilled H_2O (15 seconds); rinse under distilled H_2O. (For leaves with spray residue.)	N, P, K, Ca, Mg, Cu, Mn, Fe, B, Pb	Taylor (1956)
Apple, strawberry, blackcurrant	Rinse in 0.1% Teepol (15 seconds); rinse in distilled H_2O.	Cu, Zn, Mn, Fe, B	Bradfield and Bould (1963)
Citrus, pineapple	Rinse in 0.1% Teepol; rinse in distilled H_20; rinse in deionised H_2O.	N, P, K, Ca, Na, Cu, Mn, Fe	Steyn (1959)
Citrus	Rinse in 0.1% detergent; rinse in deionized H_2O.	N, P, K, Ca, Mg, Na, Cl, Cu, Zn, Mn, Fe, B	Labanauskas (1966)
Corn	Wipe lower leaves with 0.5% Alconox*.	P, K, Ca, Mg, Cu, Zn, Mn, Fe, B, Al	Baker *et al.* (1964)
Corn	Rinse in deionized H_2O.	Mn, Fe, Si, Al	Floyd and Ragland (1966)
Flax, Soybean	Wash in tap water containing 1% detergent. Then rinse 4 times with deionized water. Total immersion time <150 seconds.	Mn, Zn, Fe	Moraghan (1991).
Ironbark and grape leaves	0.1 M HCl and 0.02% detergent	Fe, F, Cl	Mitchell (1986)
Peach	Rinse in 0.1 % Na lauryl sulfate; rinse 3 times in deionized H_2O.	N, P, K, Ca, Mg, Cu, Zn, Mn, Fe, B	Leece (1972)
Pecan	Rinse in 0.1 % Alconox*; rinse in tap H_2O; rinse in 1% HCl; rinse 3 times in deionized H_2O.	P, K, Ca, Mg, Cl, Zn, Mn, Fe	Smith and Storey (1976)
Soybean	Rinse in distilled H_2O (to remove foliar nutrient applied to plants).	N, P, K, Ca, Mg, Cu, Zn, Mn, Fe, B, Mo	Boswell (1972)
Sorghum	Rinse in deionized H_2O.	Ca, Mg, Cu, Zn, Mn, Fe	Jacques *et al.* (1974)
Sugar beet, rye, tomato	Rinse in 0.3% detergent in 0.1 M HCl; rinse twice in distilled H_2O; rinse in redistilled H_2O (30 seconds each rinse) (to remove foliar nutrients applied to plants).	Cu, Zn, Mn, Fe, Mo	Arkley *et al.*. (1960).
Tomato	Rinse in 0.3% Teepol (30 seconds); rinse in distilled H_2O (30 seconds).	Fe	Nicholas *et al.* (1957).
Tomato, cucumber, sweet pepper, lettuce, egg-plant	Rinse in 0.1% Teepol (15 seconds); rinse in deionised H_2O or in 0.l M HCl (15 seconds); rinse in deionized H_2O.	NO_3, P, K, Ca, Mg, Na, Cl, Cu, Zn, Mn, Fe, B, Al	Sonneveld and van Dijk (1982)
Turf grass	Rinse in deionized water for 30 seconds.	N, P, K, Ca, Mg, Cu, Zn, Mn, Fe, B, Mo	McCrimmon (1994)
All crops	Rinse in 0.1 % Teepol; rinse 3 times in deionized H_2O.	General	Chapman (1964)
All species	Preliminary dry wiping (if very dirty). Brief washing and rubbing with cloth moistened with water containing a little detergent or 1% HCl. Brief vigorous rinsing under tap or via 3 baths of frequently changed distilled water volumes.	General	Martin-Prével *et al.* (1984).

* Trade name-Alconox Chemicals, Jersey City, New Jersey.

After washing, the excess water should be drained from the sample, which is then placed in a labelled paper bag and immediately oven-dried.

E.3 Sample drying

Drying is designed to rapidly deactivate all plant enzymes, thereby minimizing respiratory weight losses and biochemical changes, and to remove all water from the tissue; the sample reaches an 'oven-dry' state, in which its weight remains unchanged with renewed drying. As indicated earlier, elevated nutrient concentrations can result when samples are allowed to respire actively, and thus drying at ambient temperature is not recommended. Even so, drying temperature can influence extracted labile nutrients, such as phosphate (Etchevers *et al.* 1978).

In most laboratories, samples are dried at 65–80°C in forced-draught, stainless-steel-lined ovens, which allow circulation of air between samples. Prolonged drying at temperatures in excess of 80°C can cause thermal decomposition (seen as sample scorching) and appreciable loss of volatile constituents (Simon-Sylvestre 1975; Wetselaar and Farquhar 1980; Grundon and Asher 1981). Mayland (1968) has proposed an alternative routine: drying for 90 minutes at 100°C (to destroy enzymes rapidly), followed by further heating at 60°C to achieve an oven-dry state. However, the commendable attributes of this proposal are unlikely to be adopted by routine testing laboratories as oven drying at 65–75°C for 24–48 hours is more manageable.

Clean air is important in drying rooms. Where contamination is possible, the air should be filtered and separated from grinding rooms.

Fast (e.g. 10–20 minutes) and more economic drying of small plant samples can be achieved in domestic microwave ovens (Johnson 1978; Koh 1980; Smith and Gaines 1980; Batten and Blakeney 1994). Samples weighing less than 5 g dry weight can be dried at moderate power in polycarbonate or polypropylene open containers where circulation of air around the sample is not impeded. Charring may result if samples are dried too rapidly under poor ventilation.

E.4 Grinding and storage

Dried samples are customarily ground to reduce field samples to manageable sizes, and to facilitate the preparation of homogeneous aliquots for chemical analysis. However, grinding is not essential for small-sized samples because the whole sample contained in tissue paper can be readily crushed by hand and the total sample weighed for analysis. Grinding is not recommended where accurate analysis for cobalt is required, because mills may contaminate samples with cobalt (Barry 1984), and finer grinding can improve the extractability of plant nutrient fractions (Knowles *et al.* 1989). During grinding, particular care must be taken to ensure that the sample is not contaminated.

Mechanical grinding is accomplished using a variety of mills, which must have stainless steel grinding surfaces to minimize micronutrient contamination (e.g. Baker *et al.* 1964). The grinding surfaces must be maintained in good condition. Where iron and other trace elements are to be determined, agate or tungsten carbide mills with teflon coated blades should be used. A special mill for preparing samples of small weight has been designed by Graham (1972). Where very accurate testing for specific nutrients is required, choice of an appropriate mill requires special attention.

Segregation can be a significant source of error, particularly with samples which contain both fibrous and non-fibrous material. These pulverize at different rates and may segregate and contain markedly different nutrient concentrations (Nelson and Boodley 1965; Smith *et al.* 1968; Lockman and Molloy 1977).

Samples should be ground completely to a particle size of less than 1 mm, and mixed thoroughly before a subsample of suitable size is stored for analysis. If the grinding equipment contains a sieve, any material which does not pass through the sieve should be added to the ground sample and thoroughly mixed before a subsample is taken for analysis. Samples should be stored in clearly labelled, airtight, glass or polycarbonate containers to prevent samples from being infested with insects during storage. Storage at room temperature is normally sufficient, but long term storage of reference material requires freezing.

E.5 Sap analysis

Plant sap can also be expressed from fresh material at a laboratory and analysed using instrumentation (listed earlier), but field sap analysis kits are also available with a range of sophistication from simple test strips for single nutrients to portable instruments capable of testing for several nutrients. These kits are best suited for the mobile elements (N, P, K and S). Several papers describing sap test technology have been published (Schaefer 1986; Lyons and Barnes 1987; Handson and Sheridan 1992).

F. LABORATORY ANALYSIS

It is not the purpose of this review to describe in detail the variety of laboratory procedures for analysing nutrients in plant materials. The following references may be consulted to obtain details of procedures, instrumentation, and limits of detection: general — Piper (1947), Jones (1981), Martin-Prével *et al.* (1987), Jones *et al.* (1991), Handson and Shelley (1993); atomic absorption —Ramirez-Munoz (1968); X-ray fluorescence spectroscopy — Norrish and Hutton (1977), Hutton and Norrish (1977); inductively coupled plasma (ICP) spectrometry — Zarcinas and Cartwright (1983), Munter *et al.* (1984); inductively coupled plasma-mass spectrometry — Krushevska *et al.* (1996); laboratory quality control — Youden (1947, 1962). The use of near infrared reflectance spectroscopy for plant nutrient analysis may gain broad support in the future (Barton 1992; Batten *et al.* 1990, 1993).

With the advent of computer-linked, report-generating instrumentation (e.g. inductively coupled plasma, X-ray fluorescence and atomic absorption spectrometry) improvements in the efficiency and speed of quantitative plant analysis have become possible. However, laboratories must monitor continually the reliability of their chemical testing. They must be certain that errors introduced during sample preparation and analysis are minimized. Reputable laboratories earn their good reputations, but proven inaccuracies discredit the services offered generally and are rarely forgotten by clients.

The analytical techniques used by each laboratory must be proven to be accurate and reproducible. Satisfactory quality control measures must be implemented, maintained and audited to ensure that all reported analytical results are reliable, and are not biased by time, method, instrument or operator. Laboratory staff must be trained in their specific tasks, and retrained when new procedures, instruments or computer systems are introduced, or changed.

Success in achieving high standards of analytical accuracy and precision involves the appropriate selection and testing of laboratory methods, as well as the introduction of quality control in all phases of the routine testing service. This will be obvious intuitively to experienced chemists and it is hoped that such selection and control are widely practised in all Australian laboratories. Nevertheless, the use of satisfactory quality control needs emphasising,

TABLE 3.5 Results from an interlaboratory quality assurance program conducted among 34 Australian and Papua New Guinean laboratories in 1994*

	Eucalypt leaves		Radiata pine needles		Indian mustard leaves		Mixed pasture		Oats herbage		Wheat grain	
Element	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Nitrogen (%)	1.24	0.053	1.67	0.075	3.45	0.162	3.94	0.194	1.80	0.109	1.83	0.107
Phosphorus (%)	0.052	0.007	0.125	0.012	0.400	0.047	0.348	0.024	0.204	0.012	0.297	0.025
Potassium	0.707	0.051	0.770	0.064	3.19	0.262	3.40	0.297	1.65	0.111	0.377	0.044
Sulfur (%)	0.113	0.011	0.115	0.012	0.502	0.112	0.281	0.022	0.155	0.010	0.135	0.010
Calcium (%)	0.464	0.070	0.248	0.052	1.717	0.254	0.602	0.062	0.101	0.026	0.032	0.009
Magnesium (%)	0.188	0.022	0.120x	0.012	0.254	0.025	0.223	0.032	0.122	0.012	0.123	0.013
Sodium (%)	0.213	0.022	0.008	0.008	0.303	0.025	0.238	0.022	1.11	0.147	0.008	0.008
Chlorine (%)	0.273	0.053	0.110	0.026	0.545	0.072	1.279	0.079	2.020	0.115	0.058	0.023
Aluminium (mg kg^{-1})	56.5	20.8	588.2	44.0	80.0	30.1	5323.0	1573.0	31.0	9.9	5.54	2.99
Copper (mg kg^{-1})	5.62	0.90	3.87	1.19	4.48	0.96	11.0	1.18	4.32	0.74	4.74	0.73
Zinc (mg kg^{-1})	125.6	10.26	40.9	4.23	24.8	3.76	31.4	3.34	15.0	3.05	14.7	2.71
Manganese (mg kg^{-1})	174.3	9.94	312.6	22.2	50.7	3.84	165.1	15.9	45.1	3.41	37.8	30.9
Iron (mg kg^{-1})	58.1	10.19	65.4	11.78	146.2	30.8	5299.8	1630.2	110.2	17.76	34.8	7.91
Boron (mg kg^{-1})	19.6	6.52	20.1	3.58	29.9	4.12	16.2	6.82	6.89	3.97	2.93	2.64
Molybdenum (mg kg^{-1})	0.168	0.110	0.123	0.135	0.385	0.114	1.02	0.916	0.298	0.175	0.271	0.084
Cobalt (mg kg^{-1})	2.75	0.67	1.47	0.42	2.36	0.72	0.236	0.072	0.228	0.063	0.180	0.211

*All laboratories received homogeneous subsamples of the six plant materials and determined each element by a variety of procedures and instruments.

The above data have been adjusted to exclude results more than three standard deviations greater than the unadjusted mean value. For certain determinations, some laboratories provided results more than three standard deviations from the unadjusted mean value.

SD, standard deviation.

especially since recent comparative studies of Australian laboratories have shown significant variations in chemical determinations on a range of plant materials (Table 3.5) which suggests that major improvements are still required.

There are a number of bodies which provide quality accreditation to analytical laboratories. Since the Australian Soil and Plant Analysis Council Inc. (ASPAC) was formed in 1990, it has assumed the role of ensuring that appropriate standard samples are available and that a plant analysis quality assurance program is conducted for the benefit of all participating laboratories. Every 2 years, a set of samples is sent to approximately 40 participating laboratories. The data are collated and statistical analyses are conducted by the State Chemistry Laboratory in Victoria. When completed, participating laboratories receive a full report and are encouraged to take action to improve those analyses which are not within acceptable statistical limits.

The objective of this plant quality assurance program is to improve quality control amongst analytical services. Improvement in the quality of services provided to customers is encouraged amongst members of ASPAC and other laboratories servicing agriculture.

Ways of improving quality in chemical analysis are given below.

- Check the purity of reagents by including 'blanks' in routine testing.
- Use appropriate methods and take account of known interferences.
- Include reference plant materials with each batch of samples to monitor analytical performance.
- Regularly check the authenticity of standard solutions used to calibrate instruments, and replace them at defined intervals.
- Exchange samples with other laboratories on a regular basis, as a means of checking analytical performance (e.g. by participating in proficiency programs).
- Ensure computer software used during analysis is appropriate.
- Regularly check the calibration of all laboratory equipment.
- Audit compliance of laboratory practice within quality assurance programs.
- Use appropriate replicates.
- Develop documentation on quality assurance procedures.

Bulk supplies of Standard Plant secondary reference material for a number of species are available through ASPAC. International standard materials for a limited number of plants are also available (e.g. Bowen 1967) and should be used regularly to cross-check existing standards. Standards may also be prepared and tested for homogeneity in-house.

G. Conclusion

Reliable plant analysis requires that the best possible techniques are used in each phase from sample collection to analysis. This chapter has demonstrated how this can be achieved by being aware of the likely sources of error and taking steps to eliminate or minimize them. Figure 3.4 summarizes the concepts and the steps involved. Continued publicity is needed to ensure that these procedures are standardized in Australian plant testing services. Most importantly, the sample collected should match exactly that specified in the research work from which the test and its associated interpretation criteria were derived.

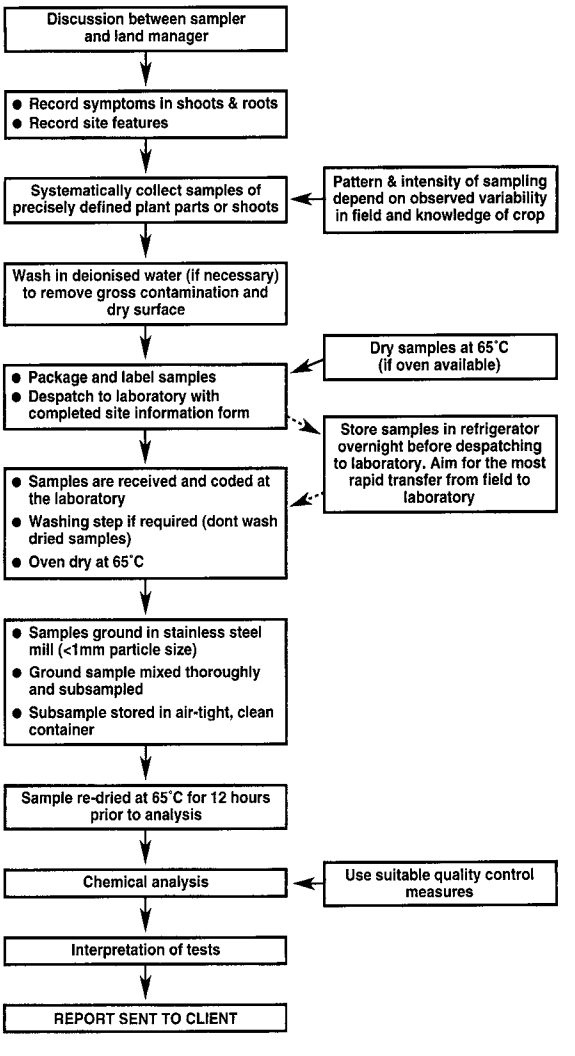


Figure 3.4 Suggested flow chart for collecting, handling and analysing plant samples.

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Definition of Terms and Abbreviations Used in the Manual

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4. Definition of Terms and Abbreviations Used in the Manual

Nutrients

Criteria for the following nutrients and nutrient fractions are described in the accompanying tables: nitrogen (N), nitrate-nitrogen (NO_3-N), phosphorus (P), phosphate-phosphorus (PO_4-P), potassium (K), sulphur (S), sulfate-sulphur (SO_4-S), calcium (Ca), magnesium (Mg), sodium (Na), chloride (CI), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), aluminium (Al), boron (B), molybdenum (Mo), cobalt (Co) and nickel (Ni). Reference is also made to published enzyme assay procedures and to rapid field testing techniques.

Unless otherwise stated the concentrations are reported on an oven-dry basis as percentages (%) or in units of mg/kg.

Plant growth stage

The nutrient concentrations listed in the tables are related to specific stages of phenological development (e.g. tillering, flowering) or to plant age (e.g. 40 days from sowing). In perennial crops, calendar dates are often used to specify sampling times. Normally, it would be unwise to use the listed values for interpreting plant analyses at other growth stages or plant ages. The three stages of growth defined for forest species (seedling, juvenile and mature) are illustrated in Figure 4.1.

The following terms and abbreviations have been used to describe plant growth stages. In addition, for some species, references to published keys of phenological development are included beneath the crop name.

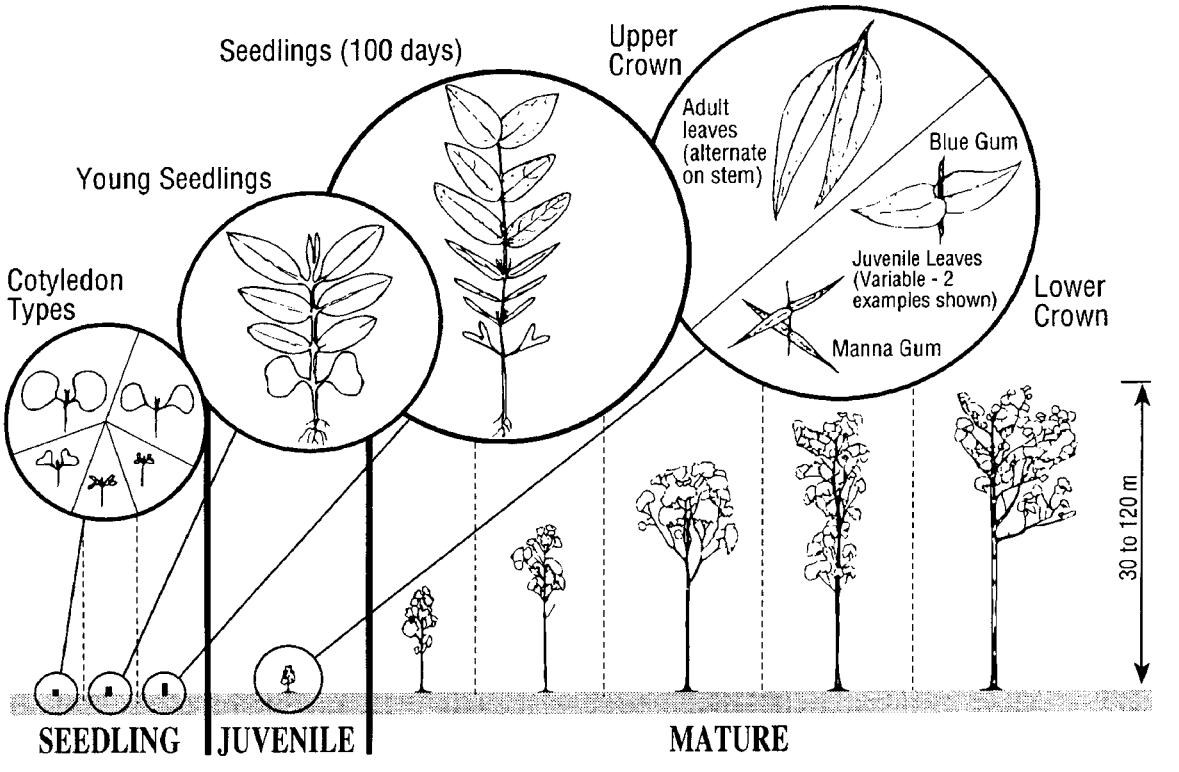
3BBE	3rd blade below the ear
DAC	days after cutting
DASAL	days after salination treatment
DOT	days of treatment
DAS/DAE/DAT	days after sowing, emergence, or transplanting respectively
FI	flowering
FS	Feeke's scale of growth stages in cereals (Large 1954, see Figure 4.2).
GS	growth stage
Head	heading
Joint	jointing
Juv	juvenile for forest trees (1–5 years)
MAS/MAE/MAT	months after sowing, emergence or transplanting respectively
Mat	mature plant or one ready for harvest. For forest species, this term means tree age >5 years old
Panicle initiat.	panicle initiation
PF	pod fill or grain fill
PS	pod set
Seedl	seedling stage. For forest species, this term means tree age <1 year old
Shoot	shooting
Stem Elong	stem elongation
Till	tillering
U	unknown
Var	Various
Veg	Vegetative
ZS	Zadok's decimal code for the growth stages of cereals (Zadok *et al.* 1974 see Table 4.1)

Plant part

The following abbreviations have been used for plant parts:

A	apex
Ap LB	apical leaf blade
A+YOL	terminal apices plus youngest open leaf blade (see below)
Basal S	basal stem (cereals)
BOBC	blade opposite and below the cob
BYOL	blade of youngest open leaf
Cot	cotyledons
Lat	lateral
LB	leaf blade (excluding sheath or petiole)
LB+P	leaf blade and petiole
LP	lowest leaf pair
LYMCL	leaflet of youngest mature compound leaf
ML	mature leaf
MRWL	midrib of wrapper leaf
P	petiole
pr	pair
PYMB	petiole of YMB (see below)
PYML	petiole of YML (see below)
PYOL	subtending petiole of YOL (see below)

1. Development Stages of Eucalypt Species



2. Development Stages of Non-Eucalypt Broad-Leafed Trees (narrow branch-angle types)

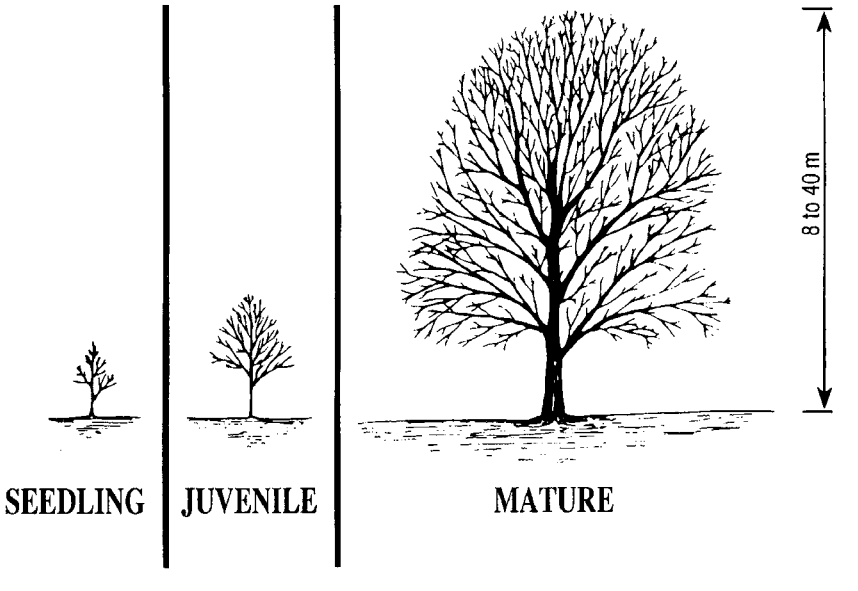
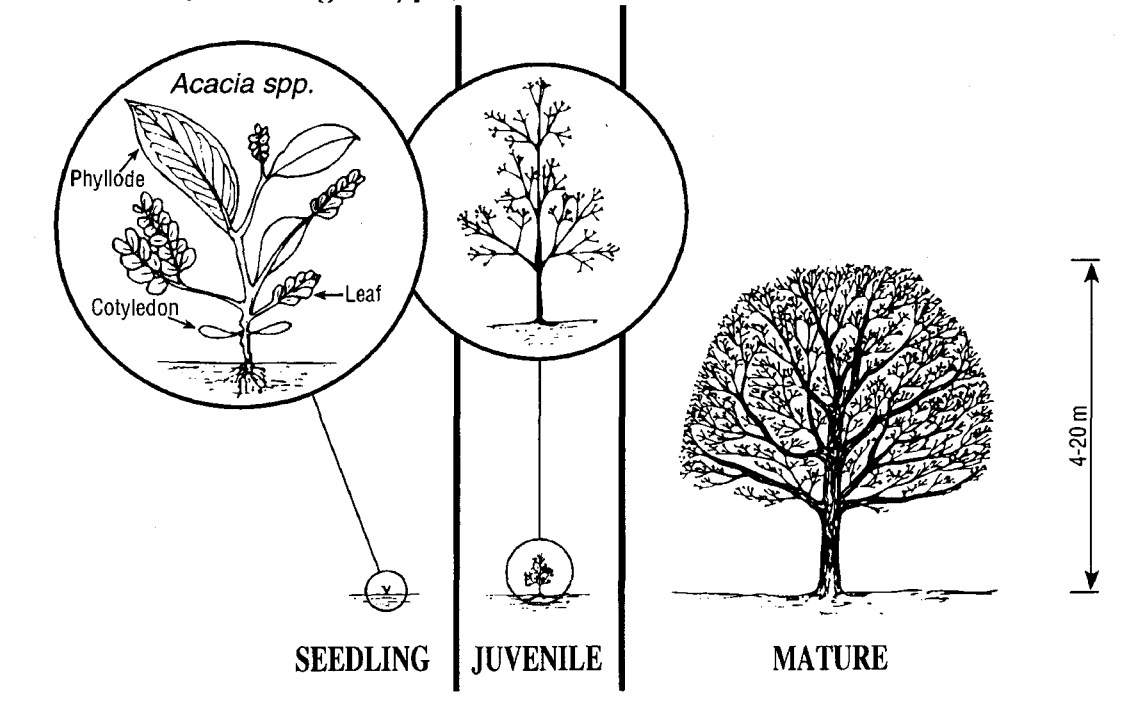


Figure 4.1 Growth stages of forest species.

3. Development Stages of Non-Eucalypt Broad-Leafed Trees (wide branch-angle type)



4. Development Stages of Pinus Species

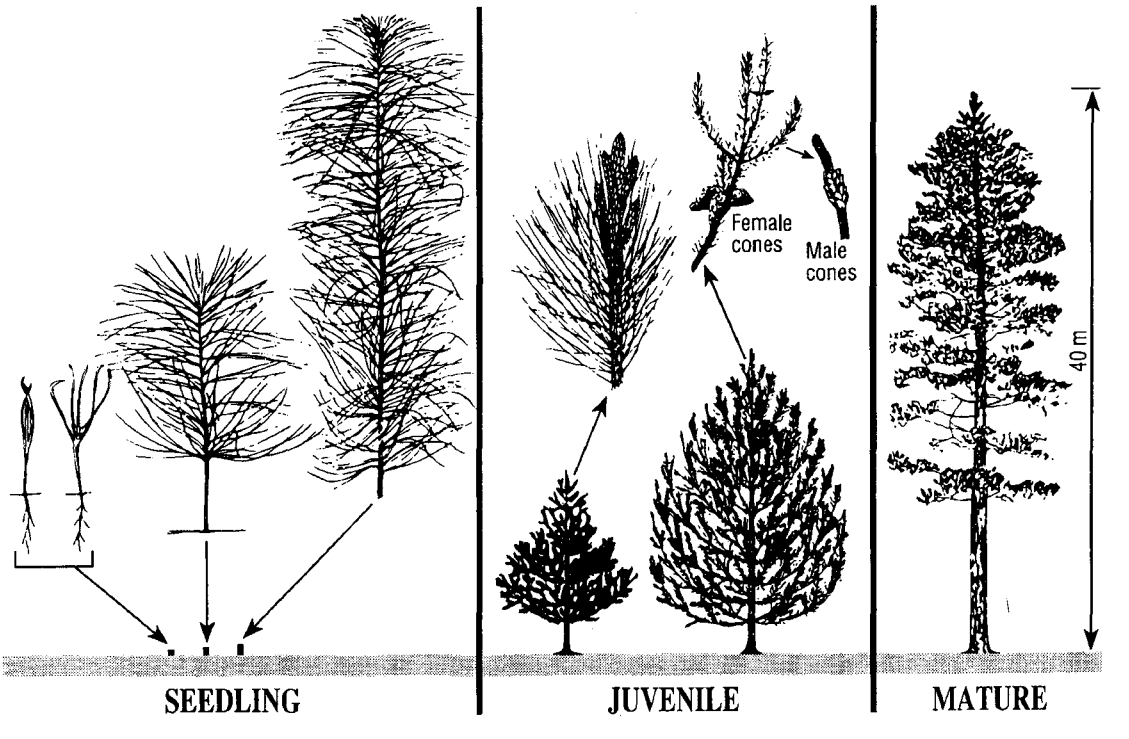


Figure 4.1 Growth stages of forest species (ctd).

RML	recently mature leaf
S	stem
Sap	sap
Tls	trifoliate leaves
TVD	top visible dewlap (sugarcane)
U	unknown
WL	wrapper leaf
WS	whole shoot or 'tops' (i.e. all of the plant parts above ground)
YB	young leaf blade (i.e. younger than YMB); in case of a compound or pinnate leaf, B indicates leaflet or pinna tissues
Y blade	youngest emerged leaf blade (rice)
YEB	youngest (i.e. upper most) emerged leaf blade; in cereals, this leaf blade has completely emerged with its auricles present (see Figure 3.3)
YEB +1	next oldest leaf blade below YEB
YF	young foliage
YFEL	youngest fully expanded leaf
YL	young leaves
YMB	youngest (i.e. upper most) mature leaf blade. Covers terms such as 'recently mature leaf blade', 'uppermost mature leaf blade' or 'youngest fully expanded leaf blade'.
YMB +1	next oldest leaf blade below YMB
YMHL	youngest mature heart leaf
YML	youngest mature leaf
YML +1	next oldest mature leaf below YML
YOB	youngest open leaf blade
YOB +1	next oldest open leaf bladebelow YOB
YOL	youngest open leaf blade in pasture legumes i.e. the three leaflets, excluding subtending petiole, which have opened fully, but which have yet to reach maximum size (see Figure 3.3)
YOL +1	next youngest open leaf blade in pasture legumes (see Figure 3.3)

Other abbreviations for plant parts are defined at the head of the table in which they appear.

How established

The following abbreviations define how the plant test criteria were derived or established.

D	diagnostic records (derived from data bank of analyses)
F	field experiment
FSC	flowing solution culture experiment
Lit	literature review
Peat	peat culture experiment undertaken in glasshouse
Peat–Ver	peat and vermiculite culture experiment undertaken in glasshouse
Pmix	potting mix
Pot	pot trials
RSC	solution culture experiment in which nutrients were replenished periodically
S	survey data from commercial crops
Sand	sand culture experiment undertaken in glasshouse
SC	solution culture experiment undertaken in glasshouse
Soil	soil culture experiment undertaken in glasshouse
U	unknown

Classification of nutrient concentrations (see Figure 4.3)

Deficient

This is the range of concentrations in the specified plant part which is associated with visible deficiency symptoms on the plant and severely reduced growth and production.

In some cases this range has been defined in experiments. In others it has been developed from analytical data collected during problem diagnosis.

Where values are found in the deficient range, corrective measures are clearly required.

Marginal

This is the range of concentrations in the specified plant part which is associated with a reduction in growth or production but within which plants do not show visible symptoms of deficiency.

This classification is essentially the 'low' range used by many authors who work with woody perennials.

Changes in fertilizer practice are usually required if values in this range are encountered. However, for some nutrient and crop combinations (e.g. nitrogen in apple and stone fruit), there may be merit in operating in this range to obtain best fruit quality.

Critical value (deficiency and toxicity)

The critical concentration for the specified plant part (sometimes stated with defined variance) is that concentration of the single nutrient at which growth or production is found experimentally (where all other conditions are optimum) to be at a predetermined proportion of maximum (e.g. 90% or 95% maximum yield are values often chosen). This value will fall within the marginal range.

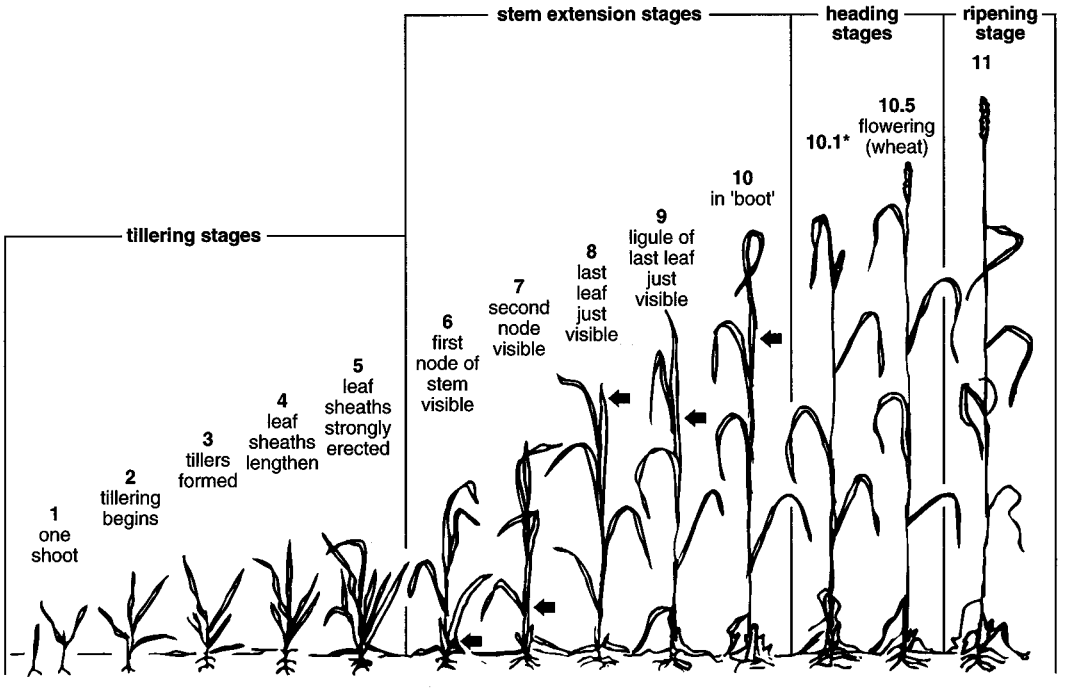
A critical value for toxicity above which growth or production falls below, say, 80% or 90% maximum yield, can be similarly defined.

Critical values are always defined objectively.

Plant nutrient status should normally be kept above the critical value (deficiency) or below the critical value (toxicity).

Table 4.1. Zadok's decimal code for the growth stages of cereals (adapted from Zadok *et al.* 1974).

Code		Code		Code	
0	Germination	33	3rd node detectable	66	—
00	Dry seed	34	4th node detectable	67	—
01	Start of imbibition	35	5th node detectable	68	—
03	—	36	6th node detectable	69	Flowering complete
04	Imbibition complete	37	Flag leaf just visible		
05	—	38	—	7	Milk development
06	Radicle emerged from seed coat	39	Flag leaf ligule just visible	70	—
07	Coleoptile emerged from seed coat			71	Seed coat water ripe
08	—	4	Booting	72	—
09	Leaf just at coleoptile	40	—	73	Early milk
		41	Flag leaf sheath extending	74	—
		42	—	75	Medium milk Increase in solids of liquid endosperm
1	Seedling growth	43	Boots just visibly swollen	76	—
10	First leaf through coleoptile	44	—	77	Late milk notable when crushing the seed between fingers
11	First leaf unfolded	45	Boots swollen	78	—
12	2 leaves unfolded	46	—	79	—
13	3 leaves unfolded	47	Flag leaf sheath opening		
14	4 leaves unfolded	48	—	8	Dough development
15	5 leaves unfolded	49	First awn visible	80	—
16	6 leaves unfolded			81	—
17	7 leaves unfolded	5	Ear emergence	82	—
18	8 leaves unfolded	50	—	83	Early dough
19	9 or more leaves unfolded	51	First spikelet of ear just visible	84	—
		52	—	85	Soft dough (Finger-nail impression not held)
2	Tillering		52	86	—
20	Main shoot only	53	25% of ear emerged	87	Hard dough (Finger-nail impression held, head losing chlorophyll)
21	Main shoot and 1 tiller	54	—	88	—
22	Main shoot and 2 tillers	55	50% of ear emerged	89	—
23	Main shoot and 3 tillers	56	—		
24	Main shoot and 4 tillers	57	75% of ear emerged	9	Ripening
25	Main shoot and 5 tillers	58	—	90	—
26	Main shoot and 6 tillers	59	Emergence of ear completed	91	Seed coat hard (difficult to divide by thumb-nail)
27	Main shoot and 7 tillers			92	Seed coat hard (can no longer be dented by thumb-nail)
28	Main shoot and 8 tillers	6	Flowering	93	Seed coat loosening in daytime
29	Main shoot and 9 or more tillers	60	—	94	Over-ripe, straw dead and collapsing
		61	Beginning of flowering (not easily detectable in barley)	95	Seed dormant
3	Stem elongation	62	—	96	Viable seed giving 50% germination
30	Pseudo-stem erection (winter cereals only)	63	—	97	Seed not dormant
31	1st node detectable	64	—	98	Secondary dormancy induced
32	2nd node detectable	65	Flowering half-way	99	Secondary dormancy lost



* The stages of heading from 10.1 to 10.5 are described in the original paper.

Figure 4.2 Growth stages of cereals defined by Large (1954).

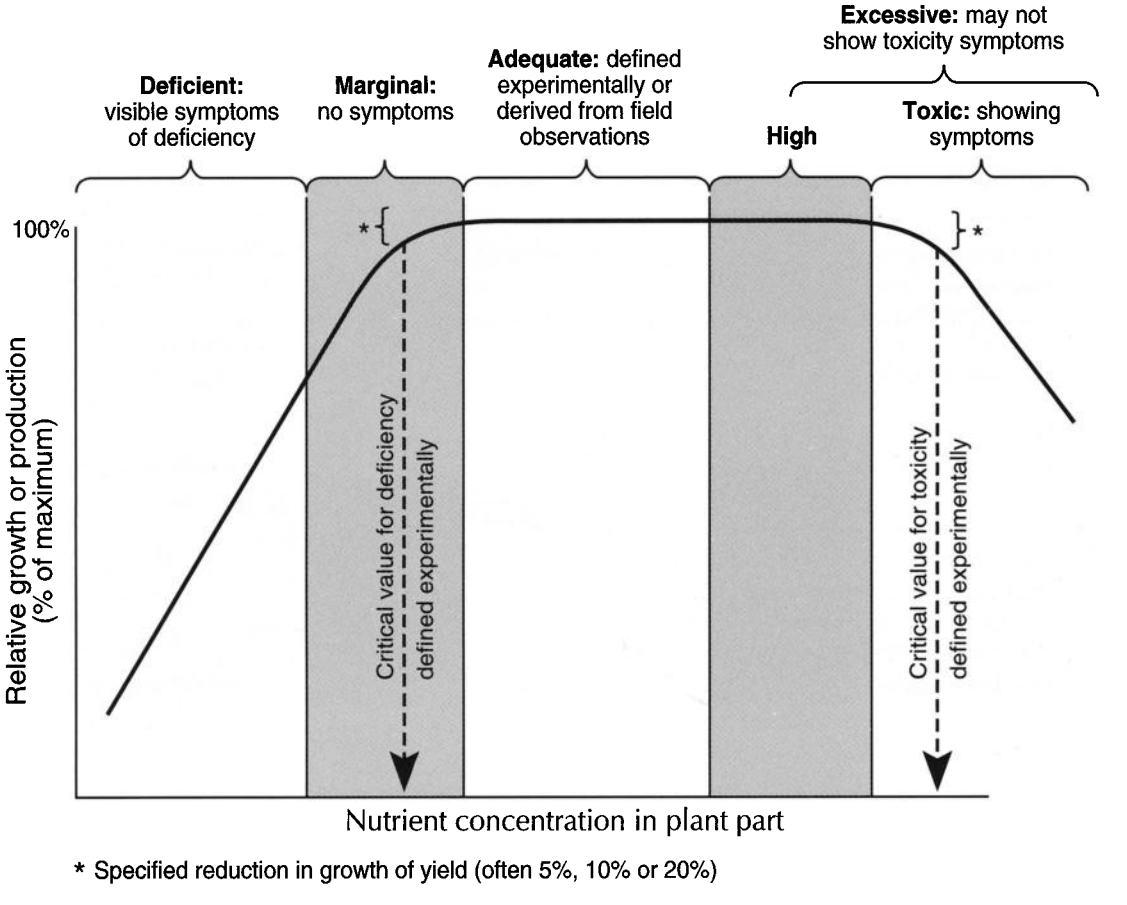


Figure 4.3 Diagrammatic representation illustrating the meaning of terms used to classify the nutrient status of plants.

Adequate

Within this range of concentrations in the specified plant part changes in concentration do not increase or decrease growth or production. This classification is also known as 'intermediate', 'satisfactory', 'normal' or 'sufficient'. It has been defined in various ways for different crops, viz:

(i) By survey of high production plantings, where the concentration range represents a mean with defined variance. A range defined this way may be further modified on the basis of experience using information on quality, vigour, etc.

(ii) By experimentation, where the range is defined as part of the plateau in the relationship between growth and nutrient concentration within the plant (see also High below).

(iii) By collation of data collected for other purposes (e.g. data banks derived from plant analysis services).

It is usually considered that fertilizer practice need not change if values fall into this classification.

High

This classification usually represents the range of concentrations in the specified plant part between the adequate range and the toxic or excessive ranges.

For some crops, this classification may be defined objectively because of its association with a trend towards undesirable quality or vigour.

Fertilizer use on crops with values in this range should be reduced until the nutritional status of plants lies in the adequate range.

Excessive or Toxic

An excessive concentration of a nutrient in the specified plant part does not lead to reduced growth or production, but is often associated with severely reduced quality or excessive vigour.

Toxic concentrations of a nutrient in the specified plant part are usually associated with symptoms of toxicity or reduced growth and production.

Toxic criteria may be defined either objectively or on the basis of accumulated experience. In some cases, a critical value equivalent to a specified reduction in growth or production (e.g. to 90% of maximum yield) has been defined experimentally. A toxic range is sometimes defined on the basis of values found in troubleshooting work. Where values in this range are encountered, corrective measures should be taken.

Where a severe deficiency of one nutrient severely stunts growth, the concentration of other nutrients may be found to be in the toxic, excessive or high range. In such cases, an induced nutritional imbalance rather than a real toxicity exists. Correction of the primary deficiency usually brings the concentration of other nutrients into the adequate or high ranges.

COUNTRY

Abbreviations of the names of countries where criteria were established are as follows:

Arg	Argentina
Aust	Australia
Bel	Belgium
Bra	Brazil
Bulg	Bulgaria
Burun	Burundi
CAfRep	Central African Republic
Can	Canada
CIAT	Centro Internacional de Agricultura Tropical
CIS	Commonwealth of Independent States (formerly USSR)
Colo	Colombia
Cos R	Costa Rica
Cub	Cuba
Cypr	Cyprus
E Afr	East Africa
Eur	Europe
Fin	Finland
Fra	France
Gam	Gambia
Ger	Germany
Gre	Greece
Guy	Guyana
Haw	Hawaii
Hun	Hungary
Ind	India
Indon	Indonesia
Iran	Iran
IRRI	International Rice Research Institute
Isr	Israel
Jam	Jamaica
Jap	Japan
Ken	Kenya
Kor	Korea
Leb	Lebanon
Lib	Liberia
Mala	Malaysia
Maur	Mauritius
Mex	Mexico
Neth	The Netherlands
Nig	Nigeria
Niger	Niger
Niue	Niue
Nor	Norway
NZ	New Zealand
Pak	Pakistan
Phil	Philippines
PNG	Papua and New Guinea
Pol	Poland
Port	Portugal
PuRi	Puerto Rico
Rom	Romania
Sen	Senegal
SiLe	Sierra Leone
Sing	Singapore
Slov	Slovakia
SI	Solomon Islands
S Afr	South Africa
Spa	Spain
Sri L	Sri Lanka
Sud	Sudan
Swe	Sweden

Swi	Switzerland
Tai	Taiwan
Tang	Tanganika
Tanz	Tanzania
Thai	Thailand
Trin	Trinidad
Tur	Turkey
U	Unknown
UAR	United Arab Republic
UK	United Kingdom
USA	United States of America
Var	Various
Ven	Venezuela
W Afr	West Africa
W Sam	Western Samoa
Yug	Yugoslavia
Zamb	Zambia
Zim	Zimbabwe

Yug	Yugoslavia
Zamb	Zambia
Zim	Zimbabwe

REFERENCES (REF)

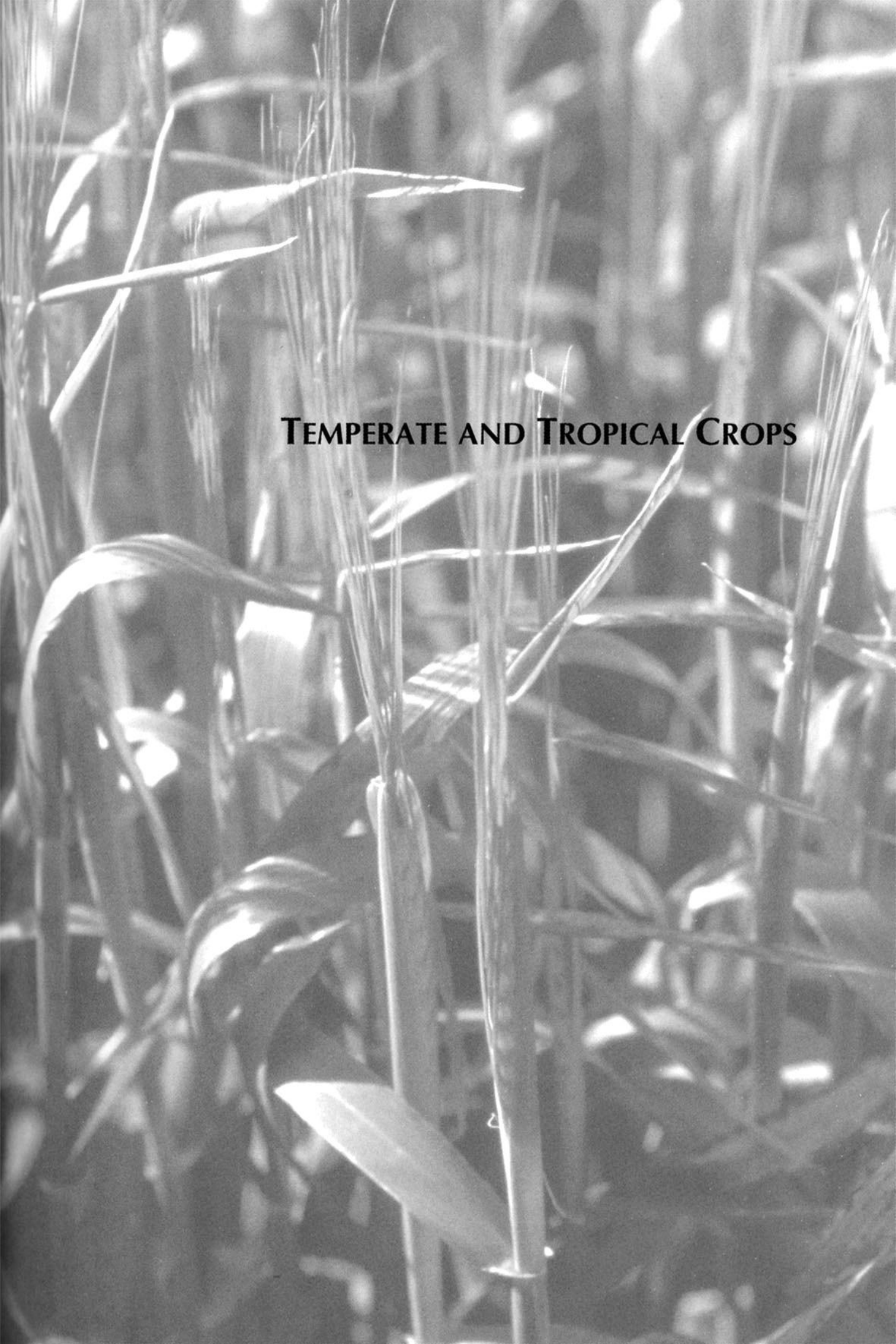
The number in the reference column denotes the reference source from which the criteria were obtained.

A list of numbered references is given at the end of each of the six sets of tables.

REFERENCES CITED

Large, E.C. (1954). Growth stages in cereals. *Plant Path.* **3**: 128.

Zadok, C.J., Chang, T.T. and Konzak, C.F. (1974) A decimal code for the growth stages of cereals. *Weed Sci.* **14**: 415-421.



Temperate and Tropical Crops

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5. TEMPERATE AND TROPICAL CROPS

D.J. Reuter, D.G. Edwards and N.S. Wilhelm

INTRODUCTION

Plant analysis criteria for annual crops vary widely with plant age, plant part and experimental conditions. As a result, it is not possible to state for a specific crop and nutrient that any one set of criteria or criterion is necessarily better than another. Thus, readers should examine the data assembled in this chapter and select tests which best suit their own situation.

Two sources of information were used to assemble the following table for temperate and tropical crops. Firstly, data published in the first edition of this manual has been reassessed: in some cases, previously unpublished Australian data have been replaced by criteria published since 1986. Secondly, a search of the international literature up until 31 December 1995 was used to augment Australian studies and information. As part of this review process, we acknowledge the following key nutritional texts:

Chapman, H.D. (1966) 'Diagnostic Criteria for Plants and Soils' (University of California).

Martin-Prével, P. *et al.* (1984) 'Plant Analysis as a Guide to the Nutritional Requirements of Temperate and Tropical Crops' (Lavoisier Publishing).

Jones, J.B. *et al.* (1991) 'Plant Analysis Handbook: a practical sampling, preparation, analysis and interpretation guide' (Micro-Macro Publishing Inc.).

Bergmann, W. (1992) 'Nutritional Disorders of Plants: visual and analytical diagnosis' (Gustav Fischer Verlag Jena);

Grundon, N.J. *et al.* (1987) 'Nutritional Disorders of Grain Sorghum' (Australian Centre for International Agricultural Research).

Blamey, F.P.C. *et al.* (1987) 'Nutritional Disorders of Sunflower' (Department of Agriculture, University of Queensland);

Weir, R.G. and Cresswell, G.C. (1994) 'Plant Nutrient Disorders 4. Pastures and Field Crops' (Inkata Press).

Calcino, D.V. (1994) 'Australian Sugarcane Nutrition Manual' (Bureau of Sugar Experiment Stations/ Sugar R&D Corporation).

Readers will readily observe that the revised table for temperate and tropical crops has expanded substantially from that compiled in the first edition. Criteria are now available for 46 crops, involving over 1100 published references. Even so, there are considerable gaps in our knowledge for many important crop species, which need to be addressed in the future.

To help with the practical use of this chapter in the field, we have assembled 'Interpretation Guidelines for Diagnosing Nutritional Disorders in Major Crops grown in Australia'. This compilation provides ready access to the more generally useful data available in the literature, but we strongly advise that data presented in the main table for each crop and nutrient be consulted before these guidelines are used.

ACKNOWLEDGEMENTS

Finally, it is a pleasure to acknowledge the contributions made by several Australian scientists: Mr M. Mason and Dr M.D.A. Bolland (Agriculture, Western Australia); Dr F.P.C. Blamey (Department of Agriculture, University of Queensland); Dr P.J. Randall and Mr A. Pinkerton (CSIRO Division of Plant Industry, Canberra), Mr J.R. Reghenzani (BSES, Tully) and Dr Graeme Batten (New South Wales Agriculture). Our sincere gratitude is especially due to Ms Cecilia Dutkiewicz for her assistance in data searches, for preparing the tables, and for her efficiency and dedication.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Ammi visnaga													
N(%)	120 DAS	L	F	3.2							Egypt	431	Predictive for 100% final yield
	135			2.7									
	150			2.1									
	120 DAS	S	F	1.34							Egypt	431	Predictive for 100% final yield
	135			0.8									
	150			0.67									
	120 DAS	Shoot	F	2.75							Egypt	431	Predictive for 100% final yield
	135			1.85									
	150			1.45									
ADZUKI BEAN (_Vigna angularis_)													
N(%)	25-33 DAT	WS	SC	1.02-1.43		2.55-3.52					Aust	75	Data for 2 cvv.
	Mat	Seed	F			3.57-3.65					USA	838	Irrigated; cv. Minoka
	Mat					3.90-4.32							Dryland; cv. Minoka
P(%)	25-33 DAT	WS	SC			0.19-0.24				0.56-1.28	Aust	75	Data for 2 cvv.
Mn(mg/kg)	18 DAT	YML	FSC						260		Aust	33	
BARLEY (_Hordeum vulgare_ and _H. distichon_)													
FS = Feeke's scale of cereal growth (see reference 511). ZS = Zadok's scale of cereal growth (see reference 1110).													
N(%)	ZS 20-25	WS	F			~6.1					UK	672	Criticals for max. shoot and grain yields.
	ZS 25-30					~5.8							Preferred sampling time from late tillering
	ZS 38-40					~2.9							to early stem extension (consult reference
	ZS 57-59					~1.3							673).
	FS 5-6	WS	Lit				2.5-5.0				Ger	82	Winter barley
	FS 7-8						2.0-2.4						
	FS 5-6	WS	Lit				2.8-5.0				Ger	82	Summer barley
	FS 7-8						2.0-4.0						
	FS 6	WS	F	<3.1	3.1-3.4		3.5-4.0	>4.0			Ger	428	Winter barley
	FS10.1	WS	Lit	<1.25	1.25-1.74		1.75-3.0	>3.0			USA	216 457	Guidelines for winter barley.
	FS10.1	WS	Lit	<1.5	1.5-1.99		2.0-3.0	>3.0			USA	216 457 1044	Guidelines for spring barley.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Fl	WS	F			1.58					Aust	989	Reviewer suggests criteria is closer to 2%N.
	Various	WS	F	N concentrations in N deficient and N adequate plants were monitored from 3 leaf stage to maturity. N in shoot tissue water was not responsive to variations in N supply.							UK	526	
	Till (56-63 DAE)	YMB	F			4.3					Cyp	701	Critical estimated at 90% max. shoot yield.
	Mid to late Till	YMB	F,S	<3.4	3.4		3.5-5.4	5.5-6.5		>6.5	Aust	1053	
	Fl	1st + 2nd blades below flag leaf	Lit			2.6					Fra	547	
	Till Shoot Fl	Leaves	F	<3.9 <3.6 <2.6	4.0-4.6 3.7-4.4 2.7-2.8		4.7-5.1 4.5-4.7 2.9-3.5	>5.1 >4.7 >3.5			CIS	335	Deficient <70% max. yield. Marginal 70-100% max. yield.
NO_3-N (mg/kg)	Early Till	Basal S	F	<7000			12900-15300				Aust	707	
	Till	Basal S	F	Cultivar differences in basal stem NO_3-N conc. are unlikely to influence interpretation criteria.							Cypr	702	
	3 leaf stage 4 leaf stage 6 leaf stage 8 leaf stage	Basal S	F	<4000		6000-8000 ~5000 ~3000 ~1000		>8000			USA	955	Criticals at max. grain yield for irrigated barley. Growth stage is number of blades visible on main culm.
	Till (56-63 DAE)	Basal S	F			1000					Cyp	701	Critical at 90% max. shoot yield. Test is more sensitive than determining N on YMB.
	ZS 13.7/21	Basal S	F			14990±950					Aust	247	Critical for near max. shoot yield. Critical for max. grain yield = 13050±1220.
	ZS 14.6/2+	Basal S	F			14790±1070					Aust	247	Critical for near max. shoot yield. Critical for max. grain yield = 13690±950.
	ZS 15.4/2+	Basal S	F			12110±910					Aust	247	Critical for near max. shoot yield. Critical for max. grain yield = 15210±840.
	ZS 16.6/2+	Basal S	F			5940±1120					Aust	247	Critical for near max. shoot yield. Critical for max. grain yield = 5490±620.
	Veg	Basal S	F	In situ sap nitrate test developed for assessing the N status of barley.							NZ Ger	441 1089 1091	

BARLEY (*Hordeum vulgare* and *H. distichon*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%)	FS 2-3 (42 DAS) FS 3 (56 DAS) FS 5 (70 DAS)	WS	F			0.41 0.4 0.31					Aust	822	Criticals at 90% max. yield
	ZS 13.5/21 ZS 14.5/2+ ZS 15.5/2+ ZS 16.5/2+	WS	F			0.59-0.69 0.48-0.58 0.38-0.48 0.28-0.38					Aust	724	Critical ranges derived from 4 experiments and cover the 95% confidence limits for 90% max. shoot yield.
	FS 5-6 FS 7-8	WS	Lit				0.3-0.6 0.28-0.5				Ger	82	Winter barley
	FS 5-6 FS 7-8	WS	Lit				0.35-0.6 0.3-0.5				Ger	82	Summer barley
	FS10.1	WS	Lit	<0.15	0.15-0.19		0.2-0.5	>0.5			USA	216 457 1044	Guideline ranges
	Fl	WS	F	<0.15			0.2-0.3				UK	527	
	ZS 13.5/21 ZS 14.5/2+ ZS 15,5/2+ ZS 16.6/2+	YEB	F			0.52-0.62 0.43-0.53 0.33-0.43 0.24-0.34					Aust	724	Critical ranges derived from 4 experiments and cover the 95% confidence limits for 90% max. shoot yield.
	Mid to late Till	YMB	F,S	<0.24	0.24-0.29		0.3-0.5	0.6-0.7		>0.7	Aust	1053	
	Till Shoot Fl	Leaves	F	<0.44 <0.37 <0.27	0.45-0.49 0.38-0.41 0.28-0.3		0.5-0.68 0.42-0.48 0.31-0.42	>0.68 >0.48 >0.42			CIS	335	Deficient <70% max. yield. Marginal 70-100% max. yield.
	Till (50 DAS)	Fully developed green LB	F	<0.17	0.21-0.25		0.26-0.27				Ind	221	
	Fl	1st + 2nd blades below flag leaf	Lit			0.3-0.35					Fra	547	
	Pre-Head	Upper leaves	F,S				0.2-0.4				USA	456	
	Mat	Grain	F			0.19-0.26					Aust	724	Critical range at 90% max. grain yield. For the same 7 experiments critical range was 0.22-0.32 %P at max. grain yield.
		Grain	Soil		Early seedling vigour enhanced by planting seed of high P content						Can	1113	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Booting	WS	F				0.075				UK	527	P concentrations measured in tissue water. This test appears to be independent of plant N and soil moisture status.
PO_4-P (mg/kg)	FS 6-7	(YMB & YMB +1)	Soil			128					Fin	861	P concentration expressed on fresh weight basis. Critical estimated at 95% max. grain yield.
	FS 6-7	(YMB & YMB +1)	F			95					Fin	861	P concentration expressed on fresh weight basis. Critical estimated at 95% max. grain yield.
K(%)	Till	WS	F				3.8-6.2				UK	525	
	Till	WS	F				0.68-0.88				UK	525	Data are for K concentrations in tissue water.
	FS 5-6 FS 7-8	WS	Lit				3.5-5.0 3.2-4.5				Ger	82	Winter barley
	FS 5-6 FS 7-8	WS	Lit				3.0-5.5 2.5-4.5				Ger	82	Summer barley
	60-140 DAS	WS	F	0.2-0.27		0.78					UK	524	Data are for K concentrations in tissue water.
	FS10.1	WS	Lit	<1.25	1.25-1.49		1.5-3.0	>3.0			USA	216 457 1044	Guideline ranges
	Mid to late Till	YMB	F,S	<1.5	1.5-2.3		2.4-4.0	4.1-5.5		>6.0	Aust	1053	
	Till Shoot Fl	Leaves	F	<3.4 <3.0 <2.0	3.5-4.1 3.1-3.4 2.1-2.2		4.2-4.7 3.5-4.1 2.3-2.8	>4.7 >4.1 >2.8			CIS	335	Deficient <70% max. yield. Marginal 70-100% max. yield.
	Pre-Head	Upper leaves	F,S				1.5-3.0				USA	456	
	Fl	1st + 2nd blades below flag leaf	Lit			0.24-0.26					Fra	547	
S(%)	U (May)	WS	F	0.14							UK	894	SO_4-S/total S and N/S ratios for S deficient winter barley plants were 9.1 and 14.6 respectively.
	U (June)	WS	F	0.13							UK	894	SO_4-S/total S and N/S ratios for S deficient winter barley plants were 8.2% and 11.9 respectively.
	FS10.1	WS	Lit		<0.15		0.15-0.4	>0.4			USA	216 457 1044	Guideline ranges.

BARLEY (*Hordeum vulgare* and *H. distichon*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%) (ctd)	Mid to late Till	YMB	F,S		<0.15		0.15-0.4	>0.4			Aust	1053	
	Mat	Grain	F	0.11			0.13				UK	894	N/S ratio for S deficient winter barley was 14.8.
N/S	FI	WS	Soil	25			17				Can	39	
	Mat	Grain	F		14.2		12.1				UK	893	Two levels of S applied.
Ca(%)	28 DAE	WS	SC				0.4-0.7	>1.04			Can	341	
	FS 5-6 FS 7-8	WS	Lit				0.3-1.0 0.25-1.0				Ger	82	Winter barley
	FS 5-6 FS 7-8	WS	Lit				0.5-1.0 0.45-1.0				Ger	82	Summer barley
	FS 8-10.5	WS	Soil			0.34					Can	446	Critical at 90% max. shoot yield. Criteria for Ca/cation ratio =0.09 at 90% max. shoot yield.
	FS10.1	WS	Lit		<0.3		0.3-1.2	>1.2			USA	216 457 1044	Guideline ranges
	Mid to late Till	YMB	F,S		<0.18		0.21-0.4	0.6-0.7			Aust	1053	
	21-28 DAS	Leaves	RSC, Soil	0.12-0.18			0.25-0.55				Can	173	
	31 DAS	Unemerged blade	RSC	0.2			0.71				Can	244	Deficiency value for salinity-induced Ca deficiency.
	90-122 DAS	Various	F		Salinity markedly reduced Ca conc. in shoots and plant parts						USA	551	
	Pre-Head	Upper leaves	F,S				0.2-0.5				USA	456	
	FI	1st + 2nd blades below flag leaf	F		Values <1.2% Ca are associated with poor Ca nutrition and high K status						Fra	547	
Mg(%)	28 DAE	WS	SC				0.16-0.36	>0.6			Can	341	
	FS 5-6 FS 7-8	WS	Lit				0.15-0.3 0.12-0.25				Ger	82	Winter barley
	FS 5-6 FS 7-8	WS	Lit				0.15-0.3 0.12-0.3				Ger	82	Summer barley
	FS10.1	WS	Lit		<0.15		0.15-0.5	>0.5			USA	216 457 1044	Guideline ranges

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mid to late Till	YMB	F,S	<0.11	0.11-0.12		0.13-0.3				Aust	1053	
	Pre-Head	Upper leaves	F,S				0.15-0.5				USA	456	
	Fl	1st + 2nd blades below flag leaf	Lit	<0.1	0.1-0.15		>0.15				Fra	547	
Na(%)	Mid to late Till	YMB	F,S				<0.5	0.6-0.7		>0.8	Aust	1053	
	22-38 DAS	Expanding blades	RSC	No correlation existed between leaf growth rate and Na conc. in leaf blades.							Aust	637	
Cl(%)	Boot to heading	WS	F	Cl conc. in WS did not reliably predict positive yield responses to applied Cl.							Can	619	
	23 DAS	YMB	RSC				0.22			0.45-1.02	USA	128	Toxic ranges markedly reduced plant yield. Data expressed on a fresh weight basis.
	23 DAS	Sheath YMB					0.28			0.65-1.47			
	Mid to late Till	YMB	F,S				<2.0	2.0-2.8		>3.0	Aust	1053	
	22-38 DAS	Expanding blades	RSC	No correlation existed between leaf growth rate and Cl conc. in leaf blades.							Aust	637	
Cu(mg/kg)	Onset Till	WS	F			4.8					Ger	988	Related to grain yield.
	Panicle init.					3.5							
	Onset Till (5 leaf stage)	WS	Sand						20		UK	225	Critical at 90% max. shoot yield
	Onset Till (5 leaf stage)	WS	Sand					11	14-25		UK	477	Critical range at 90% max. shoot yield
	ZS 25-39	WS	F	2.9-3.1			2.8-3.5				Can	726	Cu conc. in either YEB or WS did not adequately distinguish the Cu status of plants.
	FS 5-6	WS	Lit				6-12				Ger	82	Winter and summer barley
	FS 7-8						5-10						
	Early heading	WS	Soil	1.1-2.2	2.3-3.7		3.8-6.8				Can	596	Lower Cu conc. in marginal range at 85% max. shoot yield.
	FS 10	WS	Soil	<2.3			4.8-6.8				Can	362	*H. distichon*
	FS10.1	WS	Lit		<5		5-25	>25			USA	216 457	Guideline ranges
	Onset Till to FS 10	YEB	Soil	0.9	1.2	1.3	2.8				Aust	937	
	ZS 25-39	YEB	F	3.2-4.9			5.3-6.7				Can	726	Cu conc. in either YEB or WS did not adequately distinguish the Cu status of plants.

BARLEY (*Hordeum vulgare* and *H. distichon*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Cu (mg/kg) (ctd)	Mid to late Till	YMB	F,S		2-4		5-50				Aust	1053	
	Mid-Till	Young LB	Soil			1.0					Aust	649	
	Mat	Grain	F			2.0					UK	168	
	Mat	Grain	Soil	0.9	1.2		2-8				Aust	937	
	Mat	Grain	Soil	0.5-1.5			1.3-10.2				Fin	452	
Zn(mg/kg)	7-17 DAS	WS	RSC			25					USA	667	Critical at max. shoot yield.
	33 DAS	WS	Soil						540		USA	108	Critical at 80% max. yield
	45 DAS	WS	F		25-30		30-39				Ind	992	Three levels of Zn applied.
	Onset Till (5 leaf stage)	WS	Sand						290		UK	225	Critical at 90% max. yield.
	Onset Till (5 leaf stage)	WS	Sand					60	120-520		UK	224	Toxic range at 90% max. yield
	FS 5-6 FS 7-8	WS	Lit				20-60 15-60				Ger	82	Winter and summer barley
	Pre-heading (ZS45)	WS	F				16-40				Can	357	Ranges found in crops which did not respond to applied Zn.
	FS10.1	WS	Lit		<15		15-70	>70			USA	216 457	Guideline ranges
	FS 10.1	WS	F,S	<5	5-24		25-100	>100			USA	1044	
	Mid to late Till	YMB	F,S	<14	14		15-70				Aust	1053	
	Pre-Head	Upper LB	F,S				20-70				USA	456	
	Mat	Grain	F	8.3-25.3	6.3-7.9		8.7-31.4				Aust	338	Ranges found for 9 cvv. grown at two Zn deficient sites.
	Mat	Grain	F				19-40				Can	357	Ranges found in crops which did not respond to applied Zn.
	Mat	Grain	F		15-16		17-20				Ind	992	Three levels of Zn applied.
	Mat	Grain	F		15-18		16-21				Ind	974	Very marginal response to applied Zn.
Mn(mg/kg)	22 DAS	WS	Soil	12-13							Aust	579	Conc. associated with depressed growth in 2 cvv.
	30 DAS	WS	Soil			12.4					Aust	378	Critical at near max. shoot yield. Ref. 544 recommends sampling YEB for Mn diagnosis.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Young plants	WS	S						140		Ger	1117	Critical for spring barley grown on acidic soils pH<4.7.
	Young plants	WS	S						150		Ger	1117	Critical for winter barley grown on acidic soils pH<4.7.
	Onset Till (40 DAS)	WS	F	<13	13-17		>17				Aust	821	
	2-3 tillers (53 DAS)			<13	13-16		>17						
	45 DAS	WS	Soil	13-21		18.6	24-50				Ind	51	Critical estimated at ~ 85% max. shoot yield.
	FS 5-6	WS	Lit				30-100				Ger	82	Winter and summer barley
	FS 7-8						25-100						
	73 DAS	WS	Soil			8					Aust	1074	
	FS 10	WS	Soil				<140			>190	Can	353 363	*H. distichon*
	FS10.1	WS	Lit	<5	5-24		25-100	>100			USA	216 457 1044	Guideline ranges
	Onset Till (40 DAS)	YEB	F	<12	12-15		>15				Aust	821	
	2-3 tillers (53 DAS)			<12	12-15		>15						
	FS 5 (81 DAS)			<12									
	30 DAS	YEB	Soil			11.6					Aust	378	Critical estimated at near max. shoot yield. Ref. 544 recommends sampling YEB for Mn diagnosis.
	30 DAS	YEB	Soil			14.0					Aust	378	Critical estimated using chlorophyll a fluorescence.
	Early Till (49 DAS)	YEB	F			11.0					Aust	378	Critical at near max. shoot yield.
	Early Till (49 DAS)	YEB	F			13.7					Aust	378	Critical estimated using chlorophyll a fluorescence.
	Mid to late Till	YMB	F,S	<12	12-24		25-300	400-600		700	Aust	1053	
	3 weeks before FI	YMB	RSC			15					Can	60	
	FI	4 uppermost mature LB	RSC		<20					>160	Can	60	

BARLEY (*Hordeum vulgare* and *H. distichon*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	Plants 10-20 cm high	Uppermost 40% shoot	F			11					USA	565	Critical at 93% max. grain yield.
	Mat	Grain	F			9-10					Aust	1112	Critical range at 90% max. grain yield.
		Grain	F, Soil	Sowing grain of high Mn content (0.7-1.2 µg Mn/seed) produced higher yields than sowing grain with lower contents (0.08-0.26 µg Mn/seed)							Aust	545	
Fe(mg/kg)	ZS45	WS	F				35-59				Can	358	Ranges found in crops which did not respond to applied Fe.
	FS 10.1	WS	F				50-150				USA	1044	
	Pre-Head	Upper LB	F,S				25-100				USA	456	
	11 DAT	YL	RSC	<34			47-82				USA	70	Based on plant score for chlorosis.
	Mat	Grain	F				19-29				Can	358	Ranges found in crops which did not respond to applied Fe.
B(mg/kg)	21-45 DAS	WS	RSC	Genotypic variations in B uptake and B conc. in WS were observed over a range of applied B levels and root temperatures.							Aust	645	
	35 DAS	WS	SC							130-1073	Aust	641	Associated with reduced shoot growth in different genotypes. Range associated with symptoms was 65-1073 mg B /kg.
	Onset Till (5 leaf stage)	WS	Sand						80		UK	225	Critical at 90% max. yield
	FS 5-6 FS 7-8	WS	Lit				6-12 5-10				Ger	82	Winter and summer barley
	FS 7-8	WS	Soil						113-135		Ger	497	Critical at 10% reduced grain yield.
	5 leaf stage Booting Mat	WS	Sand						150 70 50		Aust	836	Criticals at 10% reduced shoot yield.
	5 leaf stage Booting Mat	WS	Sand						~40 ~50 50		Aust	836	Criticals at 10% reduced grain yield.
	FS4-10.5	WS	S				8-36			56-323	Aust	175	Toxic range associated with toxicity symptoms sampled at different stages of growth.
	FS 7-8	WS	Soil					>80	125		Ger	497	Critical at 90% max. grain yield. Onset of toxicity symptoms at 27 mg B/kg.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Boot	WS	F				10-15	>20		>40	Aust	174	Toxic conc. are related to symptoms and depend on cultivar, soil type and seasonal conditions.
	Boot	WS	Soil						70 50		Aust	831	Critical at 90% max. shoot yield. Critical at 90% max. grain yield.
	FS 10	WS	Soil	1.9-3.5	<5		6-10			>16	Can	352	*H. distichon*
	FS 10	WS	F							>13?	Can	354	*H. distichon*
	FS 10.1	WS	F				5-10				USA	1044	
	Mat	WS and Grain	Sand	Analysis of B in WS or grain at maturity is not recommended for reliably diagnosing yield reductions due to B toxicity.							Aust	833	
			Lit	Substantial difficulties in defining reliable criteria for B toxicity in shoots and blades of cereals are reviewed.							Aust	646	
	35 DAS	YEB	SC							112-710	Aust	641	Associated with reduced shoot growth in different genotypes. Range associated with toxicity symptoms was 68-710mg B /kg.
	5 leaf stage-Booting	YEB	Sand						110		Aust	545	Critical at 10% reduced shoot yield. B conc. are higher in older leaf blades. YEB sampling is recommended.
	5 leaf stage Booting	YEB	Sand						~40 ~100		Aust	545	Criticals at 10% reduced grain yield.
	Boot	YEB	Soil						110		Aust	831	Critical at 90% max. shoot yield.
	FS 7-8	YEB YEB+1 YEB+2	Soil						120 228 308		Ger	497	Criticals at 90% max. grain yield. Onset toxicity symptoms at >60 mgB/kg.
	21-35 DAS	Various	RSC	Pattern of toxic B accumulation in leaves of four cvv. closely reflected leaf size and within any blade was markedly higher at the blade tip.							Aust	642	
	Early spike emergence	Blade below Y blade	Sand						768		USA	93	
	28 DAS	YMB	RSC						155		Aust	186	Critical at 90% max. shoot yield for cv. Schooner.
	Mid to late Till	YMB	F,S	<2	2-4		5-10	11-20		30-100	Aust	1053	
	FS7-8	YMB	Soil						102-136 62-76		Ger	497	Critical at 10% reduced grain yield Critical associated with toxicity symptoms.
	Pre-Head	Upper LB	F,S				3-20				USA	456	

BARLEY (*Hordeum vulgare* and *H. distichon*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
B(mg/kg) (ctd)	4-5 leaf stage Ear formation (heading)	Leaves	F	<3 2-6			6-20			>25	Fin	909	Deficiency ranges associated with sterile florets and responses to applied B.
	Mat	Straw	Soil	5-8			14-21			>45	Can	352	H. distichon
	Mat	Grain	F							>3	Aust	174	Conc. at 17% yield loss.
	Mat	Grain	Sand						3		Aust	545	Critical at 10% reduced grain yield.
	Mat	Grain	F	2-3							Fin	909	Deficiency range associated with sterile florets and responses to applied B.
Mo(mg/kg)	Onset Till (5 leaf stage)	WS	Sand						135		UK	225	Critical at 90% max. yield.
	FS 5-6	WS	Lit				0.1-0.3				Ger	82	Winter and summer barley
	FS 7-8	WS	Lit				0.1-0.2				Ger	82	Winter barley
	FS 7-8	WS	Lit				0.1-0.3				Ger	82	Summer barley
	FS 10	WS	Soil				0.11-0.18				Can	352	*H. distichon*
	FS 10.1	WS	F				0.3-5.0				USA	1044	
	FS10.1	WS	Lit		<0.11		0.11-0.18	>0.18			USA	457	
	Mid to late Till	YMB	F,S	<0.05	0.05-0.09		0.1-0.5	0.6-0.7			Aust	1053	
	Mat Mat	Grain Straw	Soil				1.2-1.9 0.6-1.9				Can	361	
Ni(mg/kg)	39 DAS	WS	RSC			0.1					USA	156	Critical at 90% max. shoot yield.
		Shoots and Grain	RSC	Effects of Ni deficiency on the chemical composition of WS and grain are described.							USA	155	
		Grain	RSC			0.09±0.01					USA	154	Critical at 85% max. grain germination.

BLACK GRAM (*Vigna mungo*)

N(%)	15 DAS 18 DAS	WE	Soil	2.5 2.6			4.0 4.9				Aust	463	N deficient plants grown from low Mo seed.
	R1	YMB	F			3.8					Thai	79	cv. Uthong 2; crit. conc. corresponds to seed yield 1500kg/ha.
	Mat	Seed	F	3.3			3.6-3.8				Ind	231	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
P(%)	25-33 DAT	WS	SC					0.64-0.70		2.43-2.82	Aust	75	cv. Regur
	56 DAS	WS	Soil	0.20			0.39	0.56-0.8			Iran	59	
	R1	YMB	F			0.30					Thai	79	cv. Uthong 2; crit. conc. corresponds to seed yield 1500kg/ha.
	Seedl (11 DAS)	All LB	Soil				0.18-0.56				Aust	668	
	Seedl-Mid Fl (19-37 DAS)			0.09-0.14			0.15-0.35	0.49-0.77					
	36 DAS	All P	Soil	0.04			0.2	0.49			Aust	668	
	50 DAS			0.28			0.38	0.58					
	64 DAS			0.28			0.3	0.65					
	Mat	Seed	F	0.2-0.24			0.27				Ind	231	
P(µmol/g FW)	16 DAT	WS	FSC			26					Aust	279	cv. Regur; corresponds to critical soln conc. of 2.0 mM.
K(%)	R1	YMB	F			1.0					Thai	79	cv. Uthong 2; crit. conc. corresponds to seed yield 1500kg/ha.
S(%)	R1	YMB	F			0.2					Thai	79	cv. Uthong 2; crit. conc. corresponds to seed yield 1500kg/ha.
Cu(mg/kg)	R2	YMB	F			4					Thai	79	cv. Uthong 2; crit. conc. corresponds to seed yield 1500kg/ha.
	45 DAS	Leaves	Soil					18-60	67	78-97	Ind	467	cv. ADT4
Zn(mg/kg)	15 DAS	Green LB	F				>28				Ind	240	Data for 3 cvv.
	30 DAS			16-21			>21						
	45 DAS			14-15			>18						
	45 DAS	Leaves	Soil					46-134	144	157-176	Ind	467	cv. ADT4
	30 DAS (Veg)	Leaves	Soil		67	71		78-125	126	144-163	Ind	468	
	45 DAS				45	64		83-113	134	158-175			
	65 DAS (Mat)				54	66		89-177	141	142-185			
	Mat	Seed	F	25	26		31-33				Ind	914	cv. T9
	Mat	Straw		17	20		25-27						cv. T9
Mn(mg/kg)	25-33 DAT	WS	SC							345-579	Aust	75	cv. Regur
	18 DAT	YML	FSC						300		Aust	33	cv. Regur; NO_3-N in nutrient soln.
	22 DAT	YML	SC						277		Aust	33	cv. Regur; N_2-fixing plants.
B(mg/kg)	Onset Fl	YMB	F				>20				Colo	418	*V. radiata*

BLACK GRAM (*Vigna mungo*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
B(mg/kg) (ctd)	R3 R5-6 Early vegetative	YMB	F			25 20 45					Thai	79	cv. Uthong 2; crit. conc. at 90% max. seed yield.
	V2 V5 R3	Expanding LB	SC, F			15 14-17 15					Aust/ Thai	79	Crit. conc. at 90% max.imal LB elongation rate.
	17-19 DAS	Second trifoliate LB	SC			15 10					Thai	666	Unshaded / Shaded } Crit. conc. associated with 10% depression in LB elongation rate.
	40 DAS	YOL	F			31					Thai	820	cv. Regur
	40 DAS	YML	F			40					Thai	820	cv. Regur
	Mat	Seed	F	7.7-9.0	10		14				Thai	817	70-42% abnormal seedlings produced in low B soil.
	Mat	Seed	F	3-7			9				Thai	818	cv. Regur
	Mat	Seed	Soil			6					Aust	77	cv. Regur; critical for viability of imbibed seeds and production of normal seedlings.
Mo (mg/kg)	9 DAS 15 DAS	WS	Soil	0.014 0.021			1.72 1.22				Aust	463	
	R1-2	YMB				0.05					Aust	79	Crit. conc. at 90% max. seed yield.
	R1-2 R5-6	YMB				0.035 0.025-0.030					Aust	79	
	28 DAS (Fl) 44 DAS (Early PS)	YML +1b	Soil			0.022 0.022					Aust	461	cv. Regur
	53 DAS (Early PS)	YML + 1b	Soil			0.024					Aust	461	cv. Regur; critical at 90% max. seed yield.
	28 DAS (Fl) 44 DAS (Early PS)	Nodules	Soil			9.6 3.4					Aust	461	cv. Regur
	R1-2 R5-6	Nodules				7.0 2.5-3.0					Aust	79	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	28 DAS	YMB-1	Soil	0.004-0.018	0.041		0.188-0.754	4.79			Aust	462	cv. Regur
	28 DAS	YMB		0.006-0.016	0.034		0.259-0.513	4.53					
	28 DAS	YMB+1		0.003-0.006	0.011		0.034-0.159	3.12					
	44 DAS (early PF)	YMB-1		0.011-0.014	0.019	0.022	0.23-0.156	1.05					
	44 DAS (early PF)	YMB		0.003-0.011	0.016	0.019	0.020-0.195	1.03					
	44 DAS (early PF)	YMB+1		0.003-0.007	0.009	0.019	0.026-0.120	1.24					
	28 DAS	Nodules	Soil	1.92-4.08	6.36		9.98-22.0	26.3			Aust	462	cv. Regur
	44 DAS (early PF)			0.89-1.52	2.14	2.70	2.69-6.40	7.34					
Cd(mg/kg)	45 DAS	Leaves	Soil						2.7	7.0-26	Ind	467	cv. ADT4

BUCKWHEAT (*Fagopyrum esculentum*)

P(%)	28 DAS	WS	FSC	<0.4						>1.2	Ger	22	

CANOLA, RAPESEED (*Brassica napus, B. campestris*)

Growth of these species is described in reference 381. 1,2,3RML = upper three most recently mature leaf blades.

N(%)	28 DAS	WS	SC			2.1					Can	572	N(%) not reliable in soil expts; Negative effect of NH_4-N on growth.
	4-5 leaf	WS	F			6.2					Aust	399	Diagnostic for 90% max. shoot DW NO_3-N in PYML best diagnostic test before stem elongation.
	5-6 leaf					5.9-6.0							
	6-8 leaf					5.4							
	Buds visible					3.9-4.8							
	Early stem elong					4.8							
	Stem elong					4.2							
	Fl					2.7-2.8							
	4-5 leaf	WS	F			6.3					Aust	399	Predictive for 90% max. seed yield
	5-6 leaf					5.8-6.0							
	6-8 leaf					5.5							
	Buds visible					3.8-4.9							
	Early stem elong					4.9							
	Stem elong					4.2							
	Fl					2.7-2.9							
	74 DAS	WS	F	<1.4			2.2				NZ	1030	

CANOLA, RAPESEED (*Brassica napus, B. campestris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%) (ctd)	Autumn	WS	F				3.5-4.5				Var	413	
	Fl	WS	F	<1.55 <1.4 <1.4							UK	845	Diagnostic for max. shoot DW Predictive for max. seed yield Predictive for max. oil yield
	Mat	WS	F				1.5-1.9				Var	413	
	4-5 leaf 5-6 leaf 6-8 leaf Buds visible Early stem elong Stem elong Fl	YMB	F			7.2 6.8-6.9 5.8 5.4-5.9 5.8 5.5 5.2					Aust	399	Diagnostic for 90% max. shoot DW NO_3-N in PYML best diagnostic test before stem elongation
	4-5 leaf 5-6 leaf 6-8 leaf Buds visible Early stem elong Stem elong Fl	YMB	F			7.3 6.7-6.8 5.9 5.3-5.9 5.9 5.6 4.7-5.3					Aust	399	Predictive for 90% max. seed yield
	Rosette Buds visible	YMB	F			6.9 5.7					Aust	401	Diagnostic for shoot yield conc. on DW basis Critical levels halved by late seeding
	Rosette Buds visible	YMB	F			7.1 5.9					Aust	401	Predictive for seed yield on FW basis Critical levels halved by late seeding
	8 MAS (Pre Fl)	YML	F	<3.8							UK	88	Predictive for seed yield and seed protein and glucosinolate percentage
	Early Fl	YML	Lit				4.0-5.5				Ger	82	
	Pre-Fl	YML	Lit	0.8-2.7	2.8-3.2		3.5-5.5	5.6-6.5			Aust	1053	
	U	YML	Lit	2			4				Var	374	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	4-5 leaf	PYML	F			4.5					Aust	399	Diagnostic for 90% max. shoot DW
	5-6 leaf					4.2-4.5							NO_3-N in PYML best diagnostic test before
	6-8 leaf					2.8							stem elongation.
	Buds visible					2.0-2.9							
	Early stem elong					2.8							
	Stem elong					2.5							
	Fl					1.7-2.1							
	4-5 leaf	PYML	F			4.6					Aust	399	Predictive for 90% max. seed yield
	5-6 leaf					4.2							
	6-8 leaf					2.9							
	Buds visible					1.9-2.9							
	Early stem elong					2.9							
	Stem elong					2.5							
	Fl					1.7-2.2							
	Pre-Fl	1,2,3 RML	D			3.2	3.3-6.4				Aust	1051	
	Veg	ML	Lit				3-4				Ger	82	
NO_3-N (mg/kg)	4-5 leaf	PYML	F			1620					Aust	399	Diagnostic for 90% max. shoot DW
	5-6 leaf					1550-1620							NO_3-N concs on FW basis
	6-8 leaf					630							NO_3-N in PYML best diagnostic test before
	Buds visible					530-480							stem elongation
	Early stem elong					340							
	Stem elong					140							
	Fl					60-220							
	4-5 leaf	PYML	F			16500					Aust	399	Diagnostic for 90% max. shoot DW
	5-6 leaf					16000-15500							NO_3-N concs on DW basis
	6-8 leaf					5900							NO_3-N in PYML best diagnostic test before
	Buds visible					4600-4700							stem elongation
	Early stem elong					2800							
	Stem elong					1200							
	Fl					800							
	4-5 leaf	PYML	F			1710					Aust	399	Diagnostic for 90% max. seed yield
	5-6 leaf					1500-1590							NO_3-N concs on FW basis
	6-8 leaf					700							
	Buds visible					440-500							
	Early stem elong					360							
	Stem elong					150							
	Fl					60-220							

CANOLA, RAPESEED (*Brassica napus, B. campestris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
NO_3-N (mg/kg) (ctd)	4-5 leaf	PYML	F			17300					Aust	399	Diagnostic for 90% max. seed yield NO_3-N concs on DW basis
	5-6 leaf					14400-15400							
	6-8 leaf					6700							
	Buds visible					3600-4700							
	Early stem elong					3300							
	Stem elong					1300							
	Fl					800							
	Rosette	PYML	F			1500					Aust	401	Diagnostic conc. for shoot yield
	Buds visible					450							Critical levels halved by late seeding
	Rosette	PYML	F			1700					Aust	401	Predictive for seed yield on FW basis
	Buds visible					5300							Critical levels halved by late seeding
	Floral initiation	YFEL	F			1590-1180					Aust	83	Predictive for seed yield; vary with seeding date and rate. Floral initiation most reliable stage.
	Buds visible					160-790							
	Early Fl					13-210							
P(%)	30-40 DAS	WS	Soil			0.39					Ger	259	cv. Quinta; diagnostic for 80% max. shoot DW
	74 DAS	WS	F	<0.13			>0.23				NZ	1030	
	Veg	WS	SC	≤0.2							Pol	847	Diagnosed by accumulation of proline.
	Early rosette - yellow bud	WS	Sand			0.21-0.29					Aust	744	Higher by 0.05% for predictive evaluation
	Rosette (leaf 4 unfurled)	WS	F			0.28					Aust	749	Predictive for seed yield
	Plants ≤30 cm high	WS	Soil			0.26					Pak	783	Critical at 95% of max. seed yield
	55 DAS	YMB (L3-L4)	Sand	0.13-0.24		0.28-0.33	0.35-0.63				Aust	743	Criteria for YMB are derived for maxi vegetative and oil yield
	107 DAS	YMB	Sand	0.06-0.11		0.15	0.24-0.43				Aust	743	Criteria for YMB are derived for maxi vegetative and oil yield
	120 DAS	YMB (L4-L5)	F	0.17-0.27		0.28-0.32	0.3-0.48				Aust	743	Criteria for YMB are derived for maxi vegetative and oil yield
	78 DAS	YMB (L4-L6)	Sand	0.07-0.17		0.16-0.2	0.17-0.62				Aust	743	Criteria for YMB are derived for maxi vegetative and oil yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Head Mat	YMB Seed	Soil			0.26 0.72					Pak	783	Critical at 95% of max. seed yield
	Early Fl	YML	Lit				0.35-0.70				Ger	82	
	Pre-Fl	YML	Lit	0.09-0.20	0.24-0.29		0.35-0.60	0.65-0.70			Aust	1053	
	U	YML	Lit	0.15			0.42				Var	374	
	Early rosette - yellow bud	YFEL	Sand			0.15-0.28					Aust	744	Higher by 0.05% for predictive evaluation
	Rosette (leaf 4 unfurled)	YFEL	F			0.33					Aust	749	Predictive for seed yield
	Pre-Fl	1,2,3 RML	D	0.09-0.15	0.22-0.29	0.3	0.34-0.69	>0.7			Aust	1051	
	Veg	ML	Lit				0.3-0.6				Ger	82	
	Mat	Seed	F			0.35					Aust	749	
	Mat	Seed	Sand	0.25-0.41		0.45	0.7-1.0				Aust	743	Criteria for YMB are derived for maximum vegetative and oil yield
P(mg/L)	Late rosette	Basal S	Lit			150-800					Aust	373	Predictive for 90% max. seed yield
K(%)	Veg	ML	Lit				2.8-4.5				Ger	82	
	Pre-Fl	YML	Lit	<1.6	1.8-1.9		2.8-5.5	6.5-8.0			Aust	1053	
	Early Fl	YML	Lit				2.8-5.0				Ger	82	
	U	YML	Lit	1.5			3.5				Var	374	
	Pre-Fl	1,2,3 RML	D	1.0-1.3	1.8-1.9		2.9-5.1	6.3-7.8			Aust	1051	
K(mg/L)	Late rosette	Basal S	Lit			1200					Aust	373	Predictive for 90% max. seed yield
K(mg/mL sap)	35 DAS	YML	Soil			2.26					Can	765	Sap from squeeze; Predictive at 90% max. shoot DW at 56 DAS
K/Na	Mat	WS	Soil						1.3		Arg	755	Diagnostic for seed yield
S(%)	Rosette	WS	F Soil			0.38 0.48-0.56					Can	595	HIred/Tot-S (=HI-S/ST) Critical level related to N rate
	74 DAS	WS	F	<0.58			0.78-0.89				NZ	1030	
	Veg	WS	F			0.65					Ger	888	Predictive for seed yield of 4.8 t/ha

CANOLA, RAPESEED (*Brassica napus, B. campestris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%) (ctd)	1st Fl	WS Last rosette leaf	F			0.24 0.32					Aust	748	Diagnostic for shoot DW
	1st Fl	WS Last rosette leaf	F			0.30 0.37					Aust	748	Predictive for seed yield
	Buds visible	WS YFEL	F			0.36-0.52 0.35-0.47					Aust	748	cv. Barossa Diagnostic for shoot DW
	Buds visible	WS YFEL	F			0.35-0.45 0.35-0.46					Aust	748	Predictive for seed yield
	Stem elong	YL	Soil			0.55					Ger	375	Predictive for 95% max. yield (0.65 for max. yield)
	103 DAS	YMB	Sand	0.11-0.25		0.25	0.34-1.04				Aust	743	Critical at max. yield
	52 DAS	YMB (L3-L4)	Sand	0.11-0.21		0.21-0.25	0.26-0.93				Aust	743	Critical at max. yield
	72 DAS	YMB (L4-L6)	Sand	0.12-0.19		0.19-0.26	0.17-0.85				Aust	743	Critical at max. yield
	Pre-Fl	YML	Lit		0.25-0.50		0.6-1.0				Aust	1053	*Brassica napus* and *B. campestris*
	U	YML	Lit	0.13			0.65				Var	374	
	Pre-Fl	1,2,3 RML	D		0.5						Aust	1051	
	Budding	A	SC			0.24 0.19					Aust	568	Predictive for seed yield (cv. Wesbrook) Predictive for oil %.
	Stem elong	L	F		<0.6						UK	1115	
	Mat	Seed	F			0.36					Aust	748	Diagnostic for seed yield Strong Piper-Steenbjerg effect
	Mat	Straw Seed	F	<0.33 <0.33							Can	670	*Brassica napus* and *B. campestris*
	Early Fl	U	F,Soil			0.35					Pol	350	Critical N/S = 12
	Late Fl	U	F,Soil			0.26					Pol	350	Critical N/S = 10.8
S(mg/L)	Late rosette	Basal S	Lit			200-800					Aust	373	Predictive for 90% max. seed yield
N/S	Fl	WS	Soil				<14.8				Can	39	Based on correlations with soil tests
	25 DAS 59 DAS ≤104 DAS	WS	Soil			19-29 19-20 21-38					Aust	953	Diagnostic for shoot DW; Criteria not sensitive to plant part - YB, YP, OB, OP, WS; $100SO_4/S_{total}$ best all round index.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	59 DAS	WS	Soil			7-10						953	Predictive for grain yield; Criteria not sensitive to plant part - YB, YP, OB, OP, WS; $100SO_4/S_{total}$ best all round index.
$100SO_4$-S /Total S	25 DAS 59 DAS	WS	Soil			6-7 5-8 10					Aust	953	Diagnostic for shoot DW; Criteria not sensitive to plant part - YB, YP, OB, OP, WS; $100SO_4/S_{total}$ best all round index.
	59 DAS	WS	Soil			17-36						953	Predictive for grain yield; Criteria not sensitive to plant part - YB, YP, OB, OP, WS; $100SO_4/S_{total}$ best all round index.
Ca(%)	Early Fl	YML	Lit				1-2				Ger	82	*Brassica napus* var. *oliefera*
	Pre-Fl	YML	Lit		0.8-1.2		1.4-3.0				Aust	1053	*Brassica napus* and *B. campestris*
	U	YML	Lit	1			2.25					374	
	Pre-Fl	1,2,3 RML	D				1.4-3.0				Aust	1051	
	Veg	ML	Lit				0.7-2.0				Ger	82	*Brassica napus* var. *napobrassica*
Mg (%)	Young plants	WS	F				>0.4				Var	413	
	Fl	WS	F				>0.15				Var	413	
	Pre-Fl	1,2,3 RML	D	<0.14	0.16-0.19		0.21-0.62				Aust	1051	
	Veg	ML	Lit				0.25-0.60				Ger	82	*Brassica napus* var. *napobrassica*
	Pre-Fl	YML	Lit	0.14	0.16-0.19		0.21-0.65				Aust	1053	*Brassica napus* and *B. campestris*
	Early Fl	YML	Lit				0.25-0.40				Ger	82	*Brassica napus* var. *oliefera*
	U	YML	Lit	0.09			0.15				Var	374	
Na(%)	Pre-Fl	1,2,3 RML	D				0.02-0.54	0.7-1.1			Aust	1051	
	Pre-Fl	YML	Lit				0.02-0.5	0.7-1.1		1.7	Aust	1053	
Ca/Na	Mat	WS	Soil						0.3		Arg	755	Diagnostic for seed yield
Cl(%)	Fl	ML	F						5.4 6.0		USA	295	cv. Westar; Predictive for final cv. Tobin; vegetative and seed yield
	Pre-Fl	YML	Lit				0.4-1.6	2			Aust	1053	
	Pre-Fl	1,2,3 RML	D				0.4-1.5	2			Aust	1051	
Cu(mg/kg)	43 DAS (Fl)	WS	Soil	<1.7			>2.7				Can	596	
	Fl initiat Pod initiat	WS	Soil			2.8 2	2.7-6				Can	595	Diagnostic at 85% max. growth
	U	WS	Soil			2					Pol	413	
	14 DAS	L	SC							16	UK	558	

CANOLA, RAPESEED (*Brassica napus, B. campestris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg) (ctd)	Early Fl	YML	Lit				5-12				Ger	82	*Brassica napus* var. *oliefera*
	Pre-Fl	YML	Lit		2-3		4-25				Aust	1053	*Brassica napus* and *B. campestris*
	U	YML	Lit	2			4.5				Var	374	
	Pre-Fl	1,2,3 RML	D				4-25				Aust	1051	
	Veg	ML	Lit				6-12				Ger	82	*Brassica napus* var. *napobrassica*
	Mat	Seeds	Soil	<3							Can	473	cv. Westar
Zn(mg/kg)	≤30 cm high Fl Mat	WS YML Seed	Soil			29 33 29					Pak	789	Predictive; 95% max. seed yield Predictive; 95% max. seed yield Diagnostic; 95% max. seed yield
	Early Fl	YML	Lit				25-70				Ger	82	*Brassica napus* var. *oliefera*
	Pre-Fl	YML	Lit	<12	12-17		21-55				Aust	1053	*Brassica napus* and *B. campestris*
	U	YML	Lit	15			33				Var	374	
	22 DAS	YOB YOB+1 YMB	Soil			25-29 13-18 11-13					Aust	423	
	39 DAS (stem elong)	YOB YOB+1 YMB	Soil			15-17 9-10 7-8					Aust	423	
	Pre-Fl	1,2,3 RML	D				22-49				Aust	1051	
	Veg	ML	Lit				20-80				Ger	82	*Brassica napus* var. *napobrassica*
Mn(mg/kg)	Veg	ML	Lit				40-100				Ger	82	*Brassica napus* var. *napobrassica*
	Pre-Fl	YML	Lit				30-250	300-400		530-3650	Aust	1053	*Brassica napus* and *B. campestris*
	Early Fl	YML	Lit				30-100				Ger	82	*Brassica napus* var. *oliefera*
	U	YML	Lit	10			30				Var	374	
	Pre-Fl	1,2,3 RML	F,D, Soil				31-250	525-640		>670	Aust	1051	
	U		Soil							>590	Aust	908	
B(mg/kg)	Head ≤30 cm high	YMB WS	Soil			35 28			170 110		Pak	790	cv. Shiralee; Predictive for 95 % max. seed yield
	Early Fl	YML	Lit				30-60				Ger	82	*Brassica napus* var. *oliefera*

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	Pre-Fl	YML	Lit	6-13	17-20		22-50				Aust	1053	*Brassica napus* and *B. campestris*
	U	YML	Lit	9			25				Var	374	
	Pre-Fl	1,2,3 RML	D				22-54				Aust	1051	
	Rosette	Apex	Sand	4-6	9		25				Aust	776	Plants at rosette with 9 mg/kg did not produce seed
	U	Fl	F	10.6			17				Pol	413	
	Veg	ML	Lit				35-80				Ger	82	*Brassica napus* var. *napobrassica*
	112 DAS	Roots YL	Soil	<27 <56			>20				Can	899	Diagnosed by symptoms
	28-30 DAS	YFEB	RSC						84		Aust	186	cv. PAC21063
Mo(mg/kg)	Pre-Fl	YML	Lit				0.28-0.55	1.6			Aust	1053	*Brassica napus* and *B. campestris*
	Early Fl	YML	Lit				0.4-1.0				Ger	82	*Brassica napus* var. *oliefera*
	U	YML	Lit	0.05			0.3				Var	374	
	Pre-Fl	1,2,3 RML	D				0.28-0.55	1.6			Aust	1051	
	Veg	ML	Lit				0.5-1.0				Ger	82	*Brassica napus* var. *napobrassica*

CASSAVA (*Manihot esculenta*)

N(%)	Veg	YMB	F	<4.5		5.7	5.0-6.0				Colo	32 418	
	75 DAS	YMB (L4 + L5)	F			5.0					PuRi	288	
	3-4 months	YMB	F	<4.7	4.7-5.1	5.1	5.1-5.8	>5.8			Colo	419	
	3-5 months	YMB	F		3.45-5.55	5.4-5.6	5.6-6.45				Colo	420	Critical at 95% max. fresh root yield.
P(%)	28 DAS	WS	FSC			0.47-0.66					Aust	449	Critical for 12 cultivars
	98 DAS	YMB	F	0.18		0.30	0.33-0.41		0.58	0.69	Aust	396	cv. M Aus 8; critical conc. for podsol only.
	3-4 months	YMB	F	<0.30	0.30-0.36	0.36	0.36-0.50	>0.50			Colo	419	
	3-5 months	YMB	F		0.17-0.39	0.41	0.42-0.47				Colo	420	Critical at 95% max. fresh root yield.
	Veg	YMB	F	<0.2		0.4	0.3-0.5				Colo	418	
K(%)	27 DAS	YMB	SC			1.1					Aust	948	Critical at 95% max. yield
	28 DAS	YMB	FSC			2.3-3.3					Aust	949	Critical for 12 cultivars at 95% max. yield
	49 DAS	YMB	SC			0.7-1.3					Aust	949	Critical for 4 cultivars at 95% max. yield

CASSAVA (*Manihot esculenta*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	100 DAS	YMB	F				0.97-1.24				Aust	715	
	200 DAS				0.59-0.65	0.66	0.61-0.99						
	580 DAS			0.43			0.54-0.99						
	180 DAS	YMB	F	0.84	0.92	0.97	1.08-1.28				Nig	470	Mean data for 2 cvv; critical conc. for 90% max. dry tuber yield at 390 DAS.
	3-4 months	YMB	F	<1.0	1.0-1.3	1.3	1.3-2.0	>2.0			Colo	419	
	3-5 months	YMB	F		0.58-1.40	1.42	1.45-2.02				Colo	420	Critical at 95% max. fresh root yield.
	Veg	YMB	F	<1.0		1.2	1.2-2.0				Colo	418	
	175 DAS	Terminal leaves	F		1.5-1.7		2.5				Nig	427	cv. TMS 30572; response to 2.6%K contained in mulch.
S(%)	3-4 months	YMB	F	<0.24	0.24-0.26	0.26	0.26-0.30	>0.30			Colo	419	
	Veg	YMB	F	<0.3		0.32	0.3-0.4				Colo	418	
	Veg	YMB	F	<0.3							Colo	660	
Ca(%)		WS	FSC	0.10-0.29	0.39	0.65	0.71-2.35	3.67			Aust	439	cv. Nina
	Veg	YMB	F	<0.5			0.6-1.5				Colo	418	
	3-4 months	YMB	F	<0.65	0.65-0.75	0.75	0.75-0.85	>0.85			Colo	419	
	84 DAS	YML + 2	F		0.51-0.60		0.61-0.64				Nig	663	cv. TMS 30211 at Umudike
		YML + 2			0.68-0.70		0.69-0.84						2 cvv. at Nsukka
Mg(%)	3-4 months	YMB	F	<0.27	0.27-0.29	0.29	0.29-0.31	>0.31			Colo	419	
	180 DAS	YMB	F	0.33			0.36-0.39				Nig	470	cv. TMS 30211
	180 DAS			0.39			0.44-0.49						cv. TMS 30395
	Veg	YMB	F	<0.2			0.25-0.5				Colo	418	
	Veg	YMB	SC	<0.29							Aust	32	
Cu(mg/kg)	Veg	YMB	F				7-15				Colo	418	
	63 DAS	YMB	SC			6			15		Aust	421	Critical at 90% max. yield
	3-4 months	YMB	F	<5	5-6	6	6-10	10-15	15	>15	Colo	419	
Zn(mg/kg)	3-4 months	YMB	F	<25	25-30	30	30-60	60-120	120	>120	Colo	419	
	Veg	YMB	F	<35		35-50	40-100				Colo	418	
	63 DAS	YMB	SC			30			120		Aust	421	Critical at 90% max. yield
Mn(mg/kg)	30 DAS	WS	FSC		67-81		140-170		230-520		Aust	242	Toxic criteria at 90% max. yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Mn(mg/kg) (ctd)	63 DAS	YMB	SC	<14		50			250		Aust	421	Critical at 90% max. yield
	Veg	YMB	F	<50			50-250			>1000	Colo	418	
	3-4 months	YMB	F	<45	45-50	50	50-120	120-150	150	>250	Colo	419	
Fe(mg/kg)	63 DAS	YMB	SC	<60							Aust	421	
	3-4 months	YMB	F	<100	100-120	120	120-140	140-200	200	>200	Colo	419	
	Veg	YMB	F	<50			60-200			>250	Colo	418	
B(mg/kg)	40 DAS	WS	SC	5-13		17			140		Aust	283	Critical at 90% max. yield
	63 DAS	YMB	SC			35			100		Aust	421	Critical at 90% max. yield
	Veg	YMB	F	<15			15-50			>140	Colo	418	
	3-4 months	YMB	F	<20	20-30	30	30-60	60-100	100	>100	Colo	419	

CEREAL RYE, RYE (*Secale cereale*)

FS = Feeke's scale of cereal growth (see reference 511).

N(%)	FS 5-6 FS 7-8	WS	Lit				2.5-5.0 2.0-4.0				Ger	82	
	U	WS	Lit		<4.0		4.0-5.0	>5.0			USA	457	
NO_3-N (mg/kg)	Early Till.	Basal S	F	5700				11900-13900			Aust	707	
P(%)	FS 5-6 FS 7-8	WS	Lit				0.3-0.6 0.25-0.5				Ger	82	
	U	WS	Lit		<0.52		0.52-0.65	>0.65			USA	457	
K(%)	21 DAS	WS	RSC			0.59					UK	1066	Data expressed on a fresh weight basis for 90% max. relative growth rate.
	FS 5-6 FS 7-8	WS	Lit				2.8-4.5 2.7-4.0				Ger	82	
	U	WS	Lit		<1.9		1.9-2.3	>2.3			USA	457	
Ca(%)	FS 5-6 FS 7-8	WS	Lit				0.35-1.0 0.3-1.0				Ger	82	
Mg(%)	FS 5-6 FS 7-8	WS	Lit				0.15-0.3 0.12-0.3				Ger	82	
	U	WS	Lit		<0.2		0.2-0.6	>0.6			USA	457	
Cu(mg/kg)	FS 5-6 FS 7-8	WS	Lit				6-12 5-10				Ger	82	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
CEREAL RYE$_o$RYE (*Secale cereale*) (ctd)													
Cu(mg/kg) (ctd)	U	WS	Lit		<5		>5				USA	457	
Zn(mg/kg)	FS 5-6 FS 7-8	WS	Lit				20-60 15-60				Ger	82	
Mn(mg/kg)	Young plants	WS	S						200		Ger	1117	Critical for acidic soils with pH values 4.1-4.4.
	22 DAS	WS	Soil				18-69				Aust	579	cv. did not respond to applied Mn, where other cereals did.
	U	WS	Lit		3-13		14-45	>45			USA	457	
	FS 5-6 FS 7-8	WS	Lit				25-100 20-100				Ger	82	
B(mg/kg)	FS 5-6 FS 7-8	WS	Lit				5-10 4-10				Ger	82	
Mo(mg/kg)	FS 5-8	WS	Lit				0.1-0.3				Ger	82	
	U	WS	Lit		<0.2		0.2-2.0	>2.0			USA	457	
CHICKPEA (*Cicer arietinum*)													
N(%)	Veg	WS	SC			2.3					Aust	241	Criteria underestimated as max. yield not achieved
	42 DAS	WS	Soil/Ver			1.6					USA	942	Kabuli type; average of 2 soil and 1 ver expt
	Veg	YML	Lit	1.25-2.4	3.2-3.4		4.0-5.5	5.9			Aust	1053	
P(%)	<30 cm tall	WS	Soil			0.26					Pak	605	
	28 DAS	WS	F				0.38-0.45				Aust	829	Predictive for seed yield
	45 DAS	WS	Soil	0.09-0.25			0.29-0.33				Ind	884	
	77 DAS	WS	Soil	0.15-0.2			>0.26				Ind	884	
	Veg	WS	SC			0.24				>0.75	Aust	241	
	Head ≤30 cm high Mat	YMB WS Seed	Soil			0.39 0.18 0.37					Pak	783	Criticals at 95% of max. seed yield
	Fl init	YML	Soil			0.39					Pak	605	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Veg	YML	Lit	0.10-0.13	0.24		0.29-0.55				Aust	1053	
	Mat	Seed	Soil			0.37					Pak	605	
K(%)	7th leaf stage	2-4 leaf	Soil			0.15					Can	425	Apparently diagnostic for shoot yield; % of max. yield unknown; Water extractable K
	Mat	Seed Straw	F	≤3.2 ≤1.1							Ind	995	Diagnostic for max. seed yield and shoot DW
	Veg	YML	Lit	1	1.6-1.8		2.0-3.6				Aust	1053	
K(mg/mL sap)	35 DAS	YML	Soil			1.0 1.51					Can	765	Sap from squeeze Sap from freeze/squeeze Predictive at 90% max. shoot DW at 56 DAS
S(%)	Mat	WS Seed	F				≥0.27 ≥0.41				Ind	993	No plateau in DM or seed yield achieved.
	7th leaf stage	2-4 leaf	Soil			0.18					Can	425	Apparently diagnostic for shoot yield; % of max. yield unknown; Water extractable S.
	7th leaf Early Fl	ML	Soil			0.18 0.17					Can	424	Diagnostic for shoot DW; SO_4-S measured; Predictive for seed yield
	Veg	WS	SC			0.15					Aust	241	
Ca(%)	Veg	YML	Lit				1.3-2.2	2.8			Aust	1053	
Mg(%)	Veg	YML	Lit		0.15		0.35-0.65				Aust	1053	
Na (µeq/g)	42 DAS	YML	SC						340 170		USA	514	cv. L-550 cv. E-100
	56 DAT	WS	SC						50-100		USA	513	3 cultivars used
Na(%)	Veg	YML	Lit				0.01-0.20				Aust	1053	
Na(µmol/g)	44 DAT	WS	SC						200-270		USA	513	cv. L-550
Cl(%)	Veg	WS	SC							>1.6	Aust	241	
	Fl	WS	Soil							≥5	Ind	574	Almost no seed at this level
	Veg	YML	Lit				0.4-1.0	1.5		1.6-3.9	Aust	1053	
Cl(Meq/ 100g DW)	53 DAT	WS	SC						82 91 84 105		USA	516	Nil N NH_4NO_3 up to Day 31 NH_4NO_3 after Day 33 NH_4NO_3 throughout growth
Cu(mg/kg)	Veg	YML	Lit				4-30				Aust	1053	
	Veg	WS	SC				4-35			>35	Aust	241	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
CHICKPEA (*Cicer arietinum*) (ctd)													
Zn(mg/kg)	Veg	WS	SC				12-500			>510	Aust	241	
	45 DAS	WS	F				>34				Ind	992	Predictive for seed yield and shoot DW at maturity
	Mat	Straw					>37						Diagnostic for seed yield and shoot DW at maturity
	Mat	Seed					>28						
	Veg	YML	Lit				22-90				Aust	1053	
Mn(mg/kg)	Veg	WS	SC							>520	Aust	241	
	77 DAS	WS	SC					>120			Ind	884	
	Veg	YML	Lit				60-300	350			Aust	1053	
Fe^{2+} (mg/kg)	40 DAS	Terminal L	F	<9.7			>5.7				Pak	785	Criteria based on symptoms of susceptible variety
	55 DAS			<11.3			>6						
	90 DAS			<11.8			>9.7						
	U	WS	Soil			70						760	
B(mg/kg)	Veg	WS	SC			40				>235	Aust	241	
	Veg	YML	Lit				22-30				Aust	1053	
	28-30 DAS	YFEB	RSC						34		Aust	186	cv. Norwin
CHICORY (*Cichorium intybus*)													
N(%)	Mat	Roots	F				≥1.1				USA	865	Diagnostic for vegetative parts
		Veg parts				1.8							
CITRONELLA JAVA (*Cymbopogon winterianus*)													
N(%)	90 DAT	WS	F			4.9					Ind	924	Diagnostic for fresh herbage and oil yield; N% on FW basis
	180					3.6							
	270					3.7							
	360					2.4							
CORN, MAIZE (*Zea mays*)													
Growth stages of corn are described in reference 380. BOBC = blade opposite and below cob. BOAC = blade opposite and above cob. See also information for sweet corn under Vegetable Crops.													
N(%)	30-45 DAE	WS	U				3.5-5.0				USA	536	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	<30 cm tall	WS	Lit	<3.5			3.5-5.0	>5.0			USA	456 457	
	15-30 cm tall	WS	F	Data from 14 N fertilizer rate experiments indicated the site relationships between relative grain yield and N conc. in the shoots of young corn plants were inconsistent and would not provide a reliable indication of N status.							USA	89	
	8 leaf stage	WS	F			3.68					Can	438	Critical at 95% max. grain yield, derived from 3 medium term experiments
	Various	WS	Lit	From a review of published literature, a curvilinear relationship between shoot N conc. at 95 % max. yield and 11 plant growth stages in corn has been defined. A similar relationship has been developed for N/P ratios in shoots.							USA	453	
	Mat	WS	F			1.34					Can	438	
	40-60 cm tall	YMB	Lit				3.5-5.0				Ger	82	
	Pre-tasselling	YMB	F			3.0					USA	837	Critical is the just adequate value for higher yielding irrigated corn.
	Tasselling	Ear leaf	F	1.78	2.11		2.74				NZ	206	Three levels of N applied.
	Tasselling	Ear leaf	F	<2.8	2.8-3.1	3.1-3.3 and 3.3-3.6		3.6-3.9		>3.9	Fra	546	First critical range for average to very high yields. Second critical range for high yield even when climatic conditions are not favourable. Deficiency symptoms exhibited if conc. <2.8%.
	Tasselling	Ear leaf	F			3.15					Can	438	Critical at 95% max. grain yield. Derived from 3 medium-term experiments.
	Tasselling - initial silk	Ear leaf	F,D	<2.4	2.4-2.6		2.7-3.5	3.6-4.0		>4.0	Aust	1053	Toxic range is 'excessive'.
	Initial silk	Ear leaf	Lit	2.0-2.6			2.7-4.0	>4.0			USA	457	
	Silking	Ear leaf	F			2.93					USA	30	Critical at 97% max. grain yield.
	Silking	Ear leaf	F			3.1					Nig	14	Critical range defined as 2.85-3.19% N for max. grain yield for 8 cvv grown over 3 years.
	Silking	Ear leaf	F	<2.45	2.46-2.75		2.76-3.5	3.51-3.75		>3.75	USA	455	
	Silking	Ear leaf	U	<2.0	2.0-2.24		2.25-3.3	>3.3			NZ	205	
	Silking	Ear leaf	F				2.6-4.0				Ger	659	
	56 DAS	BOBC	F	1.7			3.0				USA	379	
	Full tasselling	BOBC	S,D			2.5					Aust	1052	
	Full tasselling	BOBC	F,S,D			3.0					USA	604	Critical at 100% max. yield

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N(%) (ctd)	Silking	BOBC	F			2.9					USA	1036	
	Silking	BOBC	F			2.7-2.9					USA	238	Critical at 95% max. yield
	Silking	BOBC	F			2.4-2.5					USA	41	Critical at 100% max. yield
	Silking	BOBC	F	<2.6	2.6-3.2	3.0	>3.2				Aust	1045	Critical at 90% max. yield
	Silking	BOBC	F	1.7-2.4			2.7-3.3				USA	758	
	Silking	BOBC	F			2.52					USA	219	Critical at 95% max. grain yield.
	Silking	BOBC	F			2.5					Aust	232	Critical at 90% max. grain yield. Derived from 16 experiments.
	U	Leaf below uppermost ear	F			2.52					S Afr	10	Tentative criteria for near max. grain yield.
	40-60 cm tall	Leaf opposite ear	Lit				2.8-3.5				Ger	82	
	Silking	2nd leaf below ear	F			2.6					USA	837	Critical is the just adequate value for higher yielding irrigated corn.
	Silking	2nd LB below upper ear	F			2.2-2.9					USA	1021	
	Silking	2nd LB below upper ear	F			2.4-3.3					USA	808	Critical at 95% max. yield
	Before tasselling	Leaf below whorl	Lit		<3.0		3.0-3.5	>3.5			USA	457 456	
	Silking	6th LB from base	F			2.6-3.1					USA	81	Critical at 95% max. yield
	Silking	6th LB from base	F			2.9					USA	1000	
	45 DAS	All LB	F	2.9			3.4				USA	379	
	Fl (47 DAS)	Green leaves	F			1.07±0.13					Aust	632	Unit of N as g N/m^2 or leaf N content/leaf weight. Critical at max. green leaf area.
	Early tasselling (55 DAS)	Leaves	Sand			3.4					Aust	405	Critical at max. shoot yield. Atmospheric CO_2 enrichment did not affect criteria.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	At & beyond the black layer forming in grain	Stalk (15-35 cm above ground)	F			0.21-0.47	0.4-0.9				USA	90	Critical range at 95% max. grain yield for 15 sites. Critical = 0.29%N at max. grain yield for all sites.
	Mat	Grain	F			1.3					USA	837	Critical is the just adequate value for high yielding irrigated corn.
	Mat	Grain	F			1.53					USA	30	Critical at max. grain yield.
	Mat	Grain	F			1.52±0.02					USA	736	Critical at max. grain yield for 13 site x year experiments. Criticals also given for 45, 60, 75 and 90% max. yield. Criticals for other USA and Canadian studies also reviewed.
	Mat	Grain	F			1.49					S Afr	10	Tentative critical at near max. grain yield.
	Mat	Grain	F	For 12 site x year N fertiliser rate experiments, the relationship between relative grain yield and grain N conc. was highly variable and often C-shaped. Reliable criteria for grain N% could not be estimated.							USA	181	
				Rapid *in situ* field test developed for assessing the N status of corn.							USA	794	
				The reliability of estimating canopy or leaf chlorophyll content with portable chlorophyll meters in the field has been evaluated as a means for estimating the N status of corn plants at various stages of growth.									Consult references 96, 97, 733, 734, 912, 931 and 1093.
NO_3-N (mg/kg)	20-30 cm tall	Basal S	F	Sap nitrate levels determined using a NO_3-sensitive test strip.							NZ	956	Basal S cut 10 cm above ground.
	30 DAE	Basal stalk	F			11000-16000					USA	443	Critical range at 95% max. grain yield derived from 2 field experiments.
	5-6 leaf stage (22-37 DAE)	Basal stalk (10 cm)	F			14500					USA	287	From 87 dryland experiments, corn stalk NO_3-N did not predict soil N status nor that the crop would respond to applied N.
	6 leaf stage (V6)	Basal S	F			9000-17800					USA	598	Critical values for loess and glacial soils respectively.
	Early tasselling	Basal S	Sand			2500±250					Aust	405	Critical at max. shoot yield.
	Young plants	Basal S	Soil, F	Diurnal fluctuations in stalk NO_3-N concentrations were observed, but are unlikely to affect interpretations.							USA	444	
	Within 10 days of black layer forming in grain	Stalk (15-35 cm above ground)	F			700-2000		2000-10000			USA	912	Critical ranges for near max. grain yield. This test was designed to confirm whether excess N fertiliser was applied during crop growth.

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
NO_3-N (mg/kg) (ctd)	At and beyond the black layer forming in grain	Stalk (15-35 cm above ground)	F			220-780		1800-7300			USA	90	Critical ranges for near max. grain yield. This test was designed to confirm whether excess N fertiliser was applied during crop growth.
	Black layer forming on 80% of most ears	Stalk (15-35 cm above ground)	F			250-1800		1800-7500			USA	91	Critical ranges for near max. grain yield. This test was designed to confirm whether excess N fertiliser was applied during crop growth.
	35 DAS	YMB	F			4000-6000					USA	793	Critical range for max. grain yield. An *in situ* colorimetric method for measuring NO_3 in leaves is also reported.
	35-49 DAS	LB below whorl	F				2000-3000				Can	183	
	4-5 leaf stage Onset of shooting Up to silking	Sheaths of 2 oldest green leaves	F			1100-1700 550-850 400-700					Ger	322	Units in mg NO_3-N/L pressed sap using NO_3 sensitive test strips. On soil with high N status, stated critical ranges can be lower.
P(%)	20 DAS	WS	SC							2.45	USA	195	No symptoms observed
	42 DAE	WS	Soil			0.29					Pak	567	Critical at 95% max. shoot yield.
	30-45 DAE	WS	U				0.4-0.8				USA	536	
	<30 cm tall (42 DAS)	WS	Soil			0.29					Pak	567	Critical at 95% max. yield.
	<30 cm tall	WS	Lit	<0.3			0.3-0.5	>0.5			USA	457 456	
	<30 cm tall	WS	Soil			0.24					Pak	784	Critical at near max. yield.
	40-60 cm tall	WS	F			0.22-0.26					USA	807	Critical at 95% max. yield
	6 leaf stage	WS	RSC			0.5					Can	53	Critical at max. grain yield.
	Early silking	WS and BOBC	F	P conc. in WS at seedling stage and BOBC were found to be insensitive predictors of P deficiency in several field experiments.							Can	54	Mid section of BOBC analysed.
	Silking	WS	F			0.23					Thai	713	Critical at 90% max. grain yield.
	Various	WS	Lit (F)	From a review of published literature a curvilinear relationship between shoot P conc. at ≥95% max. yield and 9 plant growth stages has been defined. A similar relationship has been developed for shoot N/P ratios.							USA	453	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	40-60 cm tall	YMB	Lit				0.35-0.6				Ger	82	
	Pre-tasselling	YMB	F			0.26					USA	837	Critical is just adequate value for high yielding, irrigated corn.
	Flower initiation	YMB	Soil			0.26					Pak	784	Criteria at near max. yield.
	Tasselling	Ear leaf	F				0.2				NZ	206	
	Tasselling	Ear leaf	F	<0.29	0.3-0.32	0.33-0.34		>0.35			Fra	546	Deficiency symptoms exhibited with P conc. <0.2%.
	Tasselling to initial silk	Ear leaf	F,D	<0.16	0.16-0.24		0.25-0.45	0.46-0.8		>0.8	Aust	1053	Toxic range is 'excessive'.
	Before tasselling	Leaf below whorl	Lit	<0.25			0.25-0.45	>0.45			USA	457	
							0.25-0.5	0.5-0.8				456	
	Initial silk	Ear leaf		0.15-0.24									
	Silking	Ear leaf	F	<0.15	0.16-0.24		0.25-0.4	0.41-0.5		>0.5	USA	455	
	Silking	Ear leaf	F				0.25-0.4				Ger	659	
	Silking	Ear leaf	F	<0.15	0.15-0.17		0.17-0.32	>0.32			NZ	205	
	Silking	Ear leaf	F				0.22-0.23				USA	807	
	Silking	Ear leaf	F			0.27					USA	458	Critical at 100% max. yield
	Silking	Ear leaf	F			0.23					Nig	14	Critical range defined as 0.2 to 0.27% P for max. grain yield for 8 cvv over 3 years.
	Silking	Ear leaf	F			0.3					Nig	472	
	Silking	Ear leaf	F			0.23-0.25					USA	573	Critical range at 95% max. grain yield derived from 41 sites/year experiments. Ear leaf P conc. does not adequately assess excess P status.
	Silking	Ear leaf	F			0.27					Thai	713	Critical at 90% max. grain yield.
	Full tasselling	BOBC	D			0.25					Aust	1052	
	Full tasselling	BOBC	F,S,D				0.25				USA	604	Critical at 100% max. yield
	Silking	BOBC	F			0.28-0.32					USA	238	
	Silking	BOBC	F			0.28					USA	1025	Critical at 95% max. yield
	Silking	BOBC	F	<0.2			>0.29				USA	379	
	Silking	BOBC	F	0.22-0.32			0.27-0.62				USA	758	
	Silking	BOBC	F			0.18					Bra	935	Reviewer suggests critical at 90% max. yield is near 0.2% P.

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	Silking	2nd leaf below ear	F			0.23					USA	837	Critical is just adequate value for high yielding, irrigated corn.
	40-60 cm tall	Leaf opposite ear	Lit				0.25-0.5				Ger	82	
	Silking	6th LB above base	F			0.32					USA	1000	
	Silking	6th LB above base	F	<0.21	<0.3		>0.33				USA	81	
	36-48 DAS	Discs from leaf 4 or 5	RSC	A leaf acid phosphatase assay was shown to confirm acute P deficiency, but not moderate P stress.							USA	250	
	Mat	Grain	Soil			0.29					Pak	784	Critical at near max. grain yield.
	Mat	Grain	F			0.28					USA	837	Critical is just adequate value for high yielding, irrigated corn.
K(%)	≤30 cm tall	WS	Lit		<2.5		2.5-4.0	>4.0			USA	457 456	
	25 cm tall	WS	F			~2.6					USA	1031	Critical estimated by reviewer.
	V4 (28 DAE) V6 (42 DAE)	WS	F	0.91 1.08	2.18 1.49		2.57-3.06 1.75-2.08				USA	806	4 levels of K applied.
	30-45 DAE	WS	U				3.0-5.0				USA	536	
	76 cm tall	WS	F			~2.0					USA	1031	Critical estimated by reviewer.
	U	YEB	Soil			1.1-1.5					USA	721	Extracted K related to photosynthetic activity.
	40-60 cm tall	YMB	Lit				3.0-4.5				Ger	82	
	Pre-tasselling	YMB	F			1.6					USA	837	Critical is just adequate value for high yielding, irrigated corn.
	Full tasselling	Ear leaf	F,S,D			1.9					USA	604	
	Full tasselling	Ear leaf	F,S,D				1.75-2.25				USA	1020	
	Tasselling	Ear leaf	F				2.3-2.4				NZ	206	Crop did not respond to applied K.
	Tasselling	Ear leaf	F	<1.3	1.5-1.7	1.7-1.9 and 1.9-2.2		2.2-2.5		>2.5	Fra	546	Deficiency symptoms occur if K conc. <1.3%. K/Mg imbalance possible where K conc. >2.5%. First and second critical ranges are for average and high yield crops respectively.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Tasselling to initial silk	Ear leaf	F,D	<1.2	1.2-1.6		1.7-2.7	2.8-4.0		>4.0	Aust	1053	Toxic range is 'excessive'.
	Initial silk	Ear leaf	Lit	1.0-1.6			1.7-3.0	3.1-5.0			USA	457	
	Silking	Ear leaf	S,D	<1.25	1.26-1.7		1.71-2.25	2.26-2.5		>2.5	USA NZ	455 205	
	Silking	Ear leaf	F	0.95	1.21		1.37-1.46				USA	806	4 levels of applied K.
	Silking	Ear leaf	U				1.7-3.0				Ger	659	
	Silking	Ear leaf	F			2.44					Nig	14 456	Critical range defined as 2.06-2.6% K for max. grain yield for 8 cvv. over 3 years.
	Full tasselling	BOBC	D			1.8					Aust	1052	
	Silking	BOBC	F	1.5-2.7			2.1-3.0				USA	758	
	Silking	BOBC	F			1.5-1.9					USA	1025	
	Silking	BOBC	F	<1.0			>1.5				USA	379	
	FI	BOBC	F	0.43	0.51-0.82		1.01-1.37				S Afr	273	Ranges for 2 cvv. grown at 5 levels of K applied.
	Before tasselling	Leaf below whorl	Lit	<2.0			2.0-2.5	>2.5			USA	456 457	
	40-60 cm tall	Leaf opposite ear	Lit				2.0-3.5				Ger	82	
	Silking	2nd leaf below ear	F			1.5					USA	837	Critical is just adequate value for high yielding, irrigated corn.
	Silking	Leaves	F			1.5					USA	654	Critical judged to be near max. grain yield.
	Silking	6th LB above base	F			1.4					USA	1000	
	Silking	6th LB above base	F	<1.0							USA	437	
	Mat	Grain	F			0.36					USA	837	Critical is just adequate value for high yielding, irrigated corn.
S(%)	1 month	WS	Soil				0.16-0.26				USA	810	
	35 DAS	WS	Soil			0.08					USA	960	N/S ratio >16 for S deficiency.
	30-45 DAE	WS	U				0.2-0.3				USA	536	
	4-6 weeks	WS	SC	0.09	0.25		0.30				USA	303	3 levels of S applied.
	<30 cm tall	WS	Lit	<0.15			0.15-0.5	>0.5			USA	457	

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
S(%) (ctd)	V4-V7 growth stage	WS	F			0.21					USA	495	Critical N/S ratio was defined as 18.7 for 4 sites and 3 years.
	10 leaf stage (V10)	WS	F	0.12			0.15-0.19				USA	160	N/S ratios for S deficient and adequate plants were 27 and 16-20 respectively.
	Tasselling	Ear leaf	F				0.19-0.21				NZ	206	Crop did not respond to applied S.
	Tasselling - initial silk	Ear leaf	F,D	<0.12	0.12-0.16		0.2-0.5	0.6-0.8		>0.8	Aust	1053	Toxic range is 'excessive'
	Initial silk	Ear leaf	Lit		0.1-0.2		0.21-0.5	0.51-0.8			USA	457	
	Early silking (R1)	Ear leaf	F			0.16					USA	495	Critical N/S ratio was defined as 20.3 for 4 sites and 3 years.
	Early silking	Ear leaf	F	0.16		0.17	0.21-0.24				USA	160	N/S ratios for S deficient and adequate plants were 22 and 15-17 respectively.
	Silking	Ear leaf	F			0.24					USA	217	
	Silking	Ear leaf	F	0.08			0.16-0.22				Nig	695	N/S ratio for S deficient and S adequate plants ranged from 23-24 and 8-14 respectively.
	Silking	Ear leaf	F	A poor relationship existed between relative grain yield and S conc.							Thai	713	
	Full tasselling	BOBC	S,D			0.15					Aust	1052	
	Silking	BOBC	F	Data are reported indicating S concentrations and N/S ratios in BOBC at silking are poorly correlated with yield responses to applied S.							USA	671	
	Silking	BOBC	F			0.17					USA	811	Critical N/S ratio in BOBC was defined at 16 for 90% max. grain yield and was the preferred index of S status.
	Before tasselling	Leaf below whorl	Lit		<0.15		0.15-0.5	>0.5			USA	457	
	Mat	Grain	F	0.17			0.23				USA	160	N/S ratios for S deficient and S adequate plants were 11 and 8-9 respectively.
SO_4-S (mg/kg)	1 month	WS	Soil	<400							USA	810	
N/S	4-6 weeks	WS	SC	36	13		10				USA	303	3 levels of S applied.
	42-56 DAS	WS	Soil			10.2					USA	960	
	42-56 DAS	WS	Soil			16					USA	984	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Ca(%)	28 DAS	WS	Soil	0.25-0.5							Nig	664	
	30-45 DAE	WS	U				0.9-1.6				USA	536	
	<30 cm tall	WS	Lit	<0.3			0.3-0.7	>0.7			USA	457 456	
	25 DAS	YMB	RSC	0.09							USA	752	Value associated with severe symptoms.
	40-60 cm tall	YMB Leaf opposite ear	Lit				0.3-1.0 0.25-1.0				Ger	82	
	Full tasselling	Ear leaf	F,S,D			0.4					USA	604	
	Tasselling - initial silk	Ear leaf	F,D	<0.1	0.1-0.2		0.2-0.5	0.6-0.9		>0.9	Aust	1053	Toxic range is 'excessive'.
	Initial silk	Ear leaf	Lit	0.1-0.2			0.21-1.0	>1.0			USA	457	
	Silking	Ear leaf	F,S,D	<0.1	0.11-0.2		0.21-0.5	0.51-0.9		>0.9	CIAT USA Ger	196a 455 659	
	Full tasselling	BOBC	D			0.2					Aust	1052	
	Before tasselling	Leaf below whorl	Lit	<0.25			0.25-0.5	>0.5			USA	456 457	
Mg(%)	<30 cm tall	WS	Lit	<0.15			0.15-0.45	>0.45			USA	456 457	
	30-45 DAE	WS	U				0.3-0.8				USA	536	
	U	YEB	Soil			0.15					USA	721	Extracted Mg related to photosynthetic activity.
	40-60 cm tall	YMB	Lit				0.25-0.5				Ger	82	
	Tasselling - initial silk	Ear leaf	F,D	<0.12	0.12-0.15		0.16-0.6	0.61-0.85		>0.85	Aust	1053	Toxic range is 'excessive'.
	Tasselling	Ear leaf	F	<0.15	0.16-0.2		0.2-0.4	>0.4			Fra	546	If conc. <0.3% K deficiency may exist.
	Tasselling	Ear leaf	F				0.16-0.17				NZ	206	Crop did not respond to applied Mg.
	Full tasselling	Ear leaf	F,S,D			0.25					USA	604	
	Initial silk	Ear leaf	Lit	0.1-0.19			0.2-1.0	>1.0			USA	457	
	Silking	Ear leaf	F,S,D	<0.l	0.11-0.2		0.21-0.4	0.41-0.55		>0.55	USA	455	
	Silking	Ear leaf	S,D	<0.l	0.1-0.12		0.13-0.24	>0.24			NZ	205	
	Silking	Ear leaf	S,D				0.31-0.5				Ger	659	
	Silking	Ear leaf	F	0.18-0.21			0.21-0.25				Nig	480	

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mg(%) (ctd)	Silking	Ear leaf	F				0.1-0.54				USA	285	Range of values at 4 sites which did not respond to applied Mg.
	Silking	Ear leaf	F				0.12-0.19				USA	1040	For grain yields exceeding 18 t/ha. Optimum range stated as 0.12-0.15% Mg.
	Full tasselling	BOBC	D			0.15					Aust	1052	
	40-60 cm tall	Leaf opposite ear	Lit				0.2-0.5				Ger	82	
	Before tasselling	Leaf before whorl	Lit		<0.13		0.13-0.3	>0.3			USA	456 457	
Na(%)	8-26 DAS	WS	RSC	Salt tolerance in maize was not correlated with Na concentration in shoots.							USA	212	
	Tasselling - initial silk	Ear leaf	F,D				<0.3	0.4-0.5		>0.5	Aust	1053	Toxic range is 'excessive'.
Cl(%)	18 DAS 18 DAS 18 DAS	YMB Sheath YMB Midrib YMB	RSC				0.08 0.08 0.06			0.15-0.61 0.22-0.3 0.19-0.67	USA	128	Conc. expressed on fresh weight basis.
	Tasselling - initial silk	Ear leaf	F,D				<1.0	1.0-1.4		>1.8	Aust	1053	Toxic range is 'excessive'.
	Silking	Ear leaf	F			0.32					USA	386	Critical at 97% max. grain yield of high yielding crops.
	Full tasselling	BOBC	D							>2.0	Aust	1052	
Cu(mg/kg)	<30 cm tall	WS	Lit		<5.0		5-20	>20			USA	456 457	
	30-45 DAE	WS	U				7-20				USA	536	
	40-60 cm tall	YMB	Lit				7-15				Ger	82	
	Tasselling - initial silk	Ear leaf	F,D	<2		2-5	6-20	21-50		>50	Aust	1053	Toxic range is 'excessive'.
	Initial silk	Ear leaf	Lit		2-5		6-20	21-70			USA	457	
	Silking	Ear leaf	F	<2		3-5	6-20	20-50		>50	NZ USA	205 455	
	Silking	Ear leaf	F				8-20				Ger	659	
	Full tasselling	BOBC	F,S,D			5					USA	604	
	40-60 cm tall	Leaf opposite ear	Lit				6-12				Ger	82	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Before tasselling	Leaf below whorl	Lit	<3.0			3-15	>15			USA	456 457	
Zn(mg/kg)	<30 cm tall	WS	Lit	<20			20-60	>60			USA	456 457	
	≤30 cm tall (15 DAS) 40 DAS	WS	Soil			27 32					Pak	787	Criticals at max. shoot yield.
	18 DAE (4 leaf)	WS	Sand				34				USA	437	
	21-42 DAS	WS	F			16					USA	171	Critical at 90% max. grain yield (7 year experiment).
	28 DAE (6 leaf)	WS	Sand				25				USA	437	
	28 DAS	WS	F	13-18							USA	126	
	28 DAS	WS	Soil						460		USA	108	Critical at 80% max. yield
	30 DAS	WS	Soil		Authors question the diagnostic value of determining Zn in shoots.						Aust	366	Data for 23 diverse soils.
	30-45 DAE	WS	U				20-50				USA	536	
	39 DAE (8 leaf)	WS	Sand				27				USA	437	
	42 DAS 56 DAS 70 DAS	WS	Soil			16 11 9.5					Ind	921	Critical values at 90% max. shoot yield. YMB (3rd blade from culm apex) is recommended for diagnosing Zn deficiency.
	56 DAS	WS	Soil			14					USA	985	
	60 DAS	WS	Soil	18						81	Pak	972	
	5 Leaf stage 5 Leaf stage	WS	F			20 17					USA	282	Critical at 90% max. shoot yield. Critical at near max. grain yield.
	Ear stage	WS	Soil	7-10			11-98				Nig	905	Severely Zn deficient plants had Zn conc. of 21mg/kg.
	42 DAS 56 DAS 70 DAS	YMB (3rd blade)	Soil			14.2 12.5 12.0					Ind	920	Criticals at 90% max. shoot yield. C-shaped curvature existed in diagnostic relationships derived for WS and YMB+1 and YMB+2.
	42 DAS 56 & 70 DAS	YMB (3rd leaf blade)	Soil			16 15					Ind	921	Critical values at 90% max. shoot yield. YMB (3rd blade from culm apex) is recommended for diagnosing Zn deficiency.
	40-60 cm tall	YMB	Lit				30-70				Ger	82	
	20 DAE	Upper mature LB	F	<17							Aust	1055	

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Zn(mg/kg) (ctd)	Tasselling	Ear leaf	F			14					USA	171	Critical at 90% max. grain yield (7 year experiment).
	Tasselling	Ear leaf	F	<15	16-20	21-25	>25				Fra	546	
	Tasselling - initial silk	Ear leaf	F,D	<17	17-18		18-60	70-150		>150	Aust	1053	Toxic range is 'excessive'.
	Initial silk	Ear leaf	Lit	15-24			25-100	101-150			USA	457	
	Early silk	Ear leaf	F			13-15					USA	282	Critical at near max. grain yield.
	Silking	Ear leaf	F	23			28-51				Nig	479	
	Silking	Ear leaf	F				14+				USA	126	
	Silking	Ear leaf	F	<10	11-20		20-70	71-100		>100	USA NZ	455 205	
	Silking	Ear leaf	F				50-150				Ger	659	
	Full tasselling	BOBC	F,S,D			15					USA	604	
	Full tasselling	BOBC	F			15					Aust	1055	Critical at 95% max. yield
	50% silking	BOBC	F				11-30				Can	1067	Range of values in crops not responding to applied Zn.
	Silking	BOBC	F			15					USA	764	Critical at 90% max. yield
	40-60 cm tall	Leaf opposite ear	Lit				25-70				Ger	82	
	Before tasselling	Leaf below whorl	Lit	<15			15-60	>60			USA	456 457	
	28 DAS 35 DAS	Leaves	RSC	21 11	28 12		38-96 14-40				Ger	769	Carbonic anhydrase activity was a more sensitive test of Zn status than Zn conc. in shoots.
	Mid whorl	Leaf	F	6-8							Can	1067	
	56 DAS	Mature leaves	Soil			15					Zamb	44	
	30 DAE	Upper two mature LB	Soil	<10							Aust	520	
	Full tasselling	6th LB above base	F			15					USA	1020	
Mn(mg/kg)	Young plants	WS	S					350			Ger	1117	Critical for acidic soils pH<4.7.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	18-31 DAE	WS	FSC						200		Aust	242	Critical at 90% max. yield.
	30-45 DAE	WS	U				50-160				USA	536	
	<30 cm tall	WS	F,S,D				25-300				USA	456	
	<30 cm tall	WS	Lit		<20		20-300	>300			USA	457	
	6 leaf stage	WS	F	8-9	11-15						USA	1012	
	40-60 cm tall	YMB	Lit				40-100				Ger	82	
	Tasselling - initial silk	Ear leaf	F,D	<15	15-19		20-200	200-300		3000	Aust	1053	Symptoms shown in toxic range.
	Initial silk	Ear leaf	Lit	10-19			20-200	201-300			USA	457	
	Early silking	Ear leaf	F			11				USA	586		
	Early silking	Ear leaf	F			11					USA	1012	Critical at 90% max. grain yield.
	Silking	Ear leaf	F	<15	16-19		20-150	151-200		>200	USA NZ	455 205	
	Silking	Ear leaf	U				34-200				Ger	659	
	Tasselling	BOBC	D			15				3000	Aust	1052	
	Tasselling	BOBC	F,S,D			15					USA	604	
	40-60 cm tall	Leaf opposite ear	Lit				35-100				Ger	82	
	Before tasselling	Leaf below whorl	Lit		<15		15-300	>300			USA	457	
	Before tasselling	Leaf below whorl	F,S,D				20-300				USA	456	
	Mat	Grain	F			5					USA	53	Critical at 90% max. grain yield
	Mat	Grain	F			5					USA	1040	Critical at 90% max. grain yield.
Fe(mg/kg)	30-45 DAE	WS	U				50-300				USA	536	
	<30 cm tall	WS	Lit		<50		50-250	>250			USA	457 456	
	Tasselling - initial silk	Ear leaf	F,D		10-20		30-200				Aust	1053	Leaf Fe is not a reliable guide.
	Initial silk	Ear leaf	Lit		10-20		21-251	251-350			USA	457	
	Silking	Ear leaf	F,S,D	<10	10-20		21-251	251-350		>350	Ger USA	218 455	
	Tasselling	BOBC	F,S,D			25					USA	604	

CORN, MAIZE (*Zea mays*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Fe(mg/kg) (ctd)	Before tasselling	Leaf below whorl	Lit		<10		10-20	>20			USA	457	
	Before tasselling	LB below whorl	F,S,D				30-200				USA	456	
	U	Mature LB	U	24-100							USA	445	
Al(mg/kg)	<30 cm tall	WS	F,S,D				<400				USA	456	
	30-45 DAE	WS	U				<70				USA	536	
	Silking	Ear leaf	F,S,D				<200			>400	USA	455	
	Before tasselling	LB below whorl	F,S,D				<200				USA	456	
B(mg/kg)	21 DAS	WS	Sand	2.5			3.4-193			515	Zim	1015	Values in plants showing deficiency or toxicity symptoms.
	30-45 DAE	WS	U				7-25				USA	536	
	25 cm tall	WS	Soil				8-38			>98	Can	355	
	≤30 cm tall	WS	Lit		<5		5-25	>25			USA	456 457	
	Until ear formation	WS	U	<9			15-90			>100	Ger	659	
	Silking	WS	F		13-36		36-87			104	Ind	322	High values
	40-60 cm tall	YMB	Lit				7-15				Ger	82	
	Tasselling - initial silk	Ear leaf	F,D	<2		2-4	5-30	30-60		>60	Aust	1053	
	Initial silk	Ear leaf	Lit		2-4		5-25	26-60			USA	457	
	Silking	Ear leaf	F,S,D	<2		3-5	6-25	26-35		>35	USA	455	
	Silking	Ear leaf	F	<2		2-5	6-20	>20			NZ	205	
	Tasselling	BOBC	F,S,D			10					USA	604	
	40-60 cm tall	Leaf opposite ear	Lit				6-15				Ger	82	
	Before tasselling	Leaf below whorl	Lit		<4		4-25	>25			USA	456 457	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	Silking	Leaves Silk	Sand	6-11 1.2-2.4			18-64 4.0-8.3				Zim	1015	Deficiency ranges for plants which developed barren or distorted cobs.
	Mat	Grain	F	10-16			14-23			27	Ind	322	High values
Mo(mg/kg)	<30 cm tall	WS	Lit	<0.1			0.1-10	>10			USA	456 457	
	40-60 cm tall	YMB	Lit				0.2-0.5				Ger	82	
	Tasselling - initial silk	Ear leaf	F,D		0.1-0.2		0.2-0.3	>0.3			Aust	1053	
	Tasselling	Ear leaf	U				0.1-0.5				NZ	205	
	Initial silk	Ear leaf	Lit	0.1-0.2			>0.2				USA	457	
	Silking	Ear leaf	F	<0.l			>0.2				Ger	659	
	Tasselling	BOBC	F,S,D			0.2					USA	604	
	Before tasselling	Leaf below whorl	Lit	<0.1			0.1-3	>3			USA	456 457	
	40-60 cm tall	Leaf opposite ear	Lit				0.15-0.5				Ger	82	
	Mat	Grain	F	<0.08							Aust	1054	
	Mat	Grain	F			0.05					Zimb	983	Premature sprouting occurs if grain Mo <0.05 mg/kg.

COTTON (*Gossypium hirsutum*)

Growth stages of cotton are described in reference 251.

N(%)	55 DAS	WS	Soil	1.19-1.52			2.13-2.47				Aust	943	cv. Deltapine 61, grown in 2 soils.
	Veg to Fl	YMB	S,D	2.3-2.5	3.0-3.3		3.5-4.7	5.0-6.0			Aust	1053	
	1st square (42 DAP)	YMB	F			5.8					USA	1094	cv. Deltapine 50; critical conc. for max. economic yield.
	1st Fl (60 DAP)					5.4							
	Mid-bloom (100 DAP)					4.0							
	<1st Fl	YMB	S,D				3.75-4.5				USA	456	
	Fl	LB at 1st node of flowering branch	F			$N_c = (91.65 - 3.84/P - 1.32p)/14.55$					Fra	138	Function derived to calculate crit. N conc. includes leaf P conc. and leaf lamina size (p).

COTTON (*Gossypium hirsutum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%) (ctd)	Jul-Aug	LB	S	<2.5	2.5-3.0		3.0-4.5	>4.5			USA	319 863	
	45 DAS	LB at 3rd & 4th node below A	F				>5.0				PuRi	880	Tentative for max. seed yield
	38 DAS	YML	Soil			5.1 4.3 3.2					Aust	846	Crit. conc. at 350 µL CO_2/L Crit. conc. at 550 µL CO_2/L Crit. conc. at 900 µL CO_2/L
	Early Fl	YML	,			3.5-4.6					USA	204	Range of crit. concentrations at 6 sites; critical for seed cotton yield.
	Fl	YML	F,S			3.3					USA	460	
	Fl - boll development	YML	Lit				3.6-4.7					82	
	Fl-Fl + 8 weeks	YML	F				NIR Spectroscopy				USA/ Aust	139 383 385	
	45 DAS	Leaves	Soil		1.7-2.8 0.9-1.5	3.3 `	5.2 2.1				Aust	1092	Crit. conc. at 320 µLCO_2/L. Crit. conc. at 640 µL CO_2/L.
NO_3-N (mg/kg)	1st square (42 DAP) 1st Fl (60 DAP) Mid-bloom (100 DAP)	PYML	F			24000 12000 1500					USA	1094	cv. Deltapine 50; critical conc. for max. economic yield.
	Squares 1st Flower open 1st bolls full size Early bolls opening	PYML	F				>15000 >12000 >6000 >4000				USA	308	For max. seed yield (see also reference 43)
	20 days after squaring (750 day degrees)	PYML	F			21500					Aust	265	Range of PET_{750} values over 3 seasons corresponding to optimum fert. N status: 1.97-2.25% N.
	Early Fl	PYML	F			16000					USA	556	
	Early Fl	PYML	F				>8000				Sud	161	For max. seed yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	1st Fl Peak Fl 70 days after 1st Fl 1st bolls open	PYML	F		12000 3000 1500		18000 7000 >2000 3500				USA	58	
	Mid-Fl	PYML	F			8000					USA	556	Critical at 90% max. lint yield
	Peak Fl	PYML	F				6000-10000				USA	968	For max. lint yield
	Fl - 7 days Fl Fl + 7 days Fl + 14 days	PYML	F			11000 5000 3000 300					USA	483	1009 kg lint/ha taken as critical yield; petiole NO_3-N satisfactory yield predictor for 4 weeks only.
	Fl Fl + 2 weeks Fl + 4 weeks Fl + 6 weeks	PYML	F	<5000 <2400 <1000 260			5000-12500 2400-9600 1000-6700 260-4600	>12500 >9600 >6700 >4600			USA	550	Values relate to lint production.
	Until late Fl	PYML	F				>2000				USA	58 308 556	Considered 'safe' for max. seed or lint yield
	Late Fl	PYML	F			2000					USA	556	
	10 leaf	P	F								USA	997	Authors indicate petiole NO_3-N is unsatisfactory for dryland cotton.
	66 DAS 70 DAS 72 DAS 78 DAS 79 DAS 86 DAS 92 DAS 93 DAS 99 DAS 100 DAS	P	F			13000 4600 4200 1400 2700 1200, 1700 1100, 600 600 1000 800					USA	599	Mean values for 3 cvv. grown for 3 years; crit. conc. estimated by reviewer are predictive for seed cotton yield.
	90 DAS	P at 3rd & 4th node below A	F			300					USA	450	Critical expressed on fresh weight basis
P(%)	42 DAS	WS	Soil	0.13	0.19		0.30				Aust	394	cv. Deltapine 16
	Veg to Fl	YMB	S,D	0.13-0.15	0.21-0.23		0.25-0.50	0.55		0.91	Aust	1053	
	<1st Fl	YMB	S,D				0.3-0.5				USA	456	
	Early fruiting Late fruiting Late Mat	YMB	F			0.31 0.33 0.24					USA	576	

COTTON (*Gossypium hirsutum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	45 DAS	LB at 3rd & 4th node below A	F				>0.4				PuRi	880	Tentative for max. seed yield
	Jul-Aug	LB	S				0.3-0.65				USA	863	
	Fl	LB at 1st node of flowering branch	F				$P_c = 5.87/(1.45p + 12.44S - 7.11)$				Fra	138 139 385	Function derived for crit. P conc. includes leaf S conc. and leaf lamina size (p).
	38 DAS	YML	Soil			0.41 0.53 0.78					Aust	846	Crit. conc. at 350 µL CO_2/L Crit. conc. at 550 µL CO_2/L Crit. conc. at 900 µL CO_2/L
	Early Fl	YML	F			0.26-0.28					USA	204	Range of crit. conc. at 6 sites; critical for seed cotton yield.
	Fl	YML	F,S			0.25					USA	460	
	Fl - boll development	YML	Lit				0.30-0.50					82	
	23 DAT	Leaves	RSC				0.51-1.28			2.08-3.24	Ger	163	cv. Deltapine 15/21; Zn deficiency increased P conc. in leaves.
PO_4-P (mg/kg)	1st Fl Peak Fl 1st bolls open Mat	PYML	F		1500 1200 1000 800			2000 1500 1200 1000			USA	58	PO_4-P conc. should be maintained above 1000 mg/kg during fruiting.
	Fl Fl + 2 weeks Fl + 4 weeks Fl + 6 weeks	PYML	F	<1350 <600 <250 <70			1350-3100 600-2400 250-1700 70-1200	>3100 >2400 >1700 >1200			USA	550	Values relate to lint production.
	90 DAS	P at 3rd & 4th node below A	F			160					USA	450	Critical expressed on fresh weight basis after extraction in Na acetate.
K(%)	90 DAS 120 DAS	WS	F			2.75-3.25 2.0-2.75					USA	80	Criticals at max. yield
	<1st Fl	YMB	S,D				2.0-3.0				USA	456	
	Veg to Fl	YMB	S,D	<1.2	1.2-1.3		1.5-3.0				Aust	1053	
	Fl-Fl + 8 weeks	YMB + 3	S			1.5					USA	731	Crit. conc. is that which occurs in plants exhibiting visual K deficiency symptoms 95% of the time.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	45 DAS	LB at 3rd & 4th Node below A	F				>3.2				PuRi	879	Tentative for max. seed yield
	Jul-Aug	LB	S				0.9-1.95				USA	863	
	Fl	LB at 1st node of flowering branch	F			$K_c = 71.03/(3.11 + 2.99f + 2.25/S)$					Fra	138 139 385	Function derived for crit. K conc. includes leaf S conc. and number of branches flowering (f).
	120 DAS	Old LB+P	F			2.5					USA	80	Old LB+ P preferred to WS for sampling
	Early Fl	YML	F			0.90-1.24					USA	204	Range of crit. conc. at 5 sites; critical for seed cotton yield.
	Early Fl	YML	F		1.48-1.88		1.40-1.89				USA	800	cv. Deltapine 50; sub-soiling and K fertilization alleviate late season K deficiency.
	Fl	YML	F,S			1.5					USA	460	
	Fl	YML	F			1.84					Nig	539	Crit. for max. seed yield.
	Fl - boll development	YML	Lit				1.7-3.5				Ger	82	
	Fl Fl	Leaves	F		0.75-1.3 0.75-1.6	1.45 1.78					USA	176	cv. Acala GC510 } Crit. for max. cv. Acala SJ-2 } seed yield.
	1st Fl	PYML	F		4.0			5.5			USA	58	
	Fl	PYML	F		2.2		3				USA	364	cv. Acala SJ2; pooled data over 2 years; predictive values for seed cotton yield.
	50 DAS (Fl)	PYML	F	<2.84*	2.84-3.26	3.26	3.26-3.66				Ind	917	Crit. conc. relate to seed cotton yield. *Authors use >40% yield reduction from the maximum as 'extreme deficiency'.
	70 DAS (Peak Fl)	Lower LB		<0.35	0.35-0.69	0.69	0.69-1.00						
		PYML		<1.80	1.80-2.60	2.60	2.60-3.30						
		P of lower leaf		<0.22	0.22-0.90	0.90	0.90-1.60						
	90 DAS (Boll development)	YMB		<0.63	0.63-0.85	0.85	0.85-1.06						
		Lower LB		<0.42	0.42-0.53	0.53	0.53-0.63						
		P of lower leaf		<0.12	0.12-0.50	0.50	0.50-0.90						
	115 DAS (Boll opening)	YMB		<0.58	0.58-0.70	0.70	0.70-0.83						
		Lower LB		<0.53	0.53-0.68	0.68	0.68-0.83						
		PYML		<1.90	1.90-2.85	2.85	2.85-3.85						
	76 DAS	PYML	F	<3.2			4.9-6.2				USA	962	
	101 DAS			<2.7			4.6-6.0						
	120 DAS			<1.3			2.5-4.0						
	>120 DAS			<1.0									Symptoms observed
	90 DAS	P at 3rd & 4th node below A	F			0.7					USA	450	Critical expressed on fresh weight basis after extraction in Na acetate

COTTON (*Gossypium hirsutum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	70 days after 1st Fl	PYML	F		1.0			2.0			USA	58	
	Peak Fl				3.0			4.0					
	1st bolls open				2.0			3.0					
S(%)	Early bud (39 DAS)	WS	Soil			0.15					USA	655	Critical at 93% max. yield
	42 DAS	WS	Soil	0.08			0.35				Aust	394	cv. Deltapine 16
	60 DAS (early square)	WS	Soil	0.09-0.17		0.18	0.26-0.59				USA	561	20 cultivars; growth depressed at N/S ratio >13.0.
	Moderate S def. symptoms in So treatment	WS	SC				0.23-0.63				USA	303	Adequate protein N:S ratio = 8-9.
	Veg	YMB	S,D				0.25-0.8				USA	457	
	Mid season	YMB	F				0.59-0.99				USA	55	No response to applied S
	Fl	LB at 1st node of flowering branch	F			Sc = 6.58/(0.6 + 1.13/P + 1.24f)					Fra	138 139 385	Function derived for crit. S conc. includes leaf P conc. and number of branches flowering (f).
	Early Fl	LB from flower axis	F		0.25						C Af Rep	137	
	Mid-season	LB+P	F	0.2							USA	464	
	Fl	YML	F,S			0.20					USA	460	
	U	Leaves	F			0.40					Bra	571	
Ca(%)	42 DAS	WS	Soil	<0.52							USA	941	
	<1st Fl	YMB	S,D				2.25-3.0				USA	456	
	Veg to Fl	YMB	S,D				2.2-3.8	4.5-5.0			Aust	1053	
	Jul-Aug	LB	S				1.9-3.5				USA	863	
	Fl	YML	F,S			2.0					USA	460	
	Fl - boll development	YML	Lit				0.60-1.5				Ger	82	
Mg(%)	<1st Fl	YMB	S,D				0.5-0.9				USA	456	
	Veg to Fl	YMB	S,D		0.02-0.29		0.30-0.90	1.0-1.2		1.4-1.5	Aust	1053	'Toxic' conc. associated with low leaf K.
	Jul-Aug	LB	S				0.3-0.75				USA	863	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	34-105 DAS	All LB	Sand	<0.05	<0.2		0.65-0.8				USA	324	
	Fl	YML	F,S			0.30					USA	460	
	Fl - boll development	YML	Lit				0.35-0.80				Ger	82	
	34-105 DAS	All P	Sand	<0.l			0.4-0.69				USA	324	
Na(%)	Veg to Fl	YMB	S,D				0.02-0.35	0.4-0.5		0.6	Aust	1053	
	15 DAT	LB	SC					1.08-1.31		2.25-3.31	Isr	523	cv. SJ-1-171
Cl(%)	Veg to Fl	YMB	S,D				0.5-1.5	1.7-2.0		2.2-4.3	Aust	1053	Toxic conc. associated with toxicity symptoms.
	15 DAT	LB	SC					1.78-3.27		4.83-6.57	Isr	523	cv. SJ-1-172
Cu(mg/kg)	35 DAS	WS	Soil	6-7			13				USA	152	
	<1st Fl	YMB	S,D				5-25				USA	456	
	Veg to Fl	YMB	S,D		3-4		5-30				Aust	1053	
	49 DAS	All LB	RSC							>21	USA	946	Symptoms observed
	Fl	YML	F,S			4					USA	460	
	Fl - boll development	YML	Lit				8-20				Ger	82	
	35 DAT	Leaves	SC	4.4 (A)	1.6-1.8	1.6	2.5-10.3		8.5	55	USA	781	ELISA developed to detect phenolase. (A) C-shaped curve; RY of 21% only.
Zn(mg/kg)	19 DAT	WS	RSC	13			55				Ger	165	cv. Deltapine 15/21
	22 DAT	WS	RSC	11.1-16.1			31				Ger	580	cv. Deltapine 15/21
	23 DAT	WS	RSC	11.4-12.6			34-36				Ger	163	cv. Deltapine 15/21
	35 DAS	WS	Soil	16-17							USA	152	
	56 DAT	WS	Soil	8.7			15.9-47.5				Ind	904	Values are means of 5 cvv.
	37 DAS	YMB	RSC			11				200	USA	679	Critical at 90% max. yield
	43 DAS	YMB	RSC			13-14	17-48				USA	680	Critical at 90% max. yield
	<1st Fl	YMB	S,D				20-60				USA	456	
	Veg to Fl	YMB	S,D	7-13	16-20		25-60				Aust	1053	
	Jul-Aug	LB	S				20-100				USA	863	
	Fl	YML	F,S			15				850	USA	460	
	Fl - boll development	YML	Lit				25-80				Ger	82	

COTTON (*Gossypium hirsutum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Zn(mg/kg) (ctd)	23 DAT	Middle leaves	RSC	10.6-16.0			41-56				Ger	164	cv. Deltapine 15/22
Zn(mg/kg)*	24 DAT	Middle leaves	RSC	3.1-7.6			25-31				Ger	164	cv. Deltapine; * conc. of water-soluble Zn better correlated than total Zn with deficiency.
Mn(mg/kg)	18-31 DAS	WS	FSC						750		Aust	242	Toxic critical at 90% max. yield
	35 DAS	WS	Soil							494	USA	152	
	60 DAS	WS	Soil				128-337	409-573			USA	932	cv. Stoneville 213. High conc. in plants inoculated with *Glomus ambisporum* and grown at 24-36°C soil temperature.
	<1st Fl	YMB	S,D				50-350				USA	456	
	36 DAS	YMB	RSC	2-8		10	11-247				USA	677 690	Critical at 90% max. yield
	Veg to Fl	YMB	S,D	8	15-20		25-500	1000-2000		4000	Aust	1053	
	Jul-Aug	LB	S				30-300				USA	863	
	34-105 DAS	All LB	Sand	<10	15						USA	324	
	Fl	YML	F,S			25		400			USA	460	
	Fl - boll development	YML	Lit				35-100				Ger	82	
	33 DAS	3 YML	Soil				49-57	415-782		568-689	USA	291	Data for 11 cotton genotypes.
	18 DAS	YL YL	SC				55 45	620	230 1460	962-3300 1580-2660	USA	292	cv. 517 cv. 307
	21 DAT	Youngest 3 leaves (width >1 cm)	RSC				200-270			4030-10570	USA	487	3 cultivars; peroxidase activity in leaves separated Mn toxic from adequate.
	Var	Partly expanded leaves	Sand			Polyphenol oxidase enzyme assay					Ind	928	
Fe(mg/kg)	35 DAS	WS	Soil	<47							USA	152	
	<1st Fl	YMB	S,D				50-250				USA	456	
	2 months 2 months	Young LB Old LB	SC		85-112 57-88						Gre	1027	
	Jul-Aug	LB	S				30-300				USA	863	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Fl	YML	F,S			40					USA	460	
Al(mg/kg)	35 DAS	WS	Soil							169	USA	152	
	42 DAS	WS	Soil							>200	USA	941	
	<1st Fl	YMB	S,D				<200				USA	456	
B(mg/kg)	63 DAT	WS	SC	15-31	27-85	80	146		160	165-1970	USA	676	Tentative crit. conc.
	40 DAT	YMB	SC	30	45-55	61	75		80	85-145	Ger	245	cv. Etawa
	<1st Fl	YMB	S,D				20-60				USA	456	
	Veg to Fl	YMB	S,D	<16	16-19		20-100	120-250			Aust	1053	
	41 DAS	YMB + 3	F				43-46				USA	389	Mean of 3 genotypes } conc.
	60 DAS	YMB + 3					34-39						Mean of 2 cvv. } adequate for
	102 DAS	YMB + 3					54-73						Mean of 2 cvv. } lint yield.
	U	3rd & 4th LB below A	F	<10		15					USA	638	
	Early boll	4th LB below A	F	<13							USA	611	
	Early boll	P		<10									
	Fl	YML	F,S			20		150			USA	460	
	Fl - boll development	YML	Lit				20-80				Ger	82	
Mo(mg/kg)	U	WS	SC	0.07			1.2				USA	729	
	5 months	LB	SC	1.1	1.5-1.9		2.4				Gre	466	
	Fl	YML	F,S			0.5					USA	460	
	Fl - boll development	YML	Lit				0.60-2.00				Ger	82	
	U	Leaves	Sand	0.22			0.75				USA	729	
As(mg/kg)	42 DAS	WS	Soil				0.25-2.9		3.8	6.0-12.3	USA	230	Critical conc. for 90% max. yield; data for 2 soils.

COWPEA (*Vigna unguiculata*)

N(%)	25-33 DAT	WS	SC	1.18-1.68			2.85-3.46				Aust	75	Data for 4 cvv.
	39 DAS	WS	Soil	2.4			2.76				Nig	469	
	Pre-Fl	YMB	S,D	2.0-2.4	2.6-3.2		3.6-4.6				Aust	1053	
	Early Fl	PYML	F				1.1-1.7				SiLe	825	

COWPEA (*Vigna unguiculata*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%)	28 DAT	WS	Sand		0.14		0.72				Ven	276	cv. Tuy
	25-33 DAT	WS	SC				0.36			0.76-1.17	Aust	75	cv. Vita 4
	40 DAS	WS	Soil			0.96			1.23		Ind	1100	cv. HFC-42-1
	40 DAS					0.95			1.24				cv. HFC-42-1; seed yield (predictive).
	30 cm tall	WS	F	0.28			0.27-0.35				USA	332	
	Early Fl	WS	Soil	0.15-0.18		0.25	0.26				Aust	433	cv. Vita 4
	Early Fl	WS	F	0.19-0.24			0.23-0.3				USA	332	
	52 DAS	WS	Soil	0.049-0.058	0.062		0.063-0.064				USA	36	Deficient plants grown in an eroded soil.
	56 DAS	WS	Soil				0.28				Iran	476	
	84 DAS (Early podding)	WS	Sand	0.081 - 0.097			0.149				Neth	1041	cv. Kausband
	Pre-Fl	YMB	S,D	0.14-0.20	0.22		0.28-0.48				Aust	1053	
	50 DAS (Fl)	YMB	F		0.22-0.33	0.34	0.40-0.44				Colo	593	Cowpea intercropped with cassava; conc. predictive for seed yield.
	14 DAS	YML	Soil	0.16			0.70				Aust	434	cv. Vita 4
	21 DAS			0.11			0.62						
	28 DAS			0.14			0.40						
	35 DAS			0.12			0.31						
	42 DAS			0.12			0.36						
	14 DAS	YML	Soil	0.15-0.22		0.43	0.43-0.59				Aust	433	cv. Vita 4
	24 DAS					0.49	0.48-0.53						
	34 DAS			0.18-0.21		0.42	0.31-0.51						
	44 DAS (Early Fl)					0.27	0.29-0.51						
	55 DAS					0.24	0.23-0.33						
	21 DAS	YML	F		0.19	0.35	0.44-0.55				Aust	433	cv. Vita 4
	28 DAS				0.17	0.34	0.35					435	
	42 DAS				0.22	0.35	0.37-0.39						
	49 DAS				0.27	0.35	0.36-0.38						
	56 DAS				0.23	0.36	0.39-0.41						
	24 DAS	YML	Soil			0.39-0.45					Aust	433	cv. Vita 4; range of critical P conc. in 3 soils.
	32 DAS					0.36-0.43							
	40 DAS					0.31-0.41							
	48 DAS					0.31-0.38							

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	24 DAS	YML+1	Soil			0.33					Aust	433	cv. Vita 4
	34 DAS					0.31							
	44 DAS (Early Fl)					0.25							
	55 DAS					0.16							
	31 DAS	YML	Soil	0.20						1.0	Aust	433	cv. Vita 4; deficient plants top-dressed with 230 kgP/ha at 28 DAS, become toxic.
	Early Fl	YML	Soil	0.19-0.21		0.30	0.34				Aust	433	cv. Vita 4
	Mid-Fl	YML	F		0.07-0.18	0.18	0.19-0.39				Bra	935	cv. IPEAN V-69; data based on 4 crops; L-P model used to establish crit. conc.
	Early Fl	PYML	F				0.12-0.4				SiLe	825	
	28 DAT	YL	Sand		0.52		1.04				Ven	276	cv. Tuy
		Mature leaves			0.08		0.61						
	60 DAS	Leaves	Soil		0.10-0.22		0.18-0.24				USA	508	cv. California Blackeye 5; grown in well-watered conditions +,- mycorrhizal inoculation.
		Pods			0.19-0.23		0.24-0.27						
	60 DAS	Leaves	Soil	0.09-0.17		0.15-0.18					USA	508	cv. California Blackeye 5; grown in dry conditions +,- mycorrhizal inoculation.
		Pods		0.16-0.25		0.24-0.27							
	Mat	Seed	F		0.29-0.32	0.35	0.38-0.44				Peru	326	
P(µmol/g FW)	16 DAT	WS	FSC			16					Aust	279	cv. Vita 4; corresponds to critical soln conc. of 0.8 µM.
K(%)	Pre-Fl	YMB	S,D	0.5-0.9	1.1-1.2		1.7-3.0				Aust	1053	
	30 DAS	All leaves	Sand		2.89-3.31	3.85	4.29-5.11				Ind	651	cv. Co-FOS-1
	Early Fl	PYML	F				4.9-6.6				SiLe	825	
S(%)	U	WS	SC	0.16	0.26		0.29				USA	303	Adequate protein N:S ratio = 15. Moderate S def. symptoms in So treatment.
	7 DAS	WS	Soil			0.5-0.56					Nig	290	Critical at 95% max. vegetative yield for three cultivars which differ in S requirement.
	14 DAS					0.36-0.56							
	21 DAS	YMB				0.35-0.57							
	Early Fl (42 DAS)					0.35-0.6							
	Early Fl (42 DAS)					0.32-0.65							Critical at 95% max. grain yield.
	Mat (62-90 DAS)	All LB	Soil			0.27-0.6					Nig	290	Critical at 95% max. vegetative yield for three cultivars which differ in S requirement.
	Mat	Seed	Soil			0.26					Nig	290	Critical at 95% max. grain yield.

COWPEA (*Vigna unguiculata*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Ca(%)	39 DAS	WS	Soil	0.3			0.9				Nig	469	
	20 DAT	YMB	FSC	0.16 0.11	0.99-1.31 1.25	1.75 1.9	2.35-3.40 2.76-4.24				Aust	74	cv. Vita 4 } tentative crit. cv. CPI 28215 } conc. only.
	Mid-Fl	YML	F		1.18-2.07		1.97-2.07				Bra	936	Mean conc. for 2 cvv.
	Early Fl	PYML	F				0.72-1.0				SiLe	825	
	14 DAT	Expanding leaves	RSC	0.07			0.35-0.51 0.09-0.48	2.64 1.97			Ger	416	cv. Solojo cv. TVu354
Mg(%)	33 DAS	WS	Soil		0.3	0.31	0.33-0.51		0.82	0.89-1.43	Bra	265	Reason for yield depression at high Mg supply not known.
	Pre-Fl	YMB	S,D				0.35-1.0	1.3			Aust	1053	'High' conc. an imbalance associated with low leaf K.
	Early Fl	PYML	F				0.17-0.31				SiLe	825	
	30 DAS	All leaves	Sand		0.11	0.35	0.45-0.67				Ind	651	cv. Co-FOS-2
Na(%)	Pre-Fl	YMB	S,D				0.01-0.03				Aust	1053	
Cl(%)	Pre-Fl	YMB	S,D				0.7-1.6	1.9			Aust	1053	
Cu(mg/kg)	Pre-Fl	YMB	S,D				8-20				Aust	1053	
Zn(mg/kg)	40 DAS 40 DAS	WS	Soil			56 50			74		Ind		cv. HFC-42-1 cv. HFC-42-1; seed yield (predictive).
	Pre-Fl	YMB	S,D				22-70				Aust	1053	
	42 DAS	LB	Soil	18-24			27-32			34-36?	Ind	325	Four cultivars compared
	40 DAS 40 DAS	Upper blades Upper petioles	Sand	5-17		20 12.5	50 - 290		273 145		USA	581	cv. California Blackeye 5
	40 DAS 40 DAS	Lower blades Lower petioles	Sand	10-37		50 30	150 - 435		440 300		USA	581	cv. California Blackeye 6
	Early Fl	YML	Soil			21					USA	786	cv. California Blackeye 5; critical conc. for 95% max. seed yield.
	Mat	Seed	Soil		16-30	36	39-54				USA	786	cv. California Blackeye 5; critical conc. for 95% max. seed yield.
	Mat	Seed Straw	Soil	14-20 12-15	22-24	25 13	30-45 17-21	29-125			Nig	905	cv. FS68 cv. FS68; slight Piper-Steenbjerg curvature.
Mn(mg/kg)	18-31 DAS	WS	FSC						720		Aust	242	Toxic critical at 90% max. yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	25 DAS	WS	SC			280					USA	471	One cultivar examined; critical at 50% max. yield
	25-33 DAT	WS	SC				79-299	536-715			Aust	75	Data for 2 cvv.
	28 DAS	WS	Soil				385 - 525		620	1350-5140	USA	1017	Linear decline in RY with increase in Mn conc. in WS.
	35 DAS	WS	F				<1000			>2000	USA	471	43 cultivars examined; toxic criterion at 50% max. yield
	Pre-Fl	YMB	S,D				70-300	350-600			Aust	1053	
	20 DAT	YMB	SC				68	371			Ger	1088	cv. TVu91, sensitive to Mn toxicity; symptoms in old leaves only.
	20 DAT	Old LB					183			310			
	20 DAT	YMB	SC					55	324		Ger	1088	cv. TVu 1987, tolerant to Mn toxicity; no symptoms.
	20 DAT	Old LB						158	296				
	45 DAS	Old LB	Sand							>2000	Ger	415	29 cultivars examined
	Var (Veg)	LB	SC			Callose fluorescence with aniline blue					Ger	1087	More sensitive indicator of Mn toxicity than leaf conc.
	18 DAT	YML	FSC						1220		Aust	33	cv. CPI 28215
	18 DAT								430				cv. Ife Brown
	22 DAT	YML	SC						310		Aust	33	cv. CPI 28215 } N_2-fixing
	22 DAT								224				cv. Ife Brown } plants
Fe(mg/kg)	56 DAS	WS	Soil	<70			>100				Iran	476	
B(mg/kg)	48 DAS	ML	Sand				83 - 186		280	336-1065	USA	294	cv. California Blackeye 5; critical at 90% max. yield.
	48 DAS	ML	Sand				85 - 181		270	284-1086	USA	1017	cv. California Blackeye 77; critical at 90% max. yield.
Ni(mg/kg)	42 DAS	WS	SC	0.01-0.11			0.22-2.83				USA/	1028	cv. Vita 5; urea accumulated in necrotic leaf tips of Ni-deficient plants.
	92 DAS			0.11-0.83			2.48-10.3				Aust		
	101 DAS	Mat leaves	SC	0.142				3.59			USA/	1028	
	101 DAS	Mat seed		<0.010				0.514			Aust		

FABA or FIELD BEAN (*Vicia faba*)

N(%)	Fl	WS	F				≥4.2				UK	945	Diagnostic for shoot DM yield cvv. Minor and Mavis Bead
	Onset of Fl	YML	Lit				2.8-3.5				Ger	82	
	Early Fl	YML	Lit	1.6-2.5	3.6		4.3-5.0				Aust	1053	

FABA or FIELD BEAN (*Vicia faba*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N(%) (ctd)	Fl	LB 3rd from A	F				4.8-5.3				Can	95	Fertilizers did not increase yield
	Fl	L	Lit	3			5				USA	881	Unknown criteria for critical level
	Mat	Seed	F	≥4.9							UK	945	Diagnostic for seed yield cvv. Minor and Mavis Bead
P(%)	U	WS	Lit	0.11			0.31			1.90	Aust	939	Adequate plants no symptoms
	Early Fl	YML	Lit	0.16	0.19-0.24		0.30-0.55	0.82			Aust	1053	
	Onset of Fl	YML	Lit				0.25-0.45				Ger	82	
	U	L	Lit	<0.2			0.2-0.4				USA	881	Unknown criteria for critical level
	10% Fl	Upper ML											
	Fl	LB 3rd from A	F				0.32-0.41				Can	95	Fertilizers did not increase yield
	Pre Fl	YOL	F			0.51					Aust	529	Diagnostic for vegetative yield
		WS				0.40							
	Initial Fl	YOL				0.43							
		WS				0.38							
	Full Fl	YOL				0.39							
		WS				0.31							
	End of Fl	WS				0.29							
	Pre Fl	YOL	F			0.4					Aust	529	Predictive for seed yield
		WS				0.4							
	Initial Fl	YOL				0.41							
		WS				0.39							
	Full Fl	YOL				0.41							
		WS				0.3							
	End of Fl	YOL				0.41							
		WS				0.27							
	Mat	Seed				0.36							Diagnostic for seed yield
K(%)	Early Fl	YML	Lit	1.7	1.8-2.0		2.2-4.0				Aust	1053	
	Onset of Fl	YML	Lit				2.1-2.8				Ger	82	
	7th leaf stage	2-4 leaf	Soil			0.15					Can	425	Apparently diagnostic for shoot yield; % of max. yield unknown; Water extractable K.
	Fl	LB 3rd from A	F				2.2-3.2				Can	95	Fertilisers did not increase yield
	Fl	L	Lit	<2			2				USA	881	Unknown criteria for critical level
S(%)	U	WS	Lit	0.07			0.25				Aust	939	Adequate plants no symptoms

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	7^{th} leaf stage	2-4 leaf	Soil			0.038					Can	425	Apparently diagnostic for shoot yield; % of max. yield unknown; Water extractable S.
	47 DAS	L	Soil			0.31					Ger	9	Diagnostic for shoot FW and DW
	U	L	Lit			0.2-0.25					USA	881	Unknown criteria for critical level
	7^{th} leaf Early Fl	ML	Soil			0.038 0.057					Can	424	Diagnostic for shoot DW; SO_4-S measured; Predictive for seed yield; Poor plateau definition
Ca(%)	Onset of Fl	YML	Lit				0.5-2.0				Ger	82	
	Early Fl	YML	Lit				0.6-1.2				Aust	1053	
	U	L	Lit			1.44	2				USA	881	Unknown criteria for critical level
Mg(%)	U	WS	Lit	0.03			0.29				Aust	939	Adequate plants no symptoms
	Early Fl	YML	Lit				0.24-0.50				Aust	1053	
	Onset of Fl	YML	Lit				0.25-0.7				Ger	82	
Na(%)	28-56 DAS	WS	Sand				<0.23			>0.69	UK	1109	
	Early Fl	YML	Lit				0.02-0.40	0.7		2.2	Aust	1053	
Cl(%)	28-56 DAS	WS	Sand				<0.35			>3.2	UK	1109	
	Early Fl	YML	Lit				<0.8	0.9-1.2			Aust	1053	
Cu(mg/kg)	U	YL	Lit	1.4			7.3				Aust	939	Adequate plants no symptoms
	Early Fl	YML	Lit				5-25				Aust	1053	
	Onset of Fl	YML	Lit				7-15				Ger	82	
	U	Upper L	Lit				15-25				USA	881	Unknown criteria for critical level
Zn(mg/kg)	Onset of Fl	YML	Lit				30-70				Ger	82	
	Early Fl	YML	Lit				28-140				Aust	1053	
	U	L	Lit			15-20	42-50			120-140	USA	881	Unknown criteria for critical level
	Initial Fl Full Fl End of Fl	WS WS WS	F, Soil			26 18 23					Aust	529	Predictive for seed yield
	End of Fl End of Fl	YOL WS	F, Soil			29 25					Aust	529	Diagnostic for vegetative yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
FABA or FIELD BEAN (*Vicia faba*) (ctd)													
Zn(mg/kg) (ctd)	Full Fl	YOL	F, Soil			20					Aust	529	Predictive for seed yield
	End of Fl	YOL				24							
	Initial Fl	YOL				19							
	Full Fl	YOL				24							
	End of Fl	YOL				24							
	Mat	Seed				14							
Mn(mg/kg)	U	YL	Lit	3.3			55				Aust	939	Adequate plants no symptoms
		WS					109			1083			
	Onset of Fl	YML	Lit				40-100				Ger	82	
	Early Fl	YML	Lit				50-300	600-900		1000-2020	Aust	1053	
Fe(mg/kg)	U	YL	Lit	20			103				Aust	939	Adequate plants no symptoms
	U	L	Lit				100-800				USA	881	Unknown criteria for critical level
B(mg/kg)	U	WS	Lit		5-50		30			312	Aust	939	Adequate plants no symptoms
	Onset of Fl	YML	Lit				40-80				Ger	82	
	U	L	Lit			20-25			300		USA	881	Unknown criteria for critical level
Mo(mg/kg)	Onset of Fl	YML	Lit				0.4-1.0				Ger	82	
	Early Fl	YML	Lit		0.19		0.4-5.5				Aust	1053	
FIELD PEA, ENGLISH PEA (*Pisum sativum*)													
N(%)	14 DAS	WS	SC			3.5					Can	1047	
	21 DAS					3.3							
	Onset of Fl	YML	Lit				3-4				Ger	82	
	Pre-Fl	YML	Lit	1.4-2.8	3.2-3.4		4.0-5.5	5.8			Aust	1053	
	8-9 nodes	LB 3rd node from A	F				4.4-5.8				Can	95	Fertilizers did not increase yield
	1st bloom	YML	Lit	3.80-3.90			4.00-6.0	>6.0			USA	457	
	4-8th node	3rd leaf from top	Lit	2.4			4.4-4.6				USA	633	
	28 DAS	Whole plant	SC	<4.8			>3.2				Can	1048	Diagnostic for max. plant DW
						4.3							Diagnostic for max. shoot DW
				<4.8			>3.2						Diagnostic for max. root DW

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
P(%)	36 DAS 51 DAS 66 DAS 81 DAS 96 DAS Pre-Fl	WS	F	<0.6 <0.53 <0.46 <0.4 <0.43			>0.92 >0.71 >0.64 >0.55 >0.6 0.16				Ind	261	
	U	WS	Lit	0.10-0.12			0.29-0.33			2.1	Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
	Onset of Fl	YML	Lit				0.25-0.5				Ger	82	
	Pre-Fl	YML	Lit	0.18	0.24-0.27		0.30-0.55	0.65-0.85			Aust	1053	
	Fl PF	YML Immature seeds	F			0.32 0.38					USA	723	Predictive for fresh immature seed yield Diagnostic for fresh immature seed yield
	8-9 nodes	LB 3rd node from A	F				0.36-0.51				Can	95	Fertilizers did not increase yield
	1st bloom	Recent fully developed leaflets	Lit	0.25-0.29			0.30-0.8	>0.8			USA	457	
	Mat	Seed	Sand	0.38-0.51			0.55-0.95				UK	157	
	4-8th node	3rd leaf from top	Lit	0.1			0.4				USA	633	
K(%)	Pre-Fl	YML	Lit	<1.5	1.6-1.8		2.0-3.4				Aust	1053	
	Onset of Fl	YML	Lit				2.2-3.5				Ger	82	
	1st bloom	Recent fully developed leaflets	Lit	1.80-1.90			2.00-3.5	>3.5			USA	457	
	8-9 nodes	LB 3rd node from A	F				2.1-2.7				Can	95	Fertilizers did not increase yield
	8 nodes (Pre-Fl)	LB 3rd node from A	F	<0.8	0.8-1.3		1.3-2.0	>2.0			USA	998	
	Full Fl	LB 3rd node from A	F	<0.7	0.7-1.1		1.1-1.5	> 1.5			USA	998	
	4-8th node	3rd leaf from top	Lit	0.3-1.5			2.3-2.6				USA	633	
K(mmol/kg)	35 DAT	Fruit S Root Yellow L Green L	SC	≤1.14 ≤1.15 ≤1.38 ≤1.01 ≤1.38							Swe	2	Diagnostic for max. root and shoot DW *Pisum arvense*

FIELD PEA, ENGLISH PEA (*Pisum sativum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%)	36 DAS	WS	Sand			0.13					Aust	746	cv. Dun
	61 DAS (budding)	WS	Sand			0.17					Aust	746	cv. Dun
	U	WS	Lit	0.07-0.08			0.24-0.30				Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
	Mat	WS Seed	F				≥0.3 ≥0.4				Ind	993	No plateau in DM or seed yield achieved
	36 DAS	YMB Top half of shoot	Sand			0.22 0.15					Aust	746	cv. Dun
	61 DAS (budding)	YMB Top half of shoot	Sand			0.29 0.18					Aust	746	cv. Dun
	Pre-Fl	YML	Lit				0.20-0.40				Aust	1053	
	4-8th node	3rd leaf from top	Lit	0.3			0.6				USA	633	
SO_4-S (mg/kg)	16 nodes	WS	F			200-600					USA	809	Critical at max. yield
Ca(%)	1st bloom	YML	Lit	1.00-1.10			1.20-2.0	>2.0			USA	457	
	Pre-Fl	YML	Lit		0.7		0.9-2.0				Aust	1053	
	Onset of Fl	YML	Lit				0.5-2.0				Ger	82	
	4-8th node	3rd leaf from top	Lit	0.7			1.0-2.8				USA	633	
Mg(%)	U	WS	Lit	0.03			0.19				Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
	Onset of Fl	YML	Lit				0.25-0.6				Ger	82	
	Pre-Fl	YML	Lit	<0.16	0.16-0.20		0.20-0.55	>0.7			Aust	1053	
	1st bloom	YML	Lit	0.22-0.29			0.30-0.7	>0.7			USA	457	
	4-8th node	3rd leaf from top	Lit	0.1			0.3-0.5				USA	633	
Na(%)	Pre-Fl	YML	Lit				<0.3	>0.4			Aust	1053	
Cl(%)	Pre-Fl	YML	Lit				<1.6	1.8-2.0		>2.0	Aust	1053	
Cu(mg/kg)	35 DAT	L	SC	<6.9			>3.8				Ger	35	
	U	YL	Lit	0.7-0.9			5.9-7.8				Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
	Pre-Fl	YML	Lit		4		6-25				Aust	1053	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Onset of Fl	YML	Lit				7-15				Ger	82	
	1st bloom	YML	Lit	4-6			7-25	>25			USA	457	
Zn(mg/kg)	Bud	WS	Soil							420-490	USA	108	Toxic critical at 80-90% max. yield
	Budding	WS	Soil						380-500			558	
	45 DAS	WS	F				>32				Ind	992	Predictive for seed yield and shoot DW at maturity
	Mat	Straw					>34						Diagnostic for seed yield and shoot DW at maturity
	Mat	Seed					>25						
	Onset of Fl	YML	Lit				25-70				Ger	82	
	Pre-Fl	YML	Lit	<16	16-19		24-100	>100			Aust	1053	
	1st bloom	YML	Lit	20-24			25-100	>100			USA	457	
	4-8th node	3rd leaf from top	Lit	20			33				USA	633	
Mn(mg/kg)	U	YL	Lit	4.2			60-65				Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
		WS					85			1743-2988			
	Onset of Fl	YML	Lit				30-100				Ger	82	
	Pre-Fl	YML	Lit		15		30-400	500-800		>1000	Aust	1053	
	1st bloom	YML	Lit	25-29			30-400	>400			USA	457	
	U	LB	F	6-13			30-60				UK	60	
	Var	LB+P of mid-stem	F	<8	8-10		>10				UK	661	
	4-8th node	3rd leaf from top	Lit	<15			75				USA	633	
	Mat	Seed	S	3-4			>9				UK	331	
Fe(mg/kg)	21 DAT	L	SC	<11			>5.4				Fra	1	Conc. on FW basis; Levels determined from leaf symptoms
	24 DAT	Stem	SC	<39			>21				Aust	1065	Criteria based on symptoms
		LP1		<73			>65						
		LP2		<74			>66						
		LP3		<87			>63						
		LP4		<102			>60						
		LP5		<94			>65						
		LP6		<80			>47						
		New growth		<82			>45						
	4-8th node	3rd leaf from top	Lit	<50			110-117				USA	633	

FIELD PEA, ENGLISH PEA (*Pisum sativum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Fe (mg/kg) (ctd)	U	YL	Lit	20-23			73-81				Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
	1st bloom	YML	Lit	40-49			50-300	>300			USA	457	
B(mg/kg)	35 DAS	WS	SC						330	>300	Aust	717	cv. Alma cv. Pennant Diagnostic for shoot, root or total DW
	Fl	WS	F			50			95	≥100	Ind	239	Predictive for fresh pod yield
	U	YL WS	Lit	1.6-3.6			17-19 17-20			566-915	Aust	939	cvv. Wirrega and Dinkum; Adequate plants no symptoms
	35 DAS	Roots	SC						70	>40	Aust	717	cv. Alma cv. Pennant Diagnostic for shoot, root or total DW
	28-30 DAS	YFEB	RSC						36		Aust	186	cv. Bonzer
	Pre-Fl	YML	Lit		<20		25-60				Aust	1053	
	Onset of Fl	YML	Lit				30-70				Ger	82	
	1st bloom	YML	Lit	20-24			25-60	>60			USA	457	
	4-8th node	3rd leaf from top	Lit	<5			20				USA	633	
	Fl	Bottom LB	RSC				50-300			>450	Spa	878	
	Mat	Seed	SC	3-5			11-13				USA	1096	
Mo(mg/kg)	16 nodes	WS	F				0.3-1.0				USA	809	
	56 DAS	WS	Soil	0.11-0.20			0.20-0.60				Bulg	323	
	Onset of Fl	YML	Lit				0.4-1.0				Ger	82	
	Pre-Fl	YML	Lit				0.3-1.0				Aust	1053	
	1st bloom	YML	Lit	0.4-0.6			>0.6				USA	457	
	4-8th node	3rd leaf from top	Lit				0.05				USA	633	
Cd(mg/kg)	28 DAS	WS							5 4 5		Spa	390	Diagnostic for shoot FW Diagnostic for nodules/plant Diagnostic for nodules/g root

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	28 DAS	Roots							60 250 40 60		Spa	390	Diagnostic for shoot FW Diagnostic for root FW Diagnostic for nodules/plant Diagnostic for nodules/g root
	35 DAS	Root S L	Sand						30 14 4		Italy	528	Diagnostic for root DW
	35 DAS	Root S L	Sand						70 22 13		Italy	528	Diagnostic for leaf DW
		WS	SC						10		UK	558	
Tl(mg/kg)	Veg	Roots S L	SC						8 20 15		Ger	756 735	Tl as EDTA salt
	Veg	Roots S L	SC						 62	>80 >120	Ger	756 735	Tl as nitrate salt
Be(mg/kg)	28 DAS	WS	SC						15		UK	558	
Se(mg/kg)	45 DAS	WS	Soil						3		UK	558	
V(mg/kg)		L	SC						1-2		UK	558	

GINGER (*Zingiber officinale*)

N(%)	180 DAS 194 DAS 208 DAS 222 DAS 251 DAS	3rd LB below A	F			3.23 3.29 3.07 2.61 2.23					Aust	519	Critical at 90% max. rhizome yield
	6.5 months (mid-Feb)	3rd LB below A	F			3.7			* 4.6		Aust	31	Critical at max. rhizome yield. *Toxic leaf symptoms and reduced rhizome yield if N applied to plants having 4.1 and 4.3%N respectively
	7 months (March) 7.5 months (mid-March)	3rd LB below A	F			3.5 3.3					Aust	31	Critical at max. rhizome yield
P(%)	2-3 months 2-3 months	Upper LB Lower LB	SC	0.13-0.14 0.13-0.15			0.24-0.33 0.3-0.35			0.69-1.4 0.83-1.6	Aust	31	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
GINGER (*Zingiber officinale*) (ctd)													
K(%)	2-3 months	Upper LB	SC	0.9-1.1			3.9-5.7				Aust	31	
	2-3 months	Lower LB		0.7-0.8			3.8-4.6						
S(%)	2-3 months	Upper LB	SC	0.09-0.11			0.35-0.4				Aust	31	
	2-3 months	Lower LB		0.11-0.14			0.38-0.43						
Ca(%)	43 DAT	WS	FSC	0.06	0.45	0.75	0.84-1.50				Aust	439	
	2-3 months	Upper LB	SC	0.05-0.07			1.1-1.3				Aust	31	
	2-3 months	Lower LB		0.2-0.3					2.2				
Mg(%)	2-3 months	Upper LB	SC	0.08-0.09			0.5-0.8				Aust	31	
	2-3 months	Lower LB		0.07-0.08			0.5-0.7						
Cu(mg/kg)	2-3 months	Upper LB	SC	2-4			8-10				Aust	31	
	2-3 months	Lower LB		3-4			9-12						
Zn(mg/kg)	2-3 months	Upper LB	SC	15-20			30-43				Aust	31	
	2-3 months	Lower LB		16-22			29-46						
Mn(mg/kg)	2-3 months	Upper LB	SC	20-22			125-250			9510	Aust	31	
	2-3 months	Lower LB		32-83			750-820			9927			
Fe(mg/kg)	2-3 months	Upper LB	SC	13-36			110-160				Aust	31	
	2-3 months	Lower LB		14-60			150-190						
B(mg/kg)	2-3 months	Upper LB	SC	14-20			80-112			275-353	Aust	31	
	2-3 months	Lower LB		38-80			155-192			608-933			
Mo(mg/kg)	2-3 months	WS	SC	0.2-0.3			0.5-0.9				Aust	31	
GREEN GRAM (*Vigna radiata*)													
N(%)	25-33 DAT	WS	SC	1.11-1.21			4.02-4.03				Aust	75	cv. Berken
P(%)	30 DAS	WS	Soil		0.085-0.107	0.11	0.11-0.17				Ind	301	Crit. conc. at 90% max. seed yield.
	Fl	WS	Soil			0.3					Pak	784	cv. NM-19
	15 DAS	YML	Soil	0.44		0.69	0.66-1.00				Aust	433	cv. Berken
	23 DAS			0.30		0.55							
	37 DAS			0.35		0.44	0.38-0.56						
	40 DAS (Early Fl)			0.22		0.43	0.49-0.53						

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	Fl	YML	Soil			0.33					Pak	784	cv. NM-19
	Mat	Seed				0.34							
	Mat	Seed	Soil		0.27-0.35	0.38	0.39-0.44				Ind	864	cv. MH83-20(Asha); critical conc. derived by reviewer.
	Mat	Straw			0.085-0.15	0.13	0.12-0.19						
Cl(%)	20-40 DAT	WS	SC						1.18	1.71-6.62	Aust	876	Crit. conc. at 90% max. RGR; data pooled from several experiments.
Zn(mg/kg)	42 DAS	WS	Soil		13-29	19	16-58				Ind	364	cv. Pusa Baisakhi; data from pot trial with 22 soils.
Mn(mg/kg)	25-33 DAT	WS	SC				247-259			784-901	Aust	75	cv. Berken
	18 DAT	YML	FSC						950		Aust	33	cv. Berken; NO_3-N in nutrient soln.
	18 DAT								870				cv. Celera; NO_3-N in nutrient soln.
	22 DAT	YML	SC						800		Aust	33	cv. Berken; N_2-fixing plants.
	40 DAS	YML	Soil		14.7-23.0	19	20-38				Ind	48	cv. ML131; study on 14 soils.
B(mg/kg)	Early Fl bud	Young unfolding leaf		13		(14)	51				Aust	78	cv. Kampaengsaen 1; tentative critical conc. below which LB elongation rate is decreased.
	Early podding	Young unfolding leaf		11		(14)	34						
	Early podding	YML		14		(14)	24						
	V2	Expanding LB	SC,F			16					Aust/	79	Crit conc. at 90% maximal LB elongation rate.
	R3					14					Thai		
	Mat	Seed	F	5.0-9.5			15.3-16.3				Thai	817	55-33% abnormal seedlings produced in low B soil.
Mo(mg/kg)	R1-2	YMB				0.09-0.13					Aust	79	
	R1-2	Nodules				3.9-4.3						603	

GUAR (*Cyamopsis tetragonoloba*)

N(%)	25-33 DAT	WS	SC	1.15-2.16			3.36-3.62				Aust	75	cv. Brooks
	Pre-Fl (37 DAS)	WS	F				3.0-5.0				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Fl (50 DAS)						2.5-4.0						
	PF (78-91 DAS)						2.2-4.0						
	44 DAS	WS	Ver		3.09-3.81		2.90-3.61				USA	27	cv. Lewis
	44 DAS				2.88-3.64		3.04-3.74						
P(%)	25-33 DAT	WS	SC				0.38-0.42	0.70			Aust	75	cv. Brooks
	Pre-Fl (37 DAS)	WS	F				0.25-0.35				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates

GUAR (*Cyamopsis tetragonoloba*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	Fl (50 DAS) PF (78-91 DAS)	WS	F				0.22-0.32 0.17-0.30				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Early Fl (40 DAS)	WS	SC	0.08							Aust	482	cv. Brooks
P(µmol/g FW)	20 DAT	WS	FSC			17					Aust	279	cv. Brooks
K(%)	Pre-Fl to Fl (37-50 DAS) PF (78-91 DAS)	WS	F				2.0-4.0 1.5-2.5				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Early Fl (40 DAS)	WS	SC	0.5							Aust	482	cv. Brooks
Ca(%)	20 DAT	WS	FSC	0.15							Aust	74	cv. Brooks
	Pre-Fl (37 DAS) Fl (50 DAS) Early PF (78 DAS) Late PF (91 DAS)	WS	F				2.0-2.5 1.7-2.2 0.9-1.3 0.6-0.9				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Early Fl (40 DAS)	WS	SC	0.26							Aust	482	cv. Brooks
	20 DAT	YMB	FSC		0.45-1.31		3.16				Aust	74	cv. Brooks
Mg(%)	Pre-Fl to Early Fl (37-50 DAS) Early PF (78 DAS) Late PF (91 DAS)	WS	F				0.62-1.15 0.51-0.9 0.36-0.66				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Early Fl (40 DAS)	WS	SC	0.09							Aust	482	cv. Brooks
Cl(%)	Pre-Fl (37 DAS)	WS	F				0.3-0.9				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	54 DAS	Mature, fully expanded leaves	F				0.06-0.45		0.48	0.72-1.71	USA	297	cvv. Kinman, Esser; crit. conc. for seed yield.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Cu(mg/kg)	Pre-Fl (37 DAS)	WS	F				8-13				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
Zn(mg/kg)	Pre-Fl (37 DAS)	WS	F				90-120				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	42 DAS	WS	Soil	10 - 15.2		15.4	16-25				Ind	919	cv. HG75; crit conc. corresponds to 80% max. yield.
Mn(mg/kg)	25-33 DAT	WS	SC				92-100	323-353			Aust	75	cv. Brooks
	Pre-Fl (37 DAS)	WS	F				60-190				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Early Fl (40 DAS)	WS	SC							2847	Aust	482	cv. Brooks
B(mg/kg)	Pre-Fl (37 DAS)	WS	F				60-90				Aust	482	cv. CP177 tested on range of soils with high fertilizer rates
	Early Fl (40 DAS)	WS	SC							377	Aust	482	cv. Brooks

HOPS (*Humulus lupulus*)

N(%)	Mid season	YML	Lit				2.5-3.5				Ger	82	
P(%)	Mid season	YML	Lit				0.35-0.60				Ger	82	
K(%)	Mid season	YML	Lit				2.8-3.5				Ger	82	
Ca(%)	Mid season	YML	Lit				1.0-2.5				Ger	82	
Mg(%)	Mid season	YML	Lit				0.3-0.6				Ger	82	
Cu(mg/kg)	Mid season	YML	Lit				6-12				Ger	82	
Zn(mg/kg)	Mid season	YML	Lit				35-80				Ger	82	
Mn(mg/kg)	Mid season	YML	Lit				30-100				Ger	82	
B(mg/kg)	Mid season	YML	Lit				25-70				Ger	82	
Mo(mg/kg)	Mid season	YML	Lit				0.2-0.5				Ger	82	

JAPANESE MINT (*Mentha arvensis*)

P(%)	4 MAT 6 MAT	WS	F				≥0.36 ≥0.30				Ind	501	Diagnostic and predictive for max. shoot FW, DW and oil yield
Zn(mg/kg)	102 DAT	L	SC	≤12.4		28					Ind	617	Cate-Nelson analysis for DM yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
JAPANESE MINT (*Mentha arvensis*) (ctd)													
Fe(mg/kg)	110 DAT 200 DAT	WS	F			212 164					Ind	964	Second harvest regenerated material following the first harvest; Diagnostic for DM herbage yield
	110 DAT 200 DAT	WS	F			210 167					Ind	964	Second harvest regenerated material following the first harvest; Diagnostic for essential oil yield
KENAF (*Hibiscus cannabinus*)													
N(%)	80 DAS (approx)	Leaves	F	2.65	3.01-3.42		3.49				USA	86	Predictive values for stem yield; cv. Tainung 1.
	Mat	Stem	F		0.30-0.43	0.44	0.48-0.53				USA	8	
NO_3-N (mg/kg)	Mat	Stem	F		110-380	390	470-800				USA	8	
NO_3-N (mg/L)	36 DAS	PYML (sap)	F			1850					Aust	552	Critical at 90% max. stem dry matter yield; cv. Guatemala 4
	46 DAS			0	400-1160	1350	1540						
	53 DAS			0	180-910	1040	1080-1250						
	60 DAS			0	73-400	400	450-990						
	67 DAS			0	2-62	75	120-710						
P(%)	Mat	Stem	Lit				0.12-0.19				USA	457	
K(%)	Mat	Stem	Lit				1.36-2.59				USA	457	
Ca(%)	Mat	Stem	Lit				0.31-0.41				USA	457	
Mg(%)	Mat	Stem	Lit				0.15-0.35				USA	457	
Cu(mg/kg)	Mat	Stem	Lit				1-3				USA	457	
Zn(mg/kg)	Mat	Stem	Lit				23-31				USA	457	
Mn(mg/kg)	Mat	Stem	Lit				14-23				USA	457	
Fe(mg/kg)	Mat	Stem	Lit				21-26				USA	457	
B(mg/kg)	115 DAE	WS	F					685			USA	52	No B toxicity symptoms
	Mat	Stem	Lit				12-21				USA	457	
Mo(mg/kg)	Mat	Stem	Lit				0.8-0.9				USA	457	

LENTIL (*Lens culinaris*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	Mat	WS	F		4.3						Can	141	Diagnostic for total shoot yield cvv. Eston and Laird
	42 DAT		F		4.0								Diagnostic for seed yield
			SC			>3							cv. Eston; diagnostic for shoot DW
Protein (%)	Mat	Seed	F				≥25				Can	140	Diagnostic for max. DW of shoots
							≥25						Diagnostic for max. seed yield
P(%)	<30 cm tall	WS	Soil			0.28					Pak	605	
	Head	YMB	Soil			0.33					Pak	783	Critical at 95% of max. seed yield
	≤30 cm high	WS				0.28							
	Mat	Seed				0.26							
	Fl init.	YML	Soil			0.33					Pak	605	
	Mat	Seed	Soil			0.26					Pak	605	
K(%)	7th leaf stage	2-4 leaf	Soil			0.18					Can	425	Apparently diagnostic for shoot yield; % of max. yield unknown; Water extractable K
S(%)	Mat	WS	F				≥0.33				Ind	993	No plateau in DM or seed yield achieved
		Seed					≥0.47						
	7th leaf stage	2-4 leaf	Soil			0.29					Can	425	Apparently diagnostic for shoot yield; % of max. yield unknown; Water extractable S
	7th leaf	ML	Soil			0.29					Can	424	Diagnostic for shoot DW; SO_4-S measured; Predictive for seed yield; Poor plateau definition
	Early Fl					0.045							
Zn(mg/kg)	45 DAS	WS	F				>32				Ind	992	Predictive for seed yield and shoot DW at maturity
	Mat	Straw					>40						Diagnostic for seed yield and shoot DW at
	Mat	Seed					>30						maturity
Mn(mg/kg)	65 DAS	Young L	Sand	<8		88					Ind	491	Plateau not defined
	89 DAS	All L				38			70				Seeds formed
Fe^{2+} (mg/kg)	50 DAS	L	Soil			74.5					Ind	869	Cate-Nelson approach; poorly defined plateau
B(mg/kg)	28-30 DAS	YFEB	RSC						194		Aust	186	cv. Callisto
									164				cv. Laird

LINSEED, LINOLA, FLAX (*Linum usitatissimum*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	42 DAS	WS	Soil	3.23			3.75-4.19				Ger	408	
	49 DAS	WS	F				2.08-2.7				Ger	408	
	63 DAS	WS	Soil				2.47-3.03				Ger	408	
	63 DAS	WS	F				1.39-3.59				Ger	408	
	77 DAS	WS	F				1.39-1.81				Ger	408	
	Pre-Fl	YML	Lit	2.2	2.6-2.8		3.2-4.5				Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				2.6-3.0				Ger	82	
	56 DAS	L	F				3.80				Ger	408	
	Buds visible	Roots	Sand	<1.3							Aust	406	Predictive for max. seed and oil yield
		L		<5.3									
	Fl	Roots	Sand	<1.1							Aust	406	Predictive for max. seed and oil yield
		S		<1.5									
		L		<5.9									
		Flowers		<3.5									
	44 DAS (tillering)	S	Sand			2.3					Aust	403	Diagnostic for shoot DW
		L				5.6							
	44 DAS (tillering)	S	Sand			2.1			3.0		Aust	403	Predictive for seed yield
		L				5.0			6.3				
	58 DAS (Buds visible)	S	Sand			1.6					Aust	403	Diagnostic for shoot DW
		L				5.0							
		Flowers				4.1							
	58 DAS (Buds visible)	S	Sand			1.4			1.8		Aust	403	Predictive for seed yield
		L				4.3			5.2				
		Flowers				4.0			4.2				
	72 DAS (Fl)	S	Sand			1.6					Aust	403	Diagnostic for shoot DW
		L				4.5							
		Flowers				2.5							
	72 DAS (Fl)	S	Sand			1.4			1.7		Aust	403	Predictive for seed yield
		L				4.0			4.8				
		Flowers				2.7			2.8				
	171 DAS (Mat)	S	Sand			1.1			1.8		Aust	403	Diagnostic for shoot DW
		L				2.3			3.5				

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	171 DAS	S	Sand			0.9			1.4		Aust	403	Predictive for seed yield
	(Mat)	L				2.0			3.1				
		Seeds				3.7			3.9				
	91 DAS	S	Sand			1.5					Aust	403	Diagnostic for shoot DW
	(PS)	L				4.0							
		Capsules				2.7							
	91 DAS	S	Sand			1.3			1.7		Aust	403	Predictive for seed yield
	(PS)	L				3.8			4.3				
		Capsules				2.6			2.8				
	Early tillering	Dry upper S	Sand			3.0					Aust	402	Diagnostic for shoot DW. Upper stem preferred for NO_3-N. Whole shoot is most convenient for total N
		Dry upper L				5.5							
		Whole S				2.2							
		Whole L				5.47							
		WS				4.5							
	Early tillering	Dry upper S	Sand			2.93					Aust	402	Predictive for seed yield. Upper stem preferred tissue for NO_3-N. Whole shoot is most convenient for total N.
		Dry upper L				5.23							
		Whole S				2.14							
		Whole L				5.16							
		WS				4.30							
	Fl	Dry upper S	Sand			2.16					Aust	402	Diagnostic for shoot DW. Upper stem preferred for NO_3-N. Whole shoot is most convenient for total N
		Dry upper L				4.54							
		Whole S				1.57							
		Whole L				4.45							
		WS				2.72							
	Fl	Dry upper S	Sand			1.98					Aust	402	Predictive for seed yield. Upper stem preferred tissue for NO_3-N. Whole shoot is most convenient for total N.
		Dry upper L				4.32							
		Whole S				1.42							
		Whole L				4.21							
		WS				2.62							
	Visible buds	Dry upper S	Sand			2.28					Aust	402	Diagnostic for shoot DW. Upper stem preferred for NO_3-N. Whole shoot is most convenient for total N.
		Dry upper L				5.08							
		Whole S				1.66							
		Whole L				4.9							
		WS				3.13							
	Visible buds	Dry upper S	Sand			2.15					Aust	402	Predictive for seed yield. Upper stem preferred tissue for NO_3-N. Whole shoot is most convenient for total N.
		Dry upper L				4.78							
		Whole S				1.43							
		Whole L				4.35							
		WS				2.80							

LINSEED, LINOLA, FLAX (*Linum usitatissimum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
NO_3-N (mg/kg)	Early tillering	Fresh upper S Dry upper S Dry main S	Sand			260 2250 2050			1900 13000 10500		Aust	402	Diagnostic for shoot DW. Upper stem preferred for NO_3-N. Whole shoot is most convenient for total N.
	Early tillering	Fresh upper S Dry upper S Dry main S	Sand			130 1080 1000			900 1300 7200		Aust	402	Predictive for seed yield. Upper stem preferred tissue for NO_3-N. Whole shoot is most convenient for total N.
	Visible buds	Dry upper S Dry main S	Sand			750 680			3000 2000		Aust	402	Diagnostic for shoot DW. Upper stem preferred for NO_3-N. Whole shoot is most convenient for total N.
	Visible buds	Fresh upper S Dry upper S Dry main S	Sand			160 1700 1050			720 4000 3200		Aust	402	Predictive for seed yield. Upper stem preferred tissue for NO_3-N. Whole shoot is most convenient for total N.
	Fl	Dry upper S Dry main S	Sand			650 600			2000 2200		Aust	402	Diagnostic for shoot DW. Upper stem preferred for NO_3-N. Whole shoot is most convenient for total N.
	Fl	Dry upper S Dry main S	Sand			300 200			1200 1500		Aust	402	Predictive for seed yield. Upper stem preferred tissue for NO_3-N. Whole shoot is most convenient for total N.
P(%)	21 DAS 35 63 Mat	WS WS WS Seed	F			0.61 0.38 <0.20 <0.67					Can	40	Diagnostic cv. Dufferin
	22 DAS 35 DAS 63 DAS	WS	F			0.62 0.38 0.20					Can	40	Predictive for seed yield cv. Dufferin
	37 DAS	WS	Soil			0.25					USA	626	
	53 DAS	WS	Soil				0.37-0.69				Ger	408	
	63 DAS	WS	Soil	0.19-0.21			0.27-1.0				Ger	408	
	63 DAS	WS	Soil				0.15-0.3				Ger	408	
	63 DAS	WS	F				0.14-0.35				Ger	408	
	70 DAS	WS	Soil				0.49-0.83				Ger	408	
	77 DAS	WS	F				0.18-0.27				Ger	408	
	PF	WS	F	0.2							Can	954	Diagnostic for max. shoot DW

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mat	WS Seed	F			0.44 0.03					Can	954	Diagnostic for max. straw DW
	Mat	WS Seed	F			0.40 0.03					Can	954	Predictive for max. seed yield
	70 DAS	Young L	Soil				0.49-0.8				Ger	408	
	Pre-Fl	YML	Lit	0.13-0.16	0.20-0.22		0.25-0.45				Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				0.35-0.5				Ger	82	
	46 DAS 60 DAS 60 DAS	YFEL	F			0.33 0.36 0.21					Aust	747	Diagnostic for shoot DW Diagnostic for shoot DW Predictive for max. seed yield
	49 DAS	L	Soil	0.21-0.32			0.5-0.79				Ger	408	
	56 DAS	L	Soil				0.9				Ger	408	
	56 DAS	L	F				0.5				Ger	408	
	49 DAS	S	Soil	0.12-0.13			0.28				Ger	408	
	Mat	Stem L Capsules Seed	Sand/Perl			0.03 0.08 0.06 0.45					Aust	407	Diagnostic for seed yield cv. Glenelg
	70 DAS	Old L	Soil				0.17-0.2				Ger	408	
K(%)	53 DAS	WS	Soil				2.5-3.5				Ger	408	
	63 DAS	WS	Soil				0.96-2.3				Ger	408	
	63 DAS	WS	F				1.51-3.37				Ger	408	
	70 DAS	YL WS	Soil				3.14-3.8 2.69-3.1				Ger	408	
	77 DAS	WS	F				1.21				Ger	408	
	91 DAS	WS	Soil				2.59				Ger	408	
	105 DAS	WS	F	1.55			2				Ger	408	
	Pre-Fl	YML	Lit	0.8	1.6-1.8		2.2-3.0				Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				2.5-3.5				Ger	82	
	49 DAS	YL L	Soil	1.92-3.32			4.23-4.94 5.15				Ger	408	
	56 DAS	L	F,Soil				2.9				Ger	408	

LINSEED, LINOLA, FLAX (*Linum usitatissimum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	49 DAS	Old L	Soil	0.68-2.1			5.62-6.13				Ger	408	
S(%)	49 DAS	L S	Soil	0.2-0.23 0.08-0.09			0.47 0.16				Ger	408	
Ca(%)	53 DAS	WS	Soil				0.96-1.7				Ger	408	
	63 DAS	WS	F				0.92-1.62				Ger	408	
	77 DAS	WS	F				5.5-7.3				Ger	408	
	91 DAS	WS	Soil				3.27-4.45				Ger	408	
	Pre-Fl	YML	Lit		0.8		1.0-1.6	2.2			Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				0.5-1.0				Ger	82	
	112 DAS	Upper shoot	F	0.28-0.54			0.6-0.72				Ger	408	
	49 DAS	L	Soil				1.5				Ger	408	
	56 DAS	L	Soil				1.2-2				Ger	408	
	56 DAS	L	F				2.4				Ger	408	
	70 DAS	YL Old L WS	Soil				2.06-2.14 3.16-3.26 1.36-1.44				Ger	408	
Mg(%)	53 DAS	WS	Soil				0.36-0.65				Ger	408	
	63 DAS	WS	F				0.39-0.78				Ger	408	
	77 DAS	WS	F				0.32-0.47			>0.89	Ger	408	
	91 DAS	WS	Soil				0.95-1.56				Ger	408	
	Early Fl	WS	Soil			0.5			1		Can	340	
	Pre-Fl	YML	Lit				0.30-0.65	0.95			Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				0.2-0.5				Ger	82	
	49 DAS	YL L Old L	Soil	0.27-0.35 0.16-0.31			0.55-0.63 0.58 0.72-0.75				Ger	408	
	56 DAS	L	Soil				0.4				Ger	408	
	56 DAS	L	F				0.5				Ger	408	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Na(%)	46 DAS	WS	F				1.08-1.15			1.4-1.46	Ger	408	
	53 DAS	WS	Soil				0.03-0.39				Ger	408	
	91 DAS	WS	Soil				0.4-1.01				Ger	408	
	Pre-Fl	YML	Lit				0.2-0.9	1.1-1.2			Aust	1053	
	56 DAS	L	Soil				0.2-1.3			3.1	Ger	408	
	70 DAS	YL WS Old L	Soil				0.49-0.5 0.37-0.45 1.06-1.38				Ger	408	
Cl(%)	Pre-Fl	YML	Lit				0.3-1.2				Aust	1053	
Cu(mg/kg)	43 DAS (PS)	WS	Soil	<2.4			>3.5				Can	596	
	53 DAS	WS	Soil				3.5-9.8				Ger	408	
	63 DAS	WS	Soil	3			4.5-9.3				Ger	408	
	63 DAS	WS	F	3.3-4.5			4.8-7.8				Ger	408	
	77 DAS	WS	F				5.1-6.7				Ger	408	
	Fl init Pod init	WS	Soil			2.4 1.7	3.5-5				Can	595	Diagnostic at 85% max. growth
	Pre-Fl	YML	Lit		4		6-25	90			Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				10-15				Ger	82	
Zn(mg/kg)	21 DAS 63 DAS	WS	Soil	≤10 ≤16							USA	622	
	42 DAS	WS	F							700-800	Ger	408	
	45 DAS	WS	F				>34				Ind	992	Predictive for seed yield and shoot DW at mat.
	Mat	Straw					>25						Diagnostic for seed yield and shoot DW at mat.
	Mat	Seed					>16						Diagnostic for seed yield and shoot DW at mat.
	53 DAS	WS	Soil				19-37				Ger	408	
	63 DAS	WS	Soil	15-18			24-31				Ger	408	
	63 DAS	WS	Soil				17-35				Ger	408	
	63 DAS	WS	F	10.4-14.9			19.1-34.2				Ger	408	
	70 DAS	WS	Soil	18-20			32-83				Ger	408	
	70 DAS	WS	Soil	12.7-19			19.3-38				Ger	408	

LINSEED, LINOLA, FLAX (*Linum usitatissimum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Zn(mg/kg) (ctd)	77 DAS	WS	F				29-43.4				Ger	408	
	PF	WS	Soil	<19							Ind	490	
	Pre-Fl	YML	Lit	9-14	15-18		20-90				Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				30-80				Ger	82	
Mn(mg/kg)	Pre-Fl	YML	Lit				60-800				Aust	1053	
	70 DAS	YL	Soil				56			1015	Ger	408	
	Onset of Fl	Upper 3rd of shoots	Lit				30-100				Ger	82	
	U	WS	Soil	6			50				Ger	408	
	77 DAS	WS	F				96-188				Ger	408	
	49-70 DAS	WS	Soil				5-50			500-2000	Ger	408	
	63 DAS	WS	Soil	14-18			108-145				Ger	408	
	63 DAS	WS	F				108-449				Ger	408	
	65 DAS	WS	Soil							≥189	USA	624	
	70 DAS	WS Old L	Soil				34 133			2295	Ger	408	
Fe(mg/kg)	70 DAS	YL WS Old L	Soil				80-122 52-84 73-271				Ger	408	
	77 DAS	WS	F				96-188				Ger	408	
	21 DAS	WS	Soil	30-80			97-242				Ger	408	
	53 DAS	WS	Soil				111-240				Ger	408	
	63 DAS	WS	Soil				73-88				Ger	408	
	63 DAS	WS	F				112-166				Ger	408	
B(mg/kg)	70 DAS	Upper shoot	Soil	7-8			20-40			290-380	Ger	408	
	84 DAS	Upper shoot	F	13			21				Ger	408	
	Pre-Fl	YML	Lit	15	19		25-60				Aust	1053	
	Onset of Fl	Upper 3rd of shoots	Lit				30-60				Ger	82	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	28 DAS	WS	Soil	10			25-35			220-960	Ger	408	
	53 DAS	WS	F				48-70			88-126	Ger	408	
	45 DAS	WS	F							≥88	Ind	190	Ca/B ratio ≤40 indicates toxicity
Mo(mg/kg)	Onset of Fl	Upper 3rd of shoots	Lit				0.3-1.0				Ger	82	
	126 DAS	WS	Soil				0.7-0.45				Ger	408	

LUPIN (*Lupinus angustifolius, L. albus, L. cosentinii*)

Data refer to *L. angustifolius* unless otherwise stated in Comments column.

N(%)	Pre-Fl	YML	Lit	1.1-2.3	2.5-2.8		3.2-6.0	7			Aust	1053	3 *Lupinus* spp.
P(%)	Veg	WS	F			0.27 0.37					Aust	114	1980; Predictive for 90% 1983; of max. seed yield
	Young plants	WS	Soil				0.16-0.5			>1.1	UK	1046	*L. luteus*
	18 DAS 32 DAS	WS	SC	<0.42		0.28					Aust	990	Diagnostic for shoot FW
	30 DAS	WS	Soil, Lit				0.25			>1.1	Aust	938	
	35 DAS	WS	Soil, Lit	0.13			0.22			2.14	Aust	938	*L. albus*
	45 DAE	WS	Soil			0.15					USA	626	*L. albus*
	56-70 DAS	WS	F,S	<0.15	0.2		0.25-0.4				Aust	732	
	70-98 DAS	WS	F			0.36					Aust	129	Approximate criterion
	77 DAS	WS	Sand/Soil	0.1-0.15			0.2-0.28			>3.2	Aust	309	*L. albus*
	127 DAS	WS	F			0.23 0.22 0.23 0.22					Aust	113	Crit. levels derived from Mitscherlich's equations. 4 *Lupinus* spp.
	132 DAS	WS	F			0.13					Aust	117	*L. cosentinii*
	170 DAS (Mat)	WS	F			0.33					Aust	121	cv. Danja
	Early Mat	WS	F,S				>0.15				Aust	732	3 *Lupinus* spp.
	Full Fl (pods on main axis)	WS	F			0.23					Aust	770	Critical at 80% max. yield. At near max. yield *L. angustifolius* criteria = 0.24-0.26% P; 4 *Lupinus* spp. compared
	Pre-Fl	YML	Lit	0.12-0.16	0.18-0.19		0.24-0.50				Aust	1053	4 *Lupinus* spp.

LUPIN (*Lupinus angustifolius, L. albus, L. cosentinii*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	56 DAS 63 DAS	Roots WS	Sand Soil	<0.14			≥0.28				Aust	6	Diagnostic for max. root DW Diagnostic for max. shoot DW *L. albus*
	Mat	Seed	F			0.42	≥0.48				Aust	119	cv. Chittick; diagnostic for seed yield
	Mat	Seed	F			0.27 0.23					Aust	116	1988; cv. 1989; Danja
K(%)	1st Fl (84 DAS)	Young LB P Shoot tips	F			1.3 1.2 2.1					Aust	210	Critical values at 90% max. grain yield
	4-6 leaf (28 DAS) 8-10 leaf (56 DAS) 1st Fl (84 DAS) Late Fl (112 DAS) Post Fl (140 DAS)	WS	F	<2.6 <2.5 <1.4 <0.9 <0.85	2.6-3.5 2.5-3.2 1.4-1.8 0.9-1.3 0.85-0.95	3.1 2.9 1.5 1.2 0.9	>3.5 >3.2 >1.8 >1.3 >0.95				Aust	210	Critical values at 90% max. grain yield
	32 DAS	WS	Lit	0.45		1.9					Aust	938	
	35 DAS	WS	Soil, Lit	0.45		1.3					Aust	938	*L. albus*
	Pre-Fl	YML	Lit	<1.1	1.1-1.4		1.6-3.5				Aust	1053	
S(%)	48 DAS	WS	Soil, Lit	0.11			0.62				Aust	938	
	54 DAS	WS	Soil, Lit	0.11			0.24				Aust	938	*L. albus*
	44 DAS	PYOL WS S	Soil			0.28 0.15 0.07					Aust	843	Critical N/S ratio in YL = 22 2 intersecting lines to define critical levels
Ca(%)	43 DAS	WS	Soil, Lit	0.7		1.0	2.2				Aust	938	
	Pre-Fl	YML	Lit				1.0-3.0				Aust	1053	3 *Lupinus* spp.
	39 DAS	YOL	Lit	0.10			0.43				Aust	938	*L. albus*

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	68 DAS	Shoots	Soil							>0.59	Aust	448	Diagnostic for max. nodule DW
									0.75				Diagnostic for max. shoot DW
									0.75				Diagnostic for max. root DW
	63 DAS	Roots	Sand						0.7		Aust	94	Diagnostic for max. nodule DW
		Shoots							3.0				Diagnostic for max. plant height
		S							1.4				Diagnostic for max. plant height
	68 DAS	Roots	Soil							>0.18	Aust	448	Diagnostic for max. nodule DW
									0.21				Diagnostic for max. shoot DW
									0.25				Diagnostic for max. root DW
Mg(%)	29 DAS, 43 DAS	YOL	Soil, Lit	0.11			0.4				Aust	938	*L. albus*
	Pre-Fl	YML	Lit		0.17		0.24-1.10				Aust	1053	
Na(%)	Pre-Fl	YML	Lit				0.02-0.35	0.4-0.7		1.0-1.6	Aust	1053	3 *Lupinus* spp.
Cl(%)	Pre-Fl	YML	Lit				0.1-1.2				Aust	1053	3 *Lupinus* spp.
Cu(mg/kg)	Near Mat	WS	F				5-10				Aust	330	Plants did not respond to applied Cu
	34 DAS	YOL	Soil, Lit	0.6		1.0-1.2	4.5				Aust	938	
	Pre-Fl	YML	Lit				5-25				Aust	1053	3 *Lupinus* spp.
Zn(mg/kg)	Pre-Fl	YML	Lit		10-15		25-100	300			Aust	1053	3 *Lupinus* spp.
	35 DAS	YOL	Soil, Lit	6.4		12-14	42				Aust	938	
	Budding	A	F			37					Aust	835	Predictive for seed yield & DM at maturity
	Fl	A				28							2 intersecting lines to define critical level
	Mat	Seed				19							Diagnostic for seed yield
Mn(mg/kg)	40 DAS	WS	Lit				277			>6164	Aust	938	
	40 DAS	WS	Soil				245			>7724	Aust	938	*L. albus*
	40 DAS	WS	Soil				277			>6164	Aust	938	
	56 DAS	WS	S	31-55			318-1300				Aust	728	
	56-70 DAS	WS	S				>50			>20000	Aust	732	
	Up to early Fl	YFEL	Soil			30					Aust	377	Diagnostic for shoot DW
						17							Diagnostic for chlorophyll *a* fluorescence
	Pre-Fl	YML	Lit				50-1200	1400-1600		1900-16000	Aust	1053	3 *Lupinus* spp.
	28 DAS	YOL	Soil	5.6							Aust	938	*L. albus*
	28 DAS	YOL	Lit	5.6			245			>7724	Aust	938	*L. albus*
	40 DAS	WS											

LUPIN (*Lupinus angustifolius, L. albus, L. cosentinii*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	Fl	S	Soil, F				>20				Aust	377	Predictive for absence of 'split seed' disorder Buds and leaves poor predictors.
	42 DAS	Seed	SC			55 75					Aust	213	cv. Danja cv. Gungurru
	Mat	Seed	F	<10		8-10					Aust	376	Diagnostic for 'split seed' disorder
	Mat	Seed	S	4-9			7-53				Aust	728	
	Mat	Seed	F			10					Aust	1039	
	Veg	Shoot tips	F			74 40					Aust	767	cv. Uniharvest; Critical at cv. Weiko 111; 90% max. seed yield
Fe(mg/kg)	49 DAS	A	Soil	<50		70					Aust	1063	cv. Yandee
	28 DAS	WS	Lit, Soil	28			56				Aust	938	*L. albus*
	Veg	YEB	SC			65 52					Aust	980	*L. angustifolius, L. luteus, L. pilosus* Diagnostic for max. chlorophyll synthesis.
	20 DAS	YL	Soil	<70							Aust	1062	Diagnostic of Fe deficiency symptoms
	20-45 DAS	YMB Nodules	SC	<65		44 325					Aust	981	Diagnostic for chlorophyll conc. Diagnostic for nodule mass
	24 DAT	Stem Lowest leaf pair	SC	<31			>18				Aust	1065	Criteria based on symptoms
		(LP1)		<88			>73						
		LP2		<77			>39						
		LP3		<74			>21						
		LP4		<60			>16						
		New growth		<48			>13						
	32 DAS	YL	SC	<76			>20				Aust	1064	
	32 DAS	YL	SC	<63			>22				Aust	1064	*L. costentinii*
B(mg/kg)	28-30 DAS	YFEB	RSC						332		Aust	186	cv. Danja
	28-30 DAS	YFEB	RSC						193		Aust	186	cv. Ultra
	46 DAS	YOL	Lit, Soil	11.5			68			1013	Aust	938	*L. albus*
	Pre-Fl	YML	Lit	12	15-18		20-60				Aust	1053	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	42 DAS	WS	Lit, Soil, SC	12			50			878	Aust	938	
Mo(mg/kg)	45 DAS	YOL	Soil, Lit	0.016			0.036				Aust	938	*L. albus*
	45 DAS	YOL	Soil, Lit	0.005			0.019				Aust	938	
	Pre-Fl	YML	Lit				0.3-5.0	9			Aust	1053	
Co(mg/kg)	42 DAS	Roots Nodules	Soil				≥0.3 ≥0.13				Aust	830	Diagnostic for normal, N fixing plant growth; cv. Uniharvest
	37 DAS	Seed	Soil			0.13					Aust	840	Shoot concentrations not suitable for diagnosis
	Mat	Seed	Soil, S	<0.03		0.095	<0.73				Aust	187 839	
Pb(mg/kg)	14 DAT	WS Root	SC							>34 >4594	Port	657	*L. albus*

MUSTARD (*Brassica juncea, B. campestris*)

P(%)	<30 cm tall	WS	Soil			0.27					Pak	605	
	58 DAS	WS	Soil				≥0.17				USA	500	
	Early rosette-Full Flower	YFEL + 4-6 WS	Sand			0.24 0.25-0.18					Aust	744	Higher by 0.05% for predictive evaluation
	Fl init.	YML	Soil			0.28					Pak	605	
	Mat	Seed	Soil			0.72					Pak	605	
K(%)	30 DAS 65 DAS	L	Sand			3 3.7					Ind	780	Leaves most sensitive tissue for prediction of max. seed yield at flowering; *B. campestris*
	30 DAS 65 DAS	Petioles	Sand			7.6 7.8					Ind	780	Leaves most sensitive tissue for prediction of max. seed yield at flowering; *B. campestris*
	30 DAS 65 DAS	Stems	Sand			5 4.5					Ind	780	Leaves most sensitive tissue for prediction of max. seed yield at flowering; *B. campestris*
S(%)	Mat	Straw Seed	F				≥38 ≥93				Ind	994	Average of 3 cultivars

MUSTARD (*Brassica juncea, B. campestris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Zn(mg/kg)	45 DAS	WS	F				>35				Ind	992	Predictive for seed yield, shoot DW at mat.
	Mat	Straw					>16						Diagnostic for seed yield, shoot DW at mat.
	Mat	Seed					>11						Diagnostic for seed yield, shoot DW at mat.
	≤30 cm high	WS	Soil			35			39		Pak	789	Predictive; 95% max. seed yield
	Fl	YML				41			43				Predictive; 95% max. seed yield
	Mat	Seed				33			35				Diagnostic; 95% max. seed yield
B(mg/kg)	Head	YMB	Soil			45			145		Pak	790	cv. Bard-I; Predictive for 95% max. seed
	Plants ≤30 cm high	WS				37			100				yield
	28 DAS	WS	Soil			57			63		Pak	788	Diagnostic for 95% max. shoot DW
	56 DAS					28			47				cv. Westar
Se(mg/kg)	45 DAS	WS	Soil						3		UK	558	

NAVY BEAN and OTHER BEANS (*Phaseolus vulgaris*)

See also the information for bean under Vegetable Crops.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	U	YML	Lit	4.24-4.99			5.00-6.0	>6.0			USA	457	
	Veg	YML	Lit				4.25-5.5				USA	370	
	U	YMB+P	F				2.5-3.0				Aust	764	
	Onset of Fl	YML	Lit				3-6				Ger	82	
	10% Fl	YMB	F				5.1				Can	555	
	30 DAS (Seedl)	S	F						3		USA	722	
		Primary LP							2.4				
		Primary LB							3.3				
		P							2.7				
		L							5.2				
		A							5.1				
	43 DAS (Fl)	S	F						2.2		USA	722	
		P							3.0				
		L							4.5				
NO_3-N (mg/kg)	30 DAS (Seedl)	S	F						7000		USA	722	
		Primary P							17000				
		Primary LB							3000				
		P							9000				
		L							4000				
		A							1000				

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	43 DAS (Fl)	S Petioles L	F						5000 7000 3000		USA	722	
P(%)	Veg	YML	Lit				0.25-0.6				USA	370	
	Onset of Fl	YML	Lit				0.25-0.50				Ger	82	
	10% Fl	YMB	F				0.4				Can	555	
	U	YML	Lit	0.25-0.34			0.35-0.75	0.75			USA	457	
	U	YMB+P	F				0.25-0.35				Aust	764	
	Fl PF	YML Immature seeds	F	<0.21 <0.28							USA	723	Predictive for fresh immature seed yield Diagnostic for fresh immature seed yield
	14 DAT	WS	SC			0.12					USA	263	
	30-40 DAS	WS	Soil			0.20					Ger	259	cv. Loma; diagnostic for 80% max. shoot DW
	33 DAT	WS	Sand			1.5					Bra	727	Average of 3 cultivars (only small differences)
	45 DAE	WS	Soil			0.14					USA	626	
	50-55 DAE	WS	Soil	0.22			0.33				USA	623	
	PF	WS	Soil	<0.29							Bra	122	cv. Carioca
	Early Fl	WS	F			0.17					Aust	1069	Strong Piper-Steenbjerg effect with yield
	Fl	WS	F	<0.34							Bra	267	
	140 DAS (Mat)	WS	Soil			0.16					USA	606	
	Mat	Root Straw Seed	Soil	<0.35		0.23 0.14					Can	918	Diagnostic for DW of roots
	Mat	Root Straw Seed	Soil	<0.38		0.21 0.14					Can	918	Diagnostic for DW of straw
	Mat	Root Straw Seed	Soil	<0.39		0.18 0.14					Can	918	Diagnostic for seed yield
K(%)	Veg	YML	Lit				1.7-3				USA	370	
	Onset of Fl	YML	Lit				2-3				Ger	82	
	10% Fl	YMB	F				2				Can	555	
	Fl	YML	F	<1.4							Tanz	934	
	U	YML	Lit	2.00-2.24			2.25-4.0	>4.0			USA	457	

NAVY BEAN and OTHER BEANS (*Phaseolus vulgaris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	U	YMB+P	F				1.5-3.0				Aust	764	
S(%)	U	YMB+P	F				0.2-0.25				Aust	764	
N/S	35 DAS	WS	Soil			16					USA	960	
Ca(%)	Veg	YML	Lit				0.35-2				USA	370	
	Onset of Fl	YML	Lit				0.5-2.0				Ger	82	
	U	YMB+P	F				1.5-2.5				Aust	764	
	U	YML	Lit	1.00-1.49			1.50-2.5	>2.5			USA	457	
Mg(%)	Veg	YML	Lit				0.25-1				USA	370	
	Onset of Fl	YML	Lit				0.25-0.7				Ger	82	
	U	YML	Lit	0.25-0.29			0.30-1.0	>1.0			USA	457	
	U	YMB+P	F				0.5-0.9				Aust	764	
Na(%)	U	YMB+P	F				0.1-0.5				Aust	764	
	42 DAS	WS	Sand						0.7 0.7 0.4		USA	34	Diagnostic for shoot DW Diagnostic for nodule number Diagnostic for pod wt
Na(mmol/kg tissue water)	11 DAT	WS	SC						20 25		Aust	875	Diagnostic for transpiration rate Diagnostic for relative growth rate Cl increased in proportion to Na
Cl(%)	U	YMB+P	F				< 1.0				Aust	764	
Cl(mmol/kg tissue water)	11 DAT	WS	SC						30 40		Aust	875	Diagnostic for transpiration rate Diagnostic for relative growth rate Na increased in proportion to Cl
Cu(mg/kg)	Veg	YML	Lit				10-30				USA	370	
	Onset of Fl	YML	Lit				7-15				Ger	82	
		YML	Lit	4-6			7-30	>30			USA	457	Higher values can be tolerated if Cu fungicides have been used
	1st trifoliate unfolding	1st trifoliate	F							>20	USA	1037	
	U	L	Soil						15	20-30	UK	558	
	U	L	SC						30		UK	558	
	15 DAT	S	SC						9		USA	1033	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Zn(mg/kg)	Veg	YML	Lit				20-70				USA	370	
	Onset of Fl	YML	Lit				30-70				Ger	82	
	Full Fl	YMB	F			15					USA	110	
	U	YML	Lit	18-19			20-200	>200			USA	457	
	U	YMB+P	F				20-100				Aust	764	
	42 DAE	L	RSC							>670	USA	753	
	U	L	SC						130		UK	558	
	U								150				
	21 DAS								200				
	57 DAS								60				
	Boot								250				
	Mat								250				
	Var	Mature LB	F	7-22			18-40				USA	1019	Mexican bean
	30-50 DAS	WS	F			15					USA	110	Critical derived from bean maturity data
	45 DAS	WS	Soil			10					Can	944	
	50-55 DAE	WS	Soil	10			29				USA	623	
	Mat	Whole plant	Soil	<16							Can	531	Diagnostic for DW of whole plant
	31 DAS	YL	Soil			21.1					Aust	29	YFEL best tissue for diagnosis; 2 intersecting lines for defining critical level
		YOL				17.1							
		YFEL				10.6							
		WS				12.5							
	Mat	Root	Soil			28-33					Can	918	Diagnostic for straw yield
		Straw		>14									
	Mat	Root	Soil			37					Can	918	Diagnostic for seed yield
		Straw		>15									
	20 DAT	Roots	SC				486				Spa	856	cv. Contender
		S					242						
		Mature L					95						
		Developing L					134						
Mn(mg/kg)	Veg	YML	Lit				20-100				USA	370	
	60 DAS	YMB	S							≥760	Tanz	329	Plants with symptoms had highest levels of Fe and Mn
	Onset of Fl	YML	Lit				40-100				Ger	82	
	U	YML	Lit	15-49			50-300	>300			USA	457	
	U	YMB+P	F				50-200				Aust	764	

NAVY BEAN and OTHER BEANS (*Phaseolus vulgaris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	Mat	L	SC						100		UK	558	
	U	L	Soil							1000	UK	558	
	19 DAT	Trifoliate L	SC			16					USA	1034	Deficiency symptoms ≤7 mg/kg
Fe(mg/kg)	Veg	YML	Lit				50-450				USA	370	
	60 DAS	YMB	S							≥3080	Tanz	329	Plants with symptoms had highest levels of Fe and Mn
	U	YML	Lit	40-49			50-300	>300			USA	457	
B(mg/kg)	42 DAS	WS	Sand Soil						50 50	>111 >158	Aust	17	
	Veg	YML	Lit				15-50				USA	370	
	Pre-Fl	YMB	F				22-70		82		USA	360	Predictive; symptoms >60
	Fl initiation	YMB	F			20-24				40-45	Colo	422	Critical at 95% max. yield
	Onset of Fl	YML	Lit				25-80				Ger	82	
	PS	YMB	F			16-18				37-39	Colo	422	Critical at 95% max. yield
	U	YML	Lit	15-19			20-75	>75			USA	457	
B(mmol/kg)	42 DAS	WS	SC						4.2 4.0 5.0 4.3		Neth	855	Total B in shoots Water insoluble B in shoots Total B in roots Water insoluble B in roots } All are diagnostic for rel. growth rate of fresh whole plants
Mo(mg/kg)	Veg	YML	Lit				1-5				USA	370	
	Onset of Fl	YML	Lit				0.4-1.0				Ger	82	
	Var	Nodules	SC			3-5					USA	293	
Cd(mg/kg)	35 DAS	Root S L	Sand						100 10 2		Italy	528	Diagnostic for root DW
	35 DAS	Root S L	Sand						2200 50 5		Italy	528	Diagnostic for leaf DW
	35 DAS	L	SC						5		UK	558	
		L	Soil						10		UK	558	
		L	SC						10-30		UK	558	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cd(mg/kg) (ctd)		L	Soil						5		UK	558	
Ag(mg/kg)	U		SC						<1		UK	558	
	21-28 DAS	L	SC						1-4		UK	558	
Co(mg/kg)	U	L	SC						4-40		UK	558	Diagnostic at 75% max. shoot DW
Cr(mg/kg)	U	L	Soil						1		UK	558	
	U	L	SC						<1		UK	558	
	15 DAS	Stem L Trifoliate Fruit	Soil						5 0.9 1.0 0.95	30 28 7	Spa	351	Diagnostic for DW of plant part sampled
Li(mg/kg)	U	L	SC						10-20		UK	558	Diagnostic at 75% max. shoot DW
Ni(mg/kg)	U	L	Soil						40		UK	558	
	U	L	Soil						66-83		UK	558	
	U	L	SC						10-15		UK	558	
	15 DAS	L	SC						25		UK	558	Diagnostic at 80% max. shoot DW
Se(mg/kg)	12 DAS	L	SC						25		UK	558	
V(mg/kg)	U	L	SC						13		UK	558	Diagnostic at 50% max. shoot DW

OATS (*Avena sativa*)

FS = Feeke's scale of cereal growth (see reference 511). ZS = Zadok's scale of cereal growth (see reference 1110).

N(%)	FS 5-6 FS 7-8	WS	Lit				3.0-5.0 2.2-3.5				Ger	82	
	FS 10.1	WS	Lit	1.55-1.99			2.0-3.0	>3.0			USA	457 1044	
	FS 10.2	WS	F	<2.3			>3.0				Aust	384	
	FS 11.l -11.2	WS	F				1.2-1.6				Aust	591	
	Mid to late Till	YMB	F,D	<3.4	3.4		3.5-5.4	5.5-6.5		>6.5	Aust	1053	Toxic range is 'excessive'.
	Till Shoot Fl	LB	F	<3.5 <2.3 <1.4	4.4-5.0 3.2-3.5 2.0-2.2		5.1-5.9 3.6-4.4 2.3-2.9	>5.9 >4.4 >2.9			CIS	335	Deficient <70% max. yield. Marginal 70-100% max. yield.
	Pre-Head	Upper LB	F,S				2.0-3.0				USA	456	
P(%)	2 leaf	WS	Soil							>3.0	Aust	852	

OATS (*Avena sativa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	FS 5-6 FS 7-8	WS	Lit				0.35-0.6 0.28-0.5				Ger	82	
	FS 10.1	WS	Lit	0.15-0.19			0.2-0.5	>0.5			USA	457 1044	
	Mid to late Till	YMB	F,D	<0.24	0.24-0.29		0.3-0.5	0.6-0.7		>0.7	Aust	1053	Toxic range is 'excessive'.
	Till Shoot Fl	LB	F	<0.45 <0.36 <0.24	0.56-0.64 0.45-0.49 0.26-0.29		0.65-0.78 0.5-0.62 0.3-0.42	>0.78 >0.62 >0.42			CIS	335	Deficient <70% max. yield. Marginal 70-100% max. yield.
	2 leaf	Oldest LB	F							>1.3	Aust	542	
	Pre-Head	Upper LB	F,S				0.2-0.4				USA	456	
PO_4-P (mg/kg)	FS 6-7	(YMB + YMB+1)	Soil			76					Fin	861	P conc. expressed on fresh wt. basis. Critical values at 95% max. grain yield.
		(YMB + YMB+1)	F			83							
K(%)	FS 5-6 FS 7-8	WS	Lit				4.5-5.8 3.8-5.0				Ger	82	
	FS 10.1	WS	F,S	<1.25	1.25-1.49		1.5-3.0	>3.0			USA	457 1044	
	Mid to late Till	YMB	F,D	<1.5	1.5-2.3		2.4-4.0	4.1-5.5		>6.0	Aust	1053	Toxic range is 'excessive'.
	Till Shoot Fl	LB	F	<3.4 <2.6 <1.8	4.3-4.9 3.1-3.2 2.3		5.0-5.7 3.3-4.1 2.4-2.9	>5.7 >4.1 >2.9			CIS	335	Deficient <70% max. yield. Marginal 70-100% max. yield
	Pre-Head	Upper LB	F,S				1.5-3.0				USA	456	
S(%)	35 DAS 56 DAS 84 DAS 119 DAS	WS	Soil			0.24 0.17 0.14 0.08					Aust	952	Critical at 90% max. yield.
	FS10.1	WS	Lit	<0.15			0.15-0.4	>0.4			USA	457 1044	
	Mid to late Till	YMB	F,D		<0.15		0.15-0.4	>0.4			Aust	1053	
SO_4-S (mg/kg)	35-119 DAS	WS	Soil			30					Aust	952	Critical at 90% max. yield
SO_4-S/S (%)	35-119 DAS	WS	Soil			5					Aust	952	Critical at 90% max. yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N/S	Before FS 6	WS	F			N/S 14-50; SO_4-S% >0.05; S% >0.15					Aust	98	Interpretation guidelines for autumn sown forage oats; S and N adequate. If N/S ratio >20, luxury N status is indicated.
						N/S 20-50; SO_4-S% <0.04; S% <0.1							S deficient. If N <1.5% then dual deficiencies of N&S are indicated.
						N/S <14; SO_4-S% >0.05; S% >0.15							S adequate; N deficient.
Ca(%)	FS 5-6 FS 7-8	WS	Lit				0.5-1.0 0.4-1.0				Ger	82	
	FS 10.1	WS	Lit	<0.2			0.2-0.5	>0.5			USA	457 1044	
	Mid to late Till	YMB	F,D		<0.18		0.21-0.4	0.6-0.7			Aust	1053	
	Pre-Head	Upper LB	F,S				0.2-0.5				USA	456	
Mg(%)	18-25 DAS	WS	Sand		<0.12						Neth	149	
	FS 5-6 FS 7-8	WS	Lit				0.2-0.3 0.15-0.25				Ger	82	
	FS 6	WS	Soil	<0.07	0.07-0.12		>0.12				Ger	346	
	Stem elongation	WS	Soil			0.15					Ger	347	Critical at near max. grain yield.
	Head	WS	Soil			0.18					Ger	1072	Critical at 95% max. yield. Critical Mg/Ca=0.3
	Head	WS	F			0.12					Ger	1071	Mg conc. corrected to constant 3%N
	FS 10.1	WS	Lit	<0.15			0.15-0.5	>0.5			USA	457 1044	
	Mid to late Till	YMB	F,D	<0.11	0.11-0.12		0.13-0.3				Aust	1053	
	Pre-Head	Upper LB	F,S				0.15-0.5				USA	456	
Na(%)	Mid to late Till	YMB	F,D				<0.5	0.6-0.7		>0.8	Aust	1053	
Cl(%)	Mid to late Till	YMB	F,D				<2.0	2.0-2.8		>3.0	Aust	1053	Toxic range is 'excessive'.
Cu(mg/kg)	Onset Till	WS	F			3.9					Ger	988	Critical for max. grain yield
	49 DAS	WS	Soil				12-15			33-64	USA	823	
	FS 5-6	WS	Lit				6-12				Ger	82	N/Cu ratio <10.
	FS 7-8	WS	Lit				5-10				Ger	82	
	FS 10	WS	Soil	<2.3			>3.3				Can	362	
	FS 10.1	WS	Lit	<5			5-25	>25			USA	457	

OATS (*Avena sativa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg) (ctd)	Early heading	WS	Soil	1.1-1.6	1.7-2.5		2.6-4.4				Can	596	1.7 mgCu/kg associated with 85% max. shoot yield.
	FS 2-10	YEB	Soil			1.3					Aust	937	
	Mid to late Till	YMB	F,D		2-4		5-50				Aust	1053	
	Mid-Till	Young LB	Soil			1.0					Aust	649	
	Mat	Grain	Soil	0.9	0.9		1.7				Aust	937	
	Mat	Grain	Soil	0.6-1.8			1.4-5.9				Fin	452	
Zn(mg/kg)	45 DAS	WS	F		26		29-38				Ind	992	Three levels of Zn applied.
	46 DAS	WS	FSC	<11	19-22						Aust	170	
	Till	WS	F	4.5-5.8	5.5-6.4		7.6-12.1				Aust	338	Ranges for four cvv. grown at two Zn deficient sites.
	FS 5-6 FS 7-8	WS	Lit				25-70 20-70				Ger	82	
	FS 10.1	WS	Lit	<15			15-70	>70			USA	457 1044	
	Mid to late Till	YMB	F,D	<14	14		15-70				Aust	1053	
	Pre-Head	Upper LB	F,S				20-70				USA	456	
	Mat	Grain	F		16-17		17-19				Ind	992	Three levels of Zn applied.
Mn(mg/kg)	Young plants	WS	S						300		Ger	1117	Critical for acidic soils pH<4.7.
	FS 5-6 FS 7-8	WS	Lit				40-100 35-100				Ger	82	
	FS 6	WS	F			16					Can	474	Critical at 90% max. grain yield.
	<45 cm tall	WS	F			17.5					Ger	278	
	FS 10	WS	S	<15	20-25		>30				USA	372	
	FS 10	WS	F			9					Can	474	Critical at 90% max. grain yield.
	FS 10.1	WS	F,S	<5	5-24		25-100	>100			USA	457 1044	
	Fl	WS	S	<14			14-150				Aust	750	
	Mid to late Till	YMB	F,D	<12	12-24		25-300	400-600		700	Aust	1053	Symptoms present in toxic range.
	Pre-Head	Upper LB	F,S				25-100				USA	456	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	FS 10	Flag leaf	F			10					Can	474	Critical at 90% max. grain yield.
	FS 10.5	Flag + next older LB	S	<12-15							Can	582	
	Mat	Grain	Soil			~16					Aust	459	Critical at 100% max. yield
	Mat	Grain	F				22-39				Can	356	Values for crops which did not respond to applied Mn.
Fe(mg/kg)	26 DAS	WS	SC	<50			50-80				USA	150	
	Booting (ZS45)	WS	F				41-65				Can	358	Values for crops which did not respond to applied Fe.
	FS 10.1	WS	Lit		<40		40-150	>150			USA	457 1044	
	Pre-head	Upper LB	F,S				25-100				USA	456	
	Mat	Grain	F				24-45				Can	358	Values for crops which did not respond to applied Fe.
Al(mg/kg)	FS6	WS	Soil							>70	Ger	346	
	Pre-Head	Upper LB	F,S				<200				USA	456	
B(mg/kg)	FS 5-6 FS 7-8	WS	Lit				6-12 5-10				Ger	82	
	FS 10	WS	Soil	1.1-3.5			6-15			>35	Can	352	
	FS 10.1	WS	F,S				5-10				USA	1044	
	FS 10.5	WS	F		<2		2-10			>10	NZ	205	
	Mid to late Till	YMB	F,D	<2	2-4		5-10	11-20		30-100	Aust	1053	Toxic range is 'excessive'.
	Pre-Head	Upper LB	F,S				3-20				USA	456	
	Mat	Straw	Soil		5-8		14-21			>45	Can	352	
Mo(mg/kg)	FS 5-6 FS 7-8	WS	Lit				0.2-0.4 0.15-0.4				Ger	82	
	FS 10	WS	Soil				0.2-0.28				Can	352	
	FS 10.1	WS	Lit		<0.2		0.2-0.3	>0.3			USA	457 1044	
	Mid to late Till	YMB	F,D	<0.05	0.05-0.09		0.1-0.5	0.6-0.7			Aust	1053	
	Mat	Grain	Soil				0.33-0.5				Can	352	
Ni(mg/kg)	35 DAS	Leaf	RSC	0.017			0.10				USA	156	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Olearia phlogopappa													
N(%)	Veg	Lateral S	Sand/Peat				2.3				Aust	237	For optimum dry matter production
P(%)	Veg	Lateral S	Sand/Peat				0.25				Aust	237	For optimum dry matter production
K(%)	Veg	Lateral S	Sand/Peat				0.4				Aust	237	For optimum dry matter production
Ca(%)	Veg	Lateral S	Sand/Peat				0.6				Aust	237	For optimum dry matter production
Mg(%)	Veg	Lateral S	Sand/Peat				0.7				Aust	237	For optimum dry matter production
PEANUT (_Arachis hypogaea_)													
N(%)	25-33 DAT	WS	SC	1.64	2.57		4.09-4.39				Aust	75	cv. Red Spanish
	Fl	WS	F		3.37		3.87				Niger	796	Data relate to pod yield.
	Pre-Fl or Fl	YMB	S,D				3.5-4.5				USA	456	
	R2 (pegging)	YMB	F	<3.2	3.2-3.7	3.8	3.8-4.5	>4.5			Thai	79	cv. Tainan 9; critical conc. corresponds to seed yield ≥1500kg/ha.
	Pre-Fl to Fl	YML	S,D	1.3-2.5	2.8-3.0		3.5-5.0				Aust	1053	
	40 DAS Fl	7th leaf YML	Lit				3.3-3.9 3.0-4.5				USA	315 751	
	Fl	YML	Lit				3.5-4.5				Ger	82	
	Early pegging	Upper S + LB	S				3.5-4.5				USA	930	Tentative range
	138 DAS	Seed	F		2.1-2.5	2.95	3.2-3.8 4.6-4.8				Ind	650	Non-nodulating genotype cvv. Robut 33-1 and J11
	138 DAS	Haulm	F		1.0-1.3		1.3 1.7-2.0 1.5-1.7				Ind	650	Non-nodulating genotype cv. Robut 33-1 cv. J11
P(%)	25-33 DAT	WS	SC				0.28-0.42				Aust	75	cv. Red Spanish
	50-57 DAS	WS	Soil	0.105 0.095	0.17 0.17	0.18 0.19	0.19-0.24 0.20-0.24				Aust	69	Non-sterilized soil, no VAMF Non-sterilized soil, + VAMF
	50-57 DAS	WS	Soil	0.06-0.07	0.15-0.19 0.08-0.10		0.22-0.23				Aust	69	Sterilized soil, + VAMF Sterilized soil, no VAMF
	42 DAS 70 DAS	YMB	F	0.29 0.27			0.32 0.32				Aust	281	
	Pre-Fl	YMB	F	<0.18							Ind	136	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Pre-Fl or Fl	YMB	S,D				0.25-0.5				USA	456	
	R1	YMB	Soil			0.19					Aust	79	cv. White Spanish
	R5-6					0.23							
	R2 (pegging)	YMB	F	<0.19	0.19-0.23	0.26	0.24-0.40	>0.4			Thai	79	cv. Tainan 9; critical conc. corresponds to seed yield ≥1500 kg/ha.
	16 DAE	YML	F	0.15-<0.30		0.30	>0.30-0.40				Aust	67	cv. Virginia Bunch; critical conc. at 90% max. pod yield; linear decline in critical conc. with time during reproductive growth.
	29 DAE			0.15-<0.30		0.30	>0.30-0.38						
	42 DAE (early PS)			0.18-<0.30		0.30	>0.30-0.38						
	60 DAE			0.08-<0.27		0.27	>0.27-0.34						
	70 DAE			0.08-<0.21		0.21	>0.21-0.30						
	85 DAE			0.07-<0.17		0.17	>0.17-0.24						
	100 DAE			0.05-<0.12		0.12	>0.12-0.20						
	Pre-Fl to Fl	YML	S,D	0.13-0.15	0.12-0.23		0.25-0.55	>0.6			Aust	1053	
	Fl	YML	Lit				0.25-0.50				Ger	82	
	40 DAS	7th leaf	Lit				0.15-0.25				USA	315	
	Fl	YML					0.20-0.50					751	
	Early pegging	Upper S +LB	S				0.2-0.35				USA	930	Tentative range
K(%)	39 DAS	WS	RSC	<2.8		2.8-3.4	3.4-3.8				Bra	261	Critical conc. range 80-90% max. yield; Adequate conc. range 90-100% max. yield
	Pre-Fl or Fl	YMB	S,D				2.0-3.0				USA	456	
	Pre-Fl	YMB	F				>0.6				Ind	136	
	R1	YMB	Soil			1.2					Aust	79	cv. White Spanish
	R3					0.5-0.9						133	
	R5-6					0.25-0.35							
	R2 (pegging)	YMB	F	<0.7	0.7-1.3	1.3	1.4-2.5	>2.5			Thai	79	cv. Tainan 9; crit. conc. corresponds to seed yield ≥1500 kg/ha.
	98 DAS	YMB	F		0.43-0.48	0.6	1.0-1.06				USA	1029	1.0% K corresponds to max. pod yield.
	Early pegging	Upper S +LB	S				1.7-3.0				USA	930	Tentative range
	Fl	YML	Lit				2.0-3.2				Ger	82	
	Pre-Fl to Fl	YML	S,D		1.0-1.3		1.6-3.0				Aust	1053	
	40 DAS	7th leaf	Lit				1.0-1.5				USA	315	
	Fl	YML					1.7-3.0					751	
	Early Fl	Leaves	F		0.76		0.55-1.61			1.11-1.65	Nig	481	Data from 2 years; yield depression at high K due to nutrient imbalance.

PEANUT (*Arachis hypogaea*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%)	R2 (pegging)	YMB	F	<0.15	0.16-0.20	0.24	0.21-0.30	>0.30			Thai	79	cv. Tainan 9; crit. conc. corresponds to seed yield ≥1500 kg/ha.
	R3 R5-6	YMB	Soil			0.18-0.22 0.17					Aust	79	cv. White Spanish
	Pre-Fl to Fl	YML	S,D				0.20-0.35				Aust	1053	
	Veg	YML	Lit				0.20-0.35				USA	457	
	40 DAS Fl	7th leaf YML	Lit				0.19-0.25 0.20-0.35				USA	315 751	
	R2 (pegging) R4 (pod formation)	YML	Soil	0.16-0.18 0.18-0.24		0.18 0.20	0.23-0.30 0.21-0.26				Aust	969	cv. White Spanish
	Pre-Fl	Upper leaves	Soil	0.10			0.20				Ind	966	cv. M-13
	Early pegging	Upper S +LB	S				0.2-0.3				USA	930	Tentative range
N/S	U	4th leaf from base	F			13-15					CAfRep, Sen	763	
Ca(%)	28 DAS	WS	Soil	0.23-0.30			0.90-1.02				USA	698	cv. Spanco; growth chamber experiment.
	20 DAT	YMB	FSC	0.15	0.54	0.62	0.98-2.15				Aust	69	cv. Red Spanish
	Pre-Fl or Fl	YMB	S,D				1.25-2.0				USA	456	
	30 DAT	YML	FSC			<0.57			1.67		Aust	1111	cv. Shulamit 2
	30 DAT					1.28			1.70				cv. Virginia Bunch 1
	30 DAT					1.29			1.85				cv. Shulamit 1
	30 DAT					1.63			1.80				cv. Florunner Jumbo
	30 DAT					1.24			1.84				cv. A125L25
	30 DAT					1.63			1.81				cv. TMV-2
	30 DAT					1.49			2.30				cv. Chico
	30 DAT					1.73			2.00				cv. Red Spanish
	30 DAT					1.08			1.62				cv. CBRR4
	30 DAT					1.42			2.05				cv. P126I945 Critical conc. for Ca deficiency and excess correspond to 95% R.Y. for all cvv.
	Fl	YML	Lit				1.2-2.5				Ger	82	
	Pre-Fl to Fl	YML	S,D				1.2-2.4				Aust	1053	
	40 DAS Fl	7th leaf YML	Lit				2.0 1.25-2.0				USA	315 751	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	90 DAS (approx)	YML	F		1.00		1.31-3.77				W Sam	66	Data from 3 sites.
	Mid-Fl	YML	F		0.58-1.17		1.13-1.68				Bra	936	Mean conc. for 2 cvv.
	Early pegging	Upper S +LB	S				1.25-1.75				USA	930	Tentative range
	Mat Mat	Shell Seed	SC			0.15 0.032			0.34 0.061		Aust	1111	cv. Virginia Bunch 1; critical conc. for 95% max. pod yield.
	Mat Mat	Shell Seed	SC			0.12 0.036					Aust	1111	cv. TMV-2; critical conc. for 95% max. pod yield.
	Mat	Seed	F		0.012-0.038	0.037-0.041	0.038-0.066				USA	5	Crit. for max. seed germination of 4 cvv.
	Seed germination	Seed	F			0.015	0.028				USA	4	Runner peanuts; 100% germination at 0.028% Ca in seed.
	Seedl survival	Seed	F			0.020	0.026				USA	4	Runner peanuts; 100% seedling survival after 21 days at 0.026% Ca in seed.
	Mat	Seed	F	0.025-0.048		0.060					Aust	68	cv. Virginia Bunch; critical conc. corresponds to ≤1% of seed showing 'dark plumule' symptoms.
	Mat	Seed	F,Soil	<0.035	0.035-0.045	0.04	0.045				Aust	60	Critical at 95% max. yield
Mg(%)	39 DAS	WS	RSC			0.25-0.3	0.3-0.36				Bra	261	Critical conc. range 80-90% max. yield
	Pre-Fl or Fl	YMB	S,D				0.3-0.8				USA	456	
	98 DAS	YMB	F		0.07-0.09	0.11	0.20-0.24				USA	1029	0.20% Mg corresponds to max. pod yield.
	Early pegging	Upper S +LB	S				0.3-0.8				USA	930	Tentative range
	Pre-Fl to Fl	YML	S,D				0.3-0.8				Aust	1053	
	40 DAS Fl	7th leaf YML	Lit				0.3 0.3-0.8				USA	315 751	
	Fl	YML	Lit				0.30-0.80				Ger	82	
Na(%)	Pre-Fl to Fl	YML	S,D				0.01-0.1	>0.3			Aust	1053	
Cl(%)	Pre-Fl to Fl	YML	S,D				0.3-1.2	>1.5			Aust	1053	
Cu(mg/kg)	Veg R1 R3 R5-6	YMB				1.3 0.7 1.5 1.3					Aust	79 669	cv. White Spanish
	R2 (pegging)	YMB	F	<1.3	1.3-1.7	2.1	1.8-5.0	>5.0			Thai	79	cv. Tainan 9
	U	YFL			1.3-1.6		2.0-3.8				Aust	566	cv. White Spanish
		YFL	Soil			1.7-2.2					Aust	842	cv. White Spanish

PEANUT (*Arachis hypogaea*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg) (ctd)	Pre-Fl to Fl	YML	S,D		3		6-30				Aust	1053	
	Fl	YML	Lit				5-20				USA	315 751	
	Fl	YML	Lit				7-15				Ger	82	
	39 DAS Early Fl (60 DAS) Mat	Shoot tip	Soil			1.2 1.2 1.7					Aust	842	
	Early pegging	Upper S +LB	S				10-50				USA	930	Tentative range
Zn(mg/kg)	56 DAS	WS	Soil F,S							>200	USA	484	
	70 DAS	WS	Soil				<100 - 239		240	240-1000	USA	222	cv. Florunner; Ca/Zn ≤35 critical for diagnosis of Zn toxicity.
	42 DAS 70 DAS	YMB	F	20 24			29 36				Aust	281	
	Pre-Fl	YMB	F	14							Ind	136	
	Pre-Fl or Fl	YMB	S,D				20-50				USA	456	
	R1,R3	YMB				8-10					Aust	76 79	cv. White Spanish
	Early pegging	Upper S +LB	S				20-50				USA	930	Tentative range
	Pre-Fl to Fl	YML	S,D		18-20		25-80	>80			Aust	1053	
	Fl	YML	Lit				20-60				USA	315 751	
	Fl	YML	Lit				20-70				Ger	82	
	PF	YML	S				50 - 302			107-358	USA	711	cv. Florunner; Zn toxicity if Ca/Zn ratio ≤50.
	Pre-Fl	Upper leaves	Soil	21			64				Ind	966	cv. M-13
	Mat Mat	Seed Straw	F		14-20 12-18		25 23				Ind	914	cv. Big Japan cv. Big Japan
Mn(mg/kg)	25-33 DAT	WS	SC				100-212				Aust	75	cv. Red Spanish
	Pre-Fl or Fl	YMB	S,D				50-350			600-800	USA	456	
	U	YMB	S	<10							USA	826	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	18 DAT	YML	FSC						2920 1290		Aust	33	cv. Virginia Bunch; NO_3-N in nutrient soln. cv. Red Spanish; NO_3-N in nutrient soln.
	22 DAT	YML	SC					512			Aust	33	cv. Red Spanish; N_2-fixing plants.
	Pre-Fl to Fl	YML	S,D		25		50-300	350-700		>700	Aust	1053	
	Fl	YML	Lit				50-100				Ger	82	
	Fl	YML	Lit				20-350				USA	315 751	
	49 DAS	YML	F	7-10		13	19-39	135-180			USA	708	cv. Florunner; critical and deficient conc. relate to plants grown at pH(water) = 6.8±0.1.
	63 DAS			7-12		15	26-64	184-292					
	77 DAS			8-11		15	34-66	225-310					
	91 DAS			9-11		15	37-100	309-413					
	105 DAS			9-13		13	36-115	369-511					
	119 DAS			9-12		12	33-118	376-544					
	90 DAS (approx)	YML	F				83-170		190	244-687	W Sam	66	Data from 3 sites; Mn toxic if Ca/Mn ratio <80.
	U	Leaves	Soil							>46	USA	131	
	Early pegging	Upper S +LB	S				100-350				USA	930	Tentative range
Fe(mg/kg)	63 DAS	WS	Soil	100			115				Bulg	1110	cv. Sadovski prodobreni; no sig. difference.
	30 DAS	YEB	RSC	17		36					Aust	982	cv. Tainan 9, inoculated with *Bradyrhizobium* NC92.
	50 DAS			16		39							
	50 DAS			25		32							cv. Tainan 9, inorganic N.
	Var	YEB+2, YEB+3	Soil,F	Chlorophyll concentration							Isr	201	cv. Shulamit
	Early pegging	Upper S +LB	S				100-250				USA	930	Tentative range
	Pre-Fl or Fl	YMB	S,D				50-300				USA	456	
	Veg	YML	Lit				60-300				USA	457	
	Fl	YML	Lit				50-300				USA	751 315	
	63 DAS	WS	Soil	27 Fe^{2+}			48 Fe^{2+}				Bulg	1110	cv. Sadovski podobreni; Fe^{2+} separates deficient and adequate plants.
	Var	Buds,YOL	F			<6					Ind	779	cv. TMV2; Fe^{2+} extracted from fresh tissue with 1.5% *o*-phenanthroline.
Fe^{2+}(mg/kg)	60 DAS	YML	Soil	4.3-6.3 3.1-4.7			8.1-10.6 7.7-11.2				Ind	505	Data for 8 cvv. Data for 15 F1 populations.
	63 DAS	WS	Soil	0.27 Fe^{2+}/Fe			0.41 Fe^{2+}/Fe				Bulg	1110	cv. Sadovski podobreni; Fe^{2+} separates deficient and adequate plants.

PEANUT (*Arachis hypogaea*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Al(mg/kg)	Pre-Fl or Fl	YMB	S,D				<200				USA	456	
	Fl	YML	Lit				<200				USA	315 751	
B(mg/kg)	Pre-Fl or Fl	YMB	S,D				25-60				USA	456	
	102 DAS	YMB	F				<112			>235	S Afr	100	
	Pre-Fl	YMB	F		18						Ind	136	
	V2 R1-2 R5-6	Expanding LB YMB YMB	SC,F F F	<13	13-23	12 22-23 22-23	24-50	>50			Aust/ Thai	79	Crit. at 90% maximal LB elongation rate. cv. Tainan 9; crit conc. for 90% max. seed yield.
	Early pegging	Upper S +LB	S				20-50				USA	930	Tentative range
	Early pod	Mature LB from upper plant	F						58		S Afr	102	Criterion at 90% kernel yield
	Pre-Fl to Fl	YML	S,D		18-20		25-60				Aust	1053	
	Fl	YML	Lit				25-70				Ger	82	
	Fl	YML	Lit				20-60				USA	315 751	
	30 DAS	YFL YFL+2			1.8 4.7		35.1 30.3				Aust	493	cv. White Spanish; marginally deficient conc. at 80% max. dry wt.
	76 DAS	5 Youngest leaves on veg shoot	SC				53-141		150	230-407	Isr	515	cv. Shulamit; crit. for seed yield at 108 DAS.
	30 DAS	Leaflet (Leaf6) Leaflet (Leaf7)	Soil				50 50			1450 1175	USA	196	cv. Argentine
	Mat	Seed	F	4		10	11-14				Thai	818	cv. Tainan 9
	Mat	Seed	S			13					Thai	658	Seed with hollow heart disorder.
	Mat	Seed	F			13.2	23-25				Thai	819	Crit. conc. at 82% max. seed yield; 34% of seed with hollow heart disorder.
Mo(mg/kg)	Fl	WS	F		0.01-0.06						Niger	797	cv. 55-437; single superphosphate decreased Mo conc. in WS.
	Pre-Fl or Fl	YMB	S,D				0.1-5				USA	456	
	R1-2 R 5-6	YMB	SC	<0.020	0.02-0.05	0.015-0.05 0.015-0.018	0.051-1.0	>1.0			Aust/ Thai	79	Crit. conc. for 90% max. seed yield.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	R1-2	YMB	SC			0.13					Aust	79	
	R1-2	Nodules				7.0							
	Pre-Fl to Fl	YML	S,D		0.05		0.10-5.0				Aust	1053	
	Fl	YML	Lit				0.50-1.00				Ger	82	
	Fl	YML	Lit				0.1-5.0				USA	315 751	
	Early pegging	Upper S+LB	S				1-5				USA	930	Tentative range
	Fl	Upper mature LB + P	F		0.06		0.13-0.14				USA	1056	Plants with Mo were sometimes darker green
	Mat	Seed	F		0.88		2.3-5.2				USA	1056	

PEARL MILLET (*Pennisetum glaucum*)

N(%)	34-37 DAS	Leaves	F			2.95,3.8					USA	618	cv. MLS; data from 2 years; crit. conc. derived by reviewer.
	57-62 DAS	Leaves				2.30,2.35							
	80-85 DAS	Leaves				2.20							
	95-96 DAS (Mat)	Leaves				1.65							
	95-96 DAS (Mat)	Grain				1.48.1.55							
	Sowing to panicle initiation	Leaves	Sand			2.1					Aust	203	cv. MX001; crit. conc. corresponds to max. rate of leaf area expansion.
	Panicle differentiation					1.8							
	Mat	Leaves	RSC		2.66-3.42		2.95-3.18				USA	933	Hybrid 85DA x 86-7497-4; dry matter yield and seed yield reduced at high NH_4^+: NO_3^- in soln.
	27 DAS	Whole plant	SC	1.40	1.96-2.67	3.2	3.36				Neth	132	Tentative crit. conc. estimated by reviewer.
	Mat	Grain	F		1.88		2.32				Niger	757	cv. CIVT; mean data from 2 year study.
	Mat	Seed	F		1.32-1.62		1.54-1.63				Niger	798	cv. HKP; grown as sole crop and intercrop with cowpea.
P(%)	20 DAS	WS	F		0.22		0.27				Niger	795	cv. CIVT; seed coating treatment with P.
	28 DAE	LB	Soil*	0.20	0.30	0.36	0.36-0.37				USA	720	cv. ICTP8203; tentative critical conc. derived by reviewer. Piper Steenbjerg curvature evident in plots at 56, 70, 80 DAE. * Pot expt conducted outdoors.
	42 DAE			0.07-0.08	0.15	0.17	0.19						
	56 DAE			0.03-0.05	0.06	0.06	0.16						
	70 DAE			0.03-0.05	0.03	0.05	0.06						
	80 DAE			0.03	0.03	0.04	0.05						

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
PEARL MILLET (*Pennisetum glaucum*) (ctd)													
P(%) (ctd)	Head	2nd leaf below head	F		0.25-0.30		0.33				Niger	223	
	Mat	Grain	F		0.28		0.38				Niger	757	cv. CIVT; mean data from 2 year study.
	Mat	Grain	F	0.18			0.25				Niger	62	
Zn(mg/kg)	Seedl (3 leaves)	WS	Soil		9.7-43	40	46 - 109				USA	786	Crit. conc. for 95% max. seed yield; cv. RMP-1.
	42 DAS	WS	Soil			18					Ind	922	Diagnostic criterion at 80% max. shoot yield.
	Ear stage	WS	Soil	9			12-18			41-193	Nig	905	Criterion at near max. shoot yield.
	Head	WS	Soil	9	12	13	14 - 193				Nig	905	cv. PHB3
	Fl Mat	Flag leaf Seed	Soil		 13	24 15	 20-51				USA	786	Crit. conc. correspond to 95% max. seed yield; cv. RMP-1.
Al(mg/kg)	37 DAS	WS	Soil						600		USA	895	
PIGEON PEA (*Cajanus cajan*)													
N(%)	25-33 DAT	WS	SC				2.86-4.23				Aust	75	Data for 4 cvv.
	74 DAS (Fl) 96 DAS (Early PF) 118 DAS (Late PF)	WS	F	1.9-2.0 1.5-1.9 1.5-1.7			2.7 2.0-2.5 1.6-1.8				Aust	391	cv. Quest; grown at different rates of applied Fe.
	Early Fl	YMB	SC	<2.38		3.0	>4.0				Aust	848	
	91 DAS	LB	Sand	2.9			3.2				Trin	662	
	Mat	Seed	F		2.4-2.6		2.5-2.6				Aust	391	cv. Quest; grown at different rates of Fe.
P(%)	49 DAS	WS	Soil		0.19-0.21	0.25	0.30-0.36				Thai	754	Crit. conc. derived from mean data for 2 soils.
	95 DAS	WS	Soil	0.04-0.08	0.10-0.21		0.20				Aust	1057	cv. Quantum
	110 DAS	WS	Soil	0.05-0.06	0.05-0.08		0.06-0.08				Bra	233	Deficient corresponds to relative yield <50%.
	25-33 DAT	WS	SC				0.28 - 0.43			0.90-1.99	Aust	75	Data for 4 cvv.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	96 DAS (50% of plants Flowering)	YMB	F		0.19-0.21	0.22	0.22-0.24				SiLe	824	Critical at 95% max. seed yield.
	Early Fl	YMB	SC	<0.07		0.10	0.12				Aust	848	
	30 DAS 60 DAS 90-100 DAS 120-130 DAS 160-165 DAS	LB	F				0.35-0.38 0.3-0.33 0.19-0.28 0.15-0.2 0.15-0.18				Ind	898	Conc. range at near max. yield
	91 DAS	LB	Sand	0.08			0.24				Trin	662	
	25 DAS 51 DAS (Early Fl)	YML	Soil		0.17 0.23	0.43 0.30	0.77-0.86 0.31-0.47				Aust	433	cv. QPL95
	25 DAS 51 DAS (Early Fl)	YML+1	Soil		0.12 0.20	0.34 0.29	0.33-0.40 0.28-0.42				Aust	433	cv. QPL96
	78 DAS	Leaves	F		0.16-0.41		0.22-0.38				Jap	11	Variable data for 6 cvv.
P(µmol/g FW)	16 DAT	WS	FSC			27					Aust	279	cv. Royes; corresponds to critical soln conc. of 1.0 µM.
K(%)	Early Fl	YMB	SC	1.9		0.78	1.2-2.6				Aust	848	Piper-Steenbjerg effect observed
	91 DAS	LB	Sand	0.81	0.81		1.72				Trin	662	
S(%)	Early Fl	YMB	SC				0.16-0.32				Aust	848	
Ca(%)	49 DAS	WS	Soil	0.32	0.77-1.35	1.75	2.13				Thai	754	
	Early Fl	YMB	SC	0.08		0.84	0.84-1.2				Aust	848	
	20 DAT	YMB	FSC	0.07	0.65-2.35		2.52				Aust	74	cv. Royes
	91 DAS	LB	Sand	0.13			1.32				Trin	662	
Mg(%)	Early Fl	YMB	SC	0.03	0.11-0.16	0.17	0.18-0.24				Aust	848	
	91 DAS	LB	Sand	0.26			>0.26				Trin	662	
Cu(mg/kg)	Early Fl	YMB	SC		1-10	10	10-12				Aust	162	Deficiency symptoms did not develop
Zn(mg/kg)	42 DAS	WS	Soil	10-13							Ind	903	Seven cvv. examined
	Early Fl	YMB	SC				7-48				Aust	162	
Mn(mg/kg)	Veg	WS	FSC				78-300			300	Aust	242	cv. Royes
	Early Fl	YMB	SC	<17		18	19-95				Aust	162	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
PIGEON PEA (*Cajanus cajan*) (ctd)													
Mn(mg/kg)	18 DAT	YML	FSC						1140		Aust	33	cv. QPL42; NO_3-N in nutrient soln.
(ctd)	18 DAT								910				cv. Hunt; NO_3-N in nutrient soln.
	22 DAT	YML	SC						2200		Aust	33	cv. Hunt; N_2-fixing plants.
Fe(mg/kg)	Early Fl	YMB	SC	<166		151	151-191				Aust	162	Treat data cautiously
	91 DAS	LB	Sand	50-69			126				Trin	662	
Al(mg/kg)	49 DAS	WS	Soil					75	80	125-175	Thai	754	
B(mg/kg)	Early Fl	YMB	SC	<10		10	10-52				Aust	162	
Mo(mg/kg)	Early Fl	YMB	SC				0.23-0.39				Aust	162	
PYRETHRUM DAISY (*Tanacetum cinerariifolium*)													
P(%)	Budding	A	F	<0.4							Aust	873	Apical tissues recommended Predictive for achene yield
K(%)	Budding, 1st crop	A	F			2					Aust	872	Apex = top 50 mm of flowering stems Predictive at 70% achene yield
	Budding, 2nd crop					2.5							
RICE (*Oryza sativa*)													
FS = Feeke's scale of cereal growth (see reference 511). The 'Y blade' is defined in reference 1036. 'Y+1' = the next older leaf blade below the Y blade.													
N(%)	25 DAT	WS	F,S	Models developed for correcting N conc. in WS at sampling to a fixed dry weight for assessing N status of rice.							Thai	612	
	Till (30 DAT)	WS	Soil			3.35-3.75	3.76-5.0				Ind	135	Critical range covers >90% max. shoot yield.
	Panicle init.	WS	F	<1.29	1.3-2.09	2.1-2.49	2.5-3.0	>3.0			Aust	63 509	Irrigated cv. Amaroo with crop density 600-700 plants/m^2.
	Panicle init.	WS	F	<1.09	1.1-1.49	1.5-1.69	1.7-2.5	>2.5			Aust	63 65 509	Irrigated cv. Amaroo with crop density 1100-1200 plants/m^2.
	Panicle init.	WS	F	20-70	70-100	80	100-140	>140			Aust	1078	Units are kgN/ha in shoots of crops not damaged by cold temperatures. Preferred test for diagnosing N deficiency in southern NSW.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Till	Y blade	U			2.5					IRRI	1107	
	Mid-Till Max. Till Panicle init.	Y blade	S			3.0 2.6 2.4	3.0-4.0 2.8-3.6 2.6-3.2				USA	609	
	Mid-Till Panicle init.	Y blade	S				3.8-5.1 2.9-4.2				USA	1044	Conc. range found in plants without symptoms.
	Max. Till Max. Till	Y blade Y+1	F			2.4-2.8 2.3-2.4					USA	986	Critical ranges related to grain yield
	Max. Till	Y or Y+1	F			2.2-2.3					USA	986	Critical at 70-75% max. grain yield
	Panicle init.	YEB	F			2.5-3.2	2.6-3.6				USA	134	Critical at 90% max. grain yield. Criteria usually higher for long grained and semi-dwarf cvv. than for medium-grained cvv.
	FS 3-5	YMB (Y blade)	F,D	<2.5	2.5-2.9		3.0-4.5	5.5			Aust	1053	
	Max. Till Panicle init.	YMB	Lit		2.6-2.7 2.4-2.5		2.8-3.6 2.6-3.2	>3.6 >3.2			USA	457	
	Before Fl	YMB	Lit				2.9-4.2				Ger	82	
	Panicle init.	YMB	F	A chlorophyll meter was assessed for estimating degree of crop N stress in rice.							Aust	999	Correlation between leaf greenness and plant N stress was reasonably strong.
	Various	YMB and flag leaf	F	Chlorophyll meter readings based on adjustments to leaf weight were evaluated for assessing the N status in rice.							IRRI	554	
	Fl	Flag leaf	Lit			2.0-2.5					Fra	182	Critical for irrigated rice.
	Flag leaf stage	Uppermost 2 leaves	Soil			1.8-1.95	1.96-2.5				Ind	135	Critical range covers >90% max. shoot yield.
	Panicle formation-just before head.	Crop canopy	F	Spectral reflectance assessed for estimating degree of crop N stress in rice.							Jap	971	Reflectance strongly correlated with N conc. and chlorophyll in young leaf blades.
P(%)	14 DAT	WS	SC	0.09-0.29			0.43-0.83				USA	263	
	25 DAT	WS	F,S	Models developed for correcting P conc. in WS at sampling to a fixed dry weight for assessing P status of rice.							Thai	612	
	Till (30 DAT)	WS	Soil				0.37-0.55				Ind	135	Adequate range for 90% max. shoot yield.
	25 DAS 50 DAS 75 DAS	WS	RSC	<0.7 <0.18 <0.26		0.7-0.8 0.18-0.26 0.26-0.36	0.8-0.86 0.26-0.4 0.36-0.48			>1.2	Bra	260	Deficient (showing symptoms); critical conc. range 80-90 % max. yield (no symptoms); adequate conc. range 90-100% max. yield
	35 DAS	WS	RSC			0.43-0.51					Indon	1112	Critical range at near max. shoot yield for 2 cvv.

RICE (*Oryza sativa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	35 DAS	WS	Soil			0.25					USA	417	Critical at 90% max. shoot yield
	55 DAS	WS	F	0.37-0.52	0.57		0.59-0.66				Aust	387	P supply did not affect P conc. in grain or straw.
	73 DAS	WS	Soil	0.12	0.22		0.27				Bra	269	Data for 25 cvv. grown at 3 levels of P supply.
	112 DAS	WS	Soil	0.11			0.17				Aust	859	
	FI	WS	F	0.08-0.18			0.14-0.22				Bra	268	Mean P conc. of 75 cvv. at 2 levels of P supply.
	FI	WS	F	0.13-0.18			0.19-0.21				Bra	267	Four levels of applied P.
	Till	Y blade	U			0.1					IRRI	1107	
	Mid-Till Panicle init.	Y blade Y blade	S				0.14-0.27 0.18-0.29				USA	1044	
	FS 3-5 (Mid Till)	YMB (Y blade)	F,D	<0.1	0.1-0.12		0.2-0.5	>0.55			Aust	1053	
	Max. Till Panicle init.	YMB	Lit	0.08-0.09 0.07-0.08			0.1-0.18 0.09-0.18	>0.18 >0.18			USA	457	
	Before FI	YMB	Lit				0.2-0.4				Ger	82	
	56 DAS (End Till)	Main stem leaves	Soil			0.18					Aust	896	Critical at max. grain yield.
	Flag leaf stage	Uppermost 2 leaves	Soil				0.21-0.24				Ind	135	Adequate range for 90% max. shoot yield.
	FI Mat	Flag leaf Straw	Lit			0.15-0.18 0.08-0.1					Fra	182	Critical for irrigated rice.
	Mat	Straw	U							1.0	IRRI	1107	
P04-P (mg/kg)	Mid-Till Max. Till Panicle init.	Y blade	S			1000 800 800	1000-1800 1000-1800 1000-1800				USA	609	P04-P extracted in 2% acetic acid
K(%)	25 DAS 50 DAS 75 DAS	WS	RSC	<3.75 <3.7 <3.5		3.75-4.25 3.7-4.0 3.5-3.62	4.25-4.35 4.0-4.62 3.62-3.99				Bra	260	Deficient (showing symptoms); critical conc. range 80-90% max. yield (no symptoms); adequate conc. range 90-100% max. yield
	Till (30 DAT)	WS	Soil			4.35	4.36-5.2				Ind	135	Critical at 90% max. shoot yield.
	48 DAT	WS	F	1.99-2.23			2.78				Nig	1102	
	FI	WS	F	<1.85			>1.9				Bra	270	Data for four cvv.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Till	Y blade	U			1.0					IRRI	1107	
	Mid-Till Panicle init.	Y blade	S				1.5-2.7 1.2-2.5				USA	1044	
	Mid-Till Max. Till Panicle init.	Y blade	S			1.2 1.0 0.8	1.4-2.8 1.2-2.4 1.0-2.2				USA	609	K extracted in 2% acetic acid.
	FS 3-5 (Mid Till)	YMB (Y blade)	F,D	<1.2	1.2-1.4		1.5-3.5	>3.5			Aust	1053	
	Max. Till Panicle init.	YMB	Lit		1.0-1.1 0.8-0.9		1.2-2.4 1.0-2.2	>2.4 >2.2			USA	457	
	Before Fl	YMB	Lit				1.8-2.6				Ger	82	
	Flag leaf stage	Uppermost 2 leaves	Soil			1.6	1.6-3.0				Ind	135	Critical at 90% max. shoot yield.
	Mat	Straw	U			1.0					IRRI	1107	
	Mat	Straw	Lit			~1.0					Fra	182	Critical for irrigated rice.
	Mat	Grain	Soil			0.4					Ind	46	Critical at 90% max. grain yield.
S(%)	1st Till (25 DAS)	WS	Soil	0.12			0.2	0.44			Aust	778	
	Mid-Till (39 DAS)			0.1	0.14		0.17	0.33					
	60 DAS			0.06	0.08		0.15						
	Till	WS	Soil			0.11					IRRI	440	Critical at 80% max. shoot yield; critical N/S = 15
	Till (30 DAT)	WS	Soil			0.17-0.22	0.23-0.32				Ind	135	Critical covers >90% max. shoot yield.
	Till	WS	U			0.16					IRRI	1107	
	Till to Fl	WS	Lit				N%>1.6; S%<0.1; N/S>15				Aust	99	Interpretation: N adequate; S deficient
	Till to Fl	WS	Lit				N%>1.6; S%0.1-0.15; N/S>10				Aust	99	Interpretation: N adequate; S marginally deficient
	Till to Fl	WS	Lit				N%>1.6; S%>0.15; N/S<10				Aust	99	Interpretation: N adequate; S adequate
	Till to Fl	WS	Lit				N%<1.6; S%>0.15; N/S<10				Aust	99	Interpretation: N deficient; S adequate
	Till to Fl	WS	Lit				N%<1.6; S%<0.1; N/S variable				Aust	99	Interpretation: N deficient; S deficient
	112 DAS	WS	Soil	0.09			0.38				Aust	859	
	Fl	Y blade	Soil			0.15					Nig	697	Critical at max. grain yield; C-shaped curvature present

RICE (*Oryza sativa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%) (ctd)	28 DAS 42 DAS 63 DAS	LB	Soil	<0.16 <0.13 <0.11							Nig	697	
	Flag leaf stage	Uppermost 2 leaves	Soil			0.09	0.09-0.14				Ind	135	Critical covers >90% max. shoot yield.
	Mat	Straw	Soil			0.1					Nig	697	Critical at max. grain yield; C-shaped curvature present.
	Mat	Straw	Soil			0.055					IRRI	440	Critical at 80% max. straw yield; critical N/S = 14
	Mat	Straw	U			0.06					IRRI	1107	
	Mat	Straw	F, Soil	0.02		0.05					Bra	1042	Critical at max. yield for three cvv.
	Mat	Grain	Soil			0.11					Aust	778	Critical at 90% max. yield; critical N/S = 14
	Mat	Grain	Soil			0.065					IRRI	440	Critical at 80% max. grain yield; critical N/S = 26
	Mat	Grain	Soil			0.12					Nig	697	Critical at max. grain yield; C-shaped curvature present
	Mat	Grain	Lit			0.1					Aust	99	Diagnostic relationship for straw was variable.
SO_4-S (mg/kg)	Till	WS	Soil			150					IRRI	440	Critical at 80% max. shoot yield
	1st Till (25 DAS)	WS	Soil	70		95	150	1600			Aust	778	Criticals at 90% max. yield.
	Mid-Till (39 DAS)			50	64-75	90	130	1200					
	39 DAS			23	45	70	120						
	Mat	Straw	Soil			100					IRRI	440	Critical at 80% max. straw yield
SO_4-S/S(%)	Till	WS	Soil			15					IRRI	440	Critical at 80% max. shoot yield
	Mat	Straw	Soil			15					IRRI	440	Critical at 80% max. straw yield
Ca(%)	38 DAS	WS	SC	<0.15	0.19-0.22		>0.36				USA	345	Values for saline-stressed plants.
	56 DAS	WS	SC	0.08-0.14							Phil	635	Values for Na stressed plants. Na/Ca ratio (molar basis) may indicate Ca deficiency.
	100 DAS	WS	RSC			0.36-0.45	0.45-0.65			>0.75	Bra	260	Critical at 80-90% max. yield; adequate at 90-100% max. yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mid-Till Panicle init.	Y blade	S				0.16-0.39 0.19-0.39				USA	1044	
	FS 3-5	YMB (Y blade)	F,D				0.1-0.3				Aust	1053	
	Max till Panicle init.	YMB	Lit		<0.15 <1.2		0.15-0.3 1.2-1.4	>0.3 >1.4			USA	457	
	Before Fl	YMB	Lit				0.2-0.6				Ger	82	
	38 DAS	Uppermost 3 leaf blades	SC	~0.32	~0.4		>0.8				USA	345	For saline-stressed plants showing Ca deficiency symptoms.
	Mat	Straw	U			0.15					IRRI	1107	
Mg(%)	33 DAS	WS	Soil				0.24-0.33	0.48-0.59			Bra	265	High range associated with reduced root and shoot yield.
	100 DAS	WS	RSC			0.12-0.17	0.17-0.3			>0.5	Bra	260	Critical at 80-90% max. yield; adequate at 90-100% max. yield.
	Till Early panicle form.	WS	SC	<0.07 <0.06	0.07-0.14 0.06-0.14	0.11 0.12	0.14-0.21 0.14-0.22				China	766	Criticals at 80% max. shoot yield.
	Mid-Till Panicle init.	Y blade	S				0.12-0.21 0.16-0.39				USA	1044	
	FS 3-5	YMB (Y blade)	F,D		<0.12		0.14-0.25				Aust	1053	
	Max till Panicle init.	YMB	Lit		<0.15 <0.20		0.15-0.3 0.2-0.3	>0.3 >0.3			USA	457	
	Before Fl	YMB	Lit				0.2-0.3				Ger	82	
	Till Early panicle form.	Leaves	SC	<0.07 <0.08	0.07-0.14 0.08-0.16	0.13 0.14	0.14-0.21 0.16-0.23				China	766	Criticals at 80% max. shoot yield.
	Mat	Straw	U			0.1					IRRI	1107	
Na(%)	22 DAS	WS	SC							>1.0	Phil	18	Considerable variation between cvv. intolerance to Na was observed.
	Veg	WS	RSC	Na concentrations in rice shoots are variety-dependent. Diagnostic criteria are difficult to assess with any certainty.							UK	1106	
	FS 3-5	YMB (Y blade)	F,D				0.01-0.2	0.4-0.5			Aust	1053	High range is tentative.
Si(%)	Mat	Straw	Lit			~8.0					Fra	182	Critical for irrigated rice. Critical for rainfed rice maybe ~3 to 4% Si.
	Mat	Straw	F			5.0					IRRI	1107	
Cl(%)	FS 3-5	YMB	F,D				0.1-0.6	1.9-2.2		2.5	Aust	1053	Toxic value is tentative.

RICE (*Oryza sativa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg)	30 DAS	WS	RSC						35		Port	532	
	30 DAS	WS	RSC				3.6	5.1		8-92	Port	533	High and toxic range reduced photosynthesis.
	Pre-Fl	WS	Soil			6.5					Pak	478	Lowland rice.
	FS 3-5	YMB (Y blade)	F,D		3-5		7-15				Aust	1053	
	Max till Panicle init.	YMB	Lit		6-7 6-7		8-25 8-25	>25 >25			USA	457	
	Before Fl	YMB	Lit				7-12				Ger	82	
	Flag leaf stage	Uppermost 2 leaves	Soil			2.5	2.5-8.5		80		Ind	135	Critical at 90% max. shoot yield. Toxic criteria at 80% max. shoot yield.
	Mat	Straw	U			<6				30	IRRI	1107	
Zn(mg/kg)	21 DAT	WS	F	<15	15-20		>20				Phil	1108	Zn conc. <10 mg/kg are definitely Zn deficient.
	28 DAS	WS	RSC	14	16		30				USA	1105	
	Till (30 DAT)	WS	Soil			75-85	86-375		375	500	Ind	135	Critical range cover 80-90% max. shoot yield.
	35 DAT	WS	Soil		35		43				Ind	870	
	37 DAS	WS	Soil			15-18					IRRI	284	
	60 DAT	WS	Soil	13			15-31				USA	866	Flooded rice.
	Till	WS	F	13			23-36				Ind	866	Grown on an alkaline sodic soil. Gypsum applications depressed Zn conc. but increased yield. Adequate range for near max. shoot and grain yield.
	Till	WS	U			10					IRRI	1107	
	Pre-Fl	WS	Soil			17.4					Pak	478	Lowland rice
	Fl	WS	Soil	21-33			48-95			181-603	Ind	792	
	Mid Till Panicle init.	Y blade	S				22-161 33-160				USA	1044	
	FS 3-5	YMB (Y blade)	F,D	<15	15-18		20-60				Aust	1053	
	Max. Till Panicle init.	YMB	Lit		20-24 16-17		25-50 18-50	>50 >50			USA	457	
	Before Fl	YMB	Lit				30-70				Ger	82	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	55 DAS	Top blade	F			17-25 +					Pak	188	
	50 DAS	3rd LB	Soil		15-21	19	25-30	32-50			Ind	868	
	35 DAT	Leaf blades	Soil		28		36				Ind	870	
	Early Fl	Flag leaf	Soil			19					USA	786	Critical at 95% max. shoot yield.
	Flag leaf stage	Uppermost 2 leaves	Soil			10	11-40		40	45-90	Ind	135	Critical covers 80-90% max. shoot yield.
	Mat	Straw	U							1500	IRRI	1107	
	Mat	Grain	Soil			15					USA	786	Critical at 95% max. grain yield. Distinctive C-shaped curvature in diagnostic relationship.
	Mat	Grain	Soil	16-24	20-34		26-33				Ind	759	Deficient <80% max. grain yield. Marginal 80-90% max. grain yield.
Mn(mg/kg)	30 DAT	WS	RSC				57-130			770-7370	USA	656	Adequate range for plants not affected by high Mn supply.
	Seedl (33-56 DAS)	WS	F			20					USA	940	Critical associated with deficiency symptoms and grain yield responses.
	Till	WS	U			20				7000	IRRI	1107	
	Various	WS	SC	<20						>2500	Phil	979	
	Mid-Till Panicle init.	Y blade	S				237-744 252-792				USA	1044	
	FS 3-5	YMB	F,D				40-500	600-1000		>5000	Aust	1053	
	Max. Till Panicle init.	YMB	Lit	100-199 100-149			200-800 150-800	>800 >800			USA	457	
	Before Fl	YMB	Lit				40-100				Ger	82	
Fe(mg/kg)	17 DAT	WS	SC							147-283	Bra	262	Toxic range for plants with reduced yield and root length.
	Till (30 DAT)	WS	Soil			50-60	61-170				Ind	135	Critical range covers 80-90% max. shoot yield.
	35 DAT	WS	RSC							3200-9575	Bra	266	Rice cvv. differ in their tolerance to Fe toxicity.
	40 DAS	WS	Soil			45 Fe^{2+}					Ind	477	
	48 DAS	WS	F							>730	Nig	1102	Fe toxicity partly linked to bronzing symptoms in rice.
	Till	Y blade	U			70				300	IRRI	1107	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
RICE (*Oryza sativa*) (ctd)													
Fe(mg/kg) (ctd)	Mid-Till Panicle init.	Y blade	S				89-193 74-192				USA	1044	
	Max. Till Panicle init.	YMB	Lit		70-74 60-69		75-200 70-150	>200 >150			USA	457	
	Panicle init.	YMB	F						300		Thai	621	Toxicity occurred when Fe^{2+} conc. in soil solution was >0.7 of total divalent charge.
	50 DAS	Leaves	Soil			44 Fe^{2+}					Ind	869	Critical Fe^{2+} at 90% max. shoot yield.
	40 DAS	Fresh leaves	Soil			45 Fe^{2+}					Ind	477	Total leaf Fe poorly correlated with yield response to applied Fe.
	Panicle init.	3-4 youngest LBs	Soil							250	Burun	318	
	40 DAS	Uppermost 2 leaves	F	29-33 Fe^{2+}	33-38 Fe^{2+}		42-50 Fe^{2+}				Ind	915	Fe^{2+} conc. associated with severe chlorosis. Chlorosis exhibited when shoot Fe/Mn >6.
	Flag leaf stage	Uppermost 2 leaves	Soil			70-80	81-180				Ind	135	Critical range covers 80-90% max. shoot yield.
	Mat	Grain	Soil					125-150		>158	Ind	714	Linked to Fe toxicity symptoms.
Al(mg/kg)	20 DAS	WS	SC				15-18			22-69	USA	1035	
	21 DAS	WS	SC						100-417		Bra	264	Critical at 90% max. shoot yield
	Till	WS	U							300	IRRI	1107	
B(mg/kg)	56 DAS	WS	S						28-59		IRRI	200	Critical at 10% yield reduction. Symptoms occurred when WS conc. >35 mg B/kg.
	FS 3-5	YMB	F,D		<5		5-15				Aust	1053	
	Panicle init.	YMB	Lit		4-5		6-7	>7			USA	457	
	Before Fl	YMB	Lit				6-15				Ger	82	
	Mat	Straw	U			<3.4				100	IRRI	1107	
Mo(mg/kg)	FS 3-5	YMB	F,D				0.2-5.0				Aust	1053	
	Before Fl	YMB	Lit				0.4-1.0				Ger	82	
SAFFLOWER (*Carthamus tinctorius*)													
N(%)	Buds visible	S	Sand	<1.3			>0.78				Aust	957	Average of 2 cultivars
Protein(%)	Mat	Seed	F	<21							USA	365	Diagnostic for seed yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
	Mat	Seed	F	<16.7							Leb	652	Diagnostic for seed yield
Mn(mg/kg)	70 DAS	YOL	F			9-12	20-55				Aust	530	Predictive for seed yield } 3 stats techniques always used. No characteristic symptoms
	70	upper S				2.6-3.1	3.5-8						"
	75	YOL				9-13	20-75						"
	75	Upper S				1.8-2.1	3-4						"
	Mat	Seed				5.6-6.2	6.5-8						Diagnostic for seed yield

SESAME (*Sesamum indicum*)

B(mg/kg)	30 DAS	YML	RSC	16.6-20.7	39-51	53	72-124				Ven	774	Critical conc. at 90% max. seed yield.
	30 DAS			16.6-20.7	39	45	51-124						Critical conc. at 90% max. WS yield.

SORGHUM (*Sorghum vulgare* and *S. bicolor*)

Growth stages (GS) of sorghum are described in reference 1014. YMB = third blade from apex. 3BBE = third blade below ear.

N(%)	Veg (8-10 leaves)	WS	F		1.60-2.29	2.45	2.52-2.68				USA	304	
	28-30 DAS (Veg)	WS	F				2.03-3.58				Aust	987	No yield response to applied N following ungrazed *Centrosema pascuorum* pasture.
	28 DAS (Veg)	WS	F		2.51		2.54-2.70				Aust	987	10% grain yield response to 30kgN/ha after grazing *Centrosema pascuorum* pasture.
	GS 2	WS	F	<3.5?	3.0-4.0		3.5-5.1				USA	538	
	GS 2	WS	S		1.6-2.7		4.3-4.6				USA Ind	453	Survey of 6 studies, which used few fertilizer N rates.
	GS 3				1.6-2.7		2.8-4.4						
	GS 4				1.3-2.4		2.5-3.5						
	GS 5				0.95-1.3		1.9-2.6						
	GS 6				0.95-1.7		1.25-2.1						
	GS 7				0.85-1.15		1.25-2.0						
	GS 8				0.9-1.2		1.35-1.8						
	GS 9				0.95-1.45		1.25-1.75						
	61 DAS	WS	F		0.81-1.82		2.00-2.34				Aust	42	cv. Nugget; grown as sole crop or intercropped with soybean. Conc. predictive for grain yield.
	GS 3	WS	Sand	<1.0	<3.0		3.0-4.0	>4.0			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	Var	WS	F				$N_c = 0.827 + 5.88 \exp(-0.00112X)$				Aust	640	Critical conc. derived as a function of accumulated degree days (X) above 0°C.

SORGHUM (*Sorghum vulgare* and *S. bicolor*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%) (ctd)	1000 degree days*	WS	F			2.7					Aust	640	* Accumulated degree days above a base of 0°C.
	2000 degree days					1.4							
	3000 degree days					1.0							
	4000 degree days					0.9							
	43 DAS	YEB	SC	2.29	2.73-2.85	2.9	3.02-3.11				Aust	804	cv. Texas 610SR; tentative critical conc. at solution osmotic pressure of –0.1 MPa only.
	43 DAT	YEB	SC			4.0					Aust	803	cv. Texas 610SR; tentative critical conc. at –0.1 MPa.
		YEB+1				3.5							
		YEB+2				3.5							
	43 DAT	YEB	SC			2.9					Aust	803	cv. Texas 610SR; tentative critical conc. at –0.4 MPa.
		YEB+1				2.7							
		YEB+2				3.1							
	GS 2	YEB	SC			5.3					Aust	349	cv. Texas 610SR
	GS 3-4					4.8							
	GS 3-4					3.3							cv. M35-1
	Fl	YMB	F	<2.0			>2.75				Aust	392	Grown under irrigation; cv. E57
	GS 3-5	YMB	F		<3.2		3.2-4.2	>4.2			USA	538	
	U	YMB	F				3.0-5.0				USA	1070	
	Veg and early Fl	3rd LB below head	S,D	1.0-2.1	2.5-2.8		3.0-4.2	5.0-6.5			Aust	1053	
	GS 6(Fl)	3BBE	F	<2.5	2.5-3.2		3.3-4.0	>4.0?			USA	538	
	GS 7-8	3BBE		<2.5	2.5-3.0		3.0-4.0	>4.0					
	Head	2nd LB below A	F	<1.6	1.6-1.8		1.9-2.4				USA	109	
	Full Head	2nd LB below A	S,D			2.5					Aust	1051 1052	
	F	YML	Lit				2.8-4.0				Ger	82	
	69 DAS (Fl)	YML+1	F		2.38		2.47-2.52				Aust	987	10% grain yield response to 30 kgN/ha after grazing *Centrosema pascuorum* pasture.
	Approx 2.5 months	3rd leaf from top	F		1.27-2.12		2.15-2.82				Aust	411	Data variable, dependent on season and management. Predictive criteria for grain yield.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Boot	Leaf 3	F		1.31-1.98	2.1	2.12-2.35				USA	304	
	Mat	Grain			1.07-1.41	1.5	1.49-1.72						
	62-69 DAS (Fl)	Second leaf	F				2.35-2.62				Aust	987	No yield response to applied N following ungrazed *Centrosema pascuorum* pasture.
	Var	Green leaves	F			$N_c = 0.587 + 6.67 \exp(-0.00133X)$					Aust	640	Critical conc. derived as a function of accumulated degree days (X) above 0°C.
	1000 degree days*	Green leaves	F			3.2					Aust	640	* Accumulated degree days above a base of 0°C.
	2000 degree days					2.2							
	3000 degree days					2.0							
	4000 degree days					1.9							
	95 DAS	Seed	F		1.2-1.3		1.2-1.5				Ind	650	cv. CSH 8R
					1.1		1.0-1.4						cv. M35-1
	Mat	Grain	F		1.45		1.66-1.84				Ind	854	cv. CSH-1
	Mat	Grain	F		0.96-1.27	1.28	1.35-1.45				USA	38	Critical conc. estimated by reviewer.
	Mat	Grain	F		1.13-1.22	1.27	1.34				Ind	628	cv. CSH-6 grown on an Alfisol.
	Mat	Grain	F		1.26-1.35	1.55	1.68-1.84				Aust	395	cv. E57 } tentative critical
	Mat				1.44-1.71	1.85	2.07-2.26						cv. Goldfinger} conc. under irrigation.
	Mat	Grain	F		1.16-1.40	1.45	1.50-1.88				Aust	393	cvv. E57, P846, Goldfinger, NK212
	Mat				1.39-1.49	1.7	1.81-2.01						cv. Goldrush. Crit. conc. under irrigation.
	Mat	Grain	F		0.93-1.02	1.1					Ind	629	Crop grown on a Vertisol.
	95 DAS	Stalk	F		0.7-0.8		0.6-0.9				Ind	650	cv. CSH 8R
					1.2-1.3		1.2-1.5						cv. M35-1
P(%)	14 DAT	WS	RSC		0.18		0.28				Neth	975	Genotype TAM428
	35 DAT				0.15		0.27						
	14 DAT	WS			0.14-0.26		0.44				Neth	976	Genotype SCO283
	35 DAT				0.08-0.09		0.12						
	30 DAS	WS	Soil	0.08	0.22-0.26		0.22-0.29				UK	227	Growth room expt. using split-root conditions.
	35 DAS	WS	SC							>1.0	USA	507	
	35 DAT	WS	SC	0.084-0.12	0.16-0.23	0.29	0.30	1.22			Neth	486	cv. TAM428
	8-9 leaf	WS	SC	0.07-0.17							USA	197	S. bicolor

SORGHUM (*Sorghum vulgare* and *S. bicolor*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	48 DAS 48 DAS	WS	Soil	0.097 0.068	0.145-0.35 0.178-0.252		0.31-0.36 0.24-0.29				USA	772	cv. SC6 cv. SC97
	48 DAS (10-12 leaf stage)	WS	Soil	0.068-0.097	0.18-0.19	0.25	0.23-0.35				USA	771	Two cultivars; critical P conc. same for mycorrhizal and non-mycorrhizal plants.
	49 DAS	WS	F	0.08-0.10	0.10-0.12		0.14				Colo	235	Data from two sites
	GS 2	WS	F	<0.25	0.25-0.3		0.3-0.6	>0.6			USA	538	
	GS 3	WS	Sand	<0.l	0.1-0.2		0.21-0.5	>0.5			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	U	WS	F		0.17		c.0.1 9				USA	812	Data averaged for 3 years; *S. bicolor*
	GS 3-4 GS 6	YEB	SC			0.47 0.52			1.6		Aust	349	cv. Texas 610SR cv. M35-1
	GS 3-4	YEB	SC			0.50					Aust	349	
	Fl	YMB	F				>0.27				Aust	392	No response to applied P
	GS 3-5	YMB	F	<0.13	0.13-0.25		0.2-0.6				USA	538	
	U	YMB	F				0.25-0.4				USA	1070	
	GS 6 GS 7-8	3BBE	F	<0.18 <0.13	0.18-0.22 0.13-0.15		0.2-0.35 0.15-0.25	>0.35 >0.25			USA	538	
	Veg and early Fl	3rd LB below head	S,D	0.11-0.15	0.17-0.23		0.25-0.45	0.5-0.7		0.81	Aust	1053	Toxic, imbalance from crop showing Zn deficiency symptoms.
	Full Head	2nd LB below A	S,D			0.25					Aust	1051 1052	
	Fl	YML	Lit				0.25-0.50				Ger	82	
K(%)	GS 2	WS	F	<2.5	2.5-3.0		3.0-4.5				USA	538	
	GS 3	WS	Sand	<1.5	1.6-2.5		2.5-4.0	>4.0			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	U	WS	F	<0.82			>1.0				USA	812	
	GS 3-4 GS 3-4	YEB	SC			2.2 2.1					Aust	349	cv. Texas 610SR cv. M35-1
	Fl	YMB	F				>1.6				Aust	392	No response to applied K

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	GS 3-5	YMB	F	<1.5	1.5-2.0		2.0-3.0				USA	538	
	U	YMB	F				2.75-4.0				USA	1070	
	GS 6 GS 7-8	3BBE	F				1.4-1.7 1.0-1.5				USA	538	
	Veg and early Fl	3rd LB below head	S,D	0.4-0.7	0.9-1.3		1.6-3.3	3.5-5.0			Aust	1053	
	Full Head	2nd LB below A	S,D			1.8					Aust	1051 1052	
	Fl	YML	Lit				2.0-3.0				Ger	82	
S(%)	56 DAE	WS	Soil	0.06-0.07	0.09	0.095	0.10-0.12				USA	426	cv. Savanna 5
	GS 3	WS	Sand	<0.03	0.2?		0.24				USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	GS 3-4 GS 3-4 GS 6	YEB	SC			0.20 0.25 0.21					Aust	349	cv. M35-1 cv. Texas 610SR
	Fl	YMB	F				>0.16				Aust	392	No response to applied S
	Full Head	2nd LB below A	S,D			0.15					Aust	1051 1052	
Ca(%)	GS 2	WS	F				0.9-1.3				USA	538	
	GS 3	WS	Sand	<0.24			1.0-1.5	>1.5			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	Fl	YEB	SC			0.34					Aust	349	cv. Texas 610SR
	GS 3-5	YMB	F				0.15-0.9	>0.9			USA	538	
	Fl	YML	Lit				0.30-0.60				Ger	82	
	Veg and early Fl	3rd LB below head	S,D		0.12-0.20		0.30-0.60	0.8-1.0		1.2-1.5	Aust	1053	
	21 DAT 21 DAT	Lower leaves (1-5) Upper leaves (>6) Lower leaves (1-5) Upper leaves (>6)	SC	0.11-0.32 0.013-0.067 0.12-0.35 0.008-0.092			0.22-0.50 0.07-0.30 0.17-0.47 0.076-0.36				USA	639	cv. Redlan; Ca def. symptoms at Na:Ca > 18 in WS. cv. Martin; Ca def. symptoms at Na:Ca > 16 in WS.
	GS 6 GS 7-8	3BBE	F		0.2-0.4? <0.2		0.3-0.6? 0.2-0.6	>0.6			USA	538	
	Full Head	2nd LB below A	S,D			0.2					Aust	1051 1052	

SORGHUM (*Sorghum vulgare* and *S. bicolor*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mg(%)	30 DAT	WS	Soil	0.13	0.16-0.26	0.27	0.28-0.31				Neth	978	cv. CV323; no relationship in unlimed acid soil.
	30 DAT	WS	Soil	0.063-0.23			0.14-0.39				Neth	977	Data for 12 genotypes
	GS 2	WS	F		0.3-0.34		0.35-0.5				USA	538	
	GS 3	WS	Sand	<0.2	0.2-0.3		0.4-0.8	>0.8			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	GS 3-4 Fl GS 3-4	YEB	SC			0.20 0.21 0.16					Aust	349	cv. Texas 610SR cv. M35-1
	GS 3-5 GS 6 GS 7-8	YMB	F		 0.1-0.2		0.2-0.5 0.2-0.5 0.1-0.5	 >0.5			USA	538	
	Veg and early Fl	3rd LB below head	S,D	0.11-0.13	0.15-0.17		0.20-0.50	0.6-0.8		0.9-1.2	Aust	1053	
	Late Fl Early milk	3rd LB below flag	F	<0.12 <0.08	0.15-0.2 0.1-0.2		>0.2 >0.2				USA	305	S. bicolor
	Full Head	2nd LB below A	S,D			0.15					Aust	1051 1052	
	Fl	YML	Lit				0.20-0.50				Ger	82	
Na(%)	GS 3-4	YEB	SC						0.003		Aust	349	cv. Texas 610SR
	Veg and early Fl	3rd LB below head	S,D				0.01-0.20				Aust	1053	
Cl(%)	GS 3-4	YEB	SC						0.2		Aust	349	cv. Texas 610SR
	Veg and early Fl	3rd LB below head	S,D				0.10-1.5	1.8		2.2	Aust	1053	
	39 DAE	Mature LB Mature L sheath	RSC				0.038 0.090		0.27 1.35	0.72-0.99 3.05-4.86	USA	128	cv. NK 1580
	After Heading	4th LB below flag	F						0.71		USA	296	S. bicolor
	Full Head	2nd LB below A	S,D				<2.0				Aust	1051 1052	
	37 DAS 86 DAS (Fl)	Live leaves Flag leaf	F				1.07 0.34			3.9 0.58	Aust	400	cv. Pacific 303; grain yield depressed to 15.6% of control by soil salinity.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Cu(mg/kg)	18 DAS	WS	Soil	6-7			14				USA	153	S. bicolor
	7-9 leaf	WS	SC	6			27			68	USA	198	
	GS 2	WS	F				8-15	>15?			USA	538	
	GS 3	WS	Sand				3-14				USA	538	Adequate range is 90-100% max. yield.
	Fl	YEB	SC			2.7					Aust	349	cv. Texas 610SR
	GS 3-5	YMB	F				2-15				USA	538	
	U	YMB	F				5-15				USA	1070	
	Veg and early Fl	3rd LB below head	S,D		1.0		2-15				Aust	1053	
	30 DAS	Middle LB	Sand	<2	2-3.6	3.6	3.6-10	>10			Ind	12	
	GS 6 GS 7-8	3BBE	F				2-7 1-3				USA	538	
	Fl	YML	Lit				5-12				Ger	82	
Zn(mg/kg)	Seedl	WS	Soil			20					USA	786	Crit. conc. correspond to 95% max. seed yield.
	18 DAS	WS	Soil	16-20				44-140			USA	153	S. bicolor
	24 DAS	WS	SC	12						271	USA	198	
	35 DAS	WS	Soil						475-570		USA	108	Toxic at 80% max. yield
	42 DAS	WS	Soil	7-19							Ind	906	
	GS 2	WS	F				40-50	>150			USA	538	
	GS 3	WS	Sand	<11			40-70	>70			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	GS 3 GS 3-4	YEB	SC			8.6			60		Aust	349	cv. Texas 610SR
	GS 3-4	YEB				10					USA	684	
	Fl	YMB	F				29				Aust	392	No response to applied Zn
	GS 3	YMB	SC			10	10-64		64		USA	684	*S. bicolor*; Deficient and toxic criteria at 90% max. yield
	GS 3-5	YMB	F		<20		20-40				USA	538	
	U	YMB	F				15-40				USA	1070	
	49 DAS	Middle LB	Sand	<15	15-20	20	20-30			>30?	Ind	12	

SORGHUM (*Sorghum vulgare* and *S. bicolor*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Zn(mg/kg) (ctd)	Veg and early Fl	3rd LB below head	S,D	8-11	12-18		20-60	70-80			Aust	1053	
	Head	2nd LB below A	F				10				USA	109	
	Full Head	2nd LB below A	S,D			18					Aust	1051 1052	
	GS 6 GS 7-8	3BBE	F		<15		15-30 7-16				USA	538	
	Fl	YML	Lit				25-70				Ger	82	
	Fl Mat	Flag leaf Grain	Soil		12-19 6-7.6	20 10	22-35 11-21				USA	786	cv. Y-101-R; critical conc. for 95% max. grain yield.
Mn(mg/kg)	24 DAS	WS	SC	24						217	USA	198	
	20 DAT	WS	SC				362-584	2290	3000	3290-12300	USA	306	Two cvv.; critical Mn conc. little affected by solution Si conc.
	35 DAS	WS	SC							>860	USA	507	
	GS 2	WS	F				40-150	>150			USA	538	
	GS 3	WS	Sand				40-70	>70			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	GS 3-4 GS 6	YEB	SC			29			278		Aust	349	cv. Texas 610SR
	GS 3-5	YMB	F				6-100				USA	538	
	GS 5 (boot)	Flag leaf (YMB)	SC			10					USA	678	Critical at 90% max. yield. Flag blade recommended for sampling
	Veg and early Fl	3rd LB below head	S,D	<8	8-10		15-350				Aust	1053	
	56 DAS	Middle LB	Sand	<12	12-15	15	20-80				Ind	12	
	GS 5 (boot)	2nd LB below A	SC			15					USA	678	S. bicolor
	GS 6 GS 7-8	3BBE	F				8-190 8-40	40-100			USA	538	
	Fl	YML	Lit				25-100				Ger	82	
Fe(mg/kg)	18 DAS	WS	Soil	15			43				USA	153	S. bicolor
	24 DAS	WS	SC	100						448	USA	198	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	30 DAS	WS	Soil	<57			98				Ind	871	S. bicolor
	35 DAS	WS	Soil			65					USA	228	S. bicolor
	GS 2	WS	F				160-250	>300		>700?	USA	538	
	GS 3	WS	Sand	<90			90-120				USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	FI	YEB	SC			88					Aust	349	cv. Texas 610SR
	GS 3-5 GS 6 GS 7-8	YMB 3BBE 3BBE	F				55-220 65-100 40-80				USA	538	
	20 DAE	L 4+5				45					Ind	973	
	32 DAT	YL	SC	13			41-50				Ger	1024	cv. Y-303A
	5-20 DAT	Upper leaves (newly developing)	SC	<20			≥ 80				USA	737	Two cvv.; daily fluctuations in leaf Fe conc.
Al(mg/kg)	GS 2	WS	F					>375			USA	538	
	GS 3	WS	Sand					>70			USA	538	Deficient, marginal and adequate ranges <50%, 50-90% and 90-100% max. yield respectively
	GS 3-5 GS 6 GS 7-8	YMB 3BBE 3BBE	F				0-25	>200 >220			USA	538	
	GS 3	Roots	SC				13.5-1430		1460	1690-2730	USA	689	Al conc. in YMB independent of Al treatments.
B(mg/kg)	GS 2	WS	F		<4?		4-13				USA	538	
	GS 3	WS	Sand	<3?	3-10		10-25	>25			USA	538	
	GS 3-5	YMB	F				1-10				USA	538	
	Veg and early FI	3rd LB below head	S,D				2-25	35-60			Aust	1053	
	35 DAS	Middle LB	Sand	<7	7-10	10	10-35			>35	Ind	12	
	Full Head	2nd LB below A	S,D			5					Aust	1051 1052	
	GS 6 GS 7-8	3BBE	F				1-10 1-6				USA	538	
	FI	YML	Lit				5-15				Ger	82	

SORGHUM (*Sorghum vulgare* and *S. bicolor*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
B(mg/kg) (ctd)	Head	Leaves	Sand				20 - 111		171	245-943	USA	93	Threshold toxic conc. for grain yield.
Mo(mg/kg)	Veg and early Fl	3rd LB below head	S,D		0.11		0.3-3.0				Aust	1053	
	Fl	YML	Lit				0.15-0.30				Ger	82	

SOYBEAN (*Glycine max*)

Growth stages of soybean are described in reference 275. YMB = upper most mature leaf blade (i.e. third and fourth LB below apex).

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	25-33 DAT	WS	SC	1.26-1.51			2.79-3.99				Aust	75	Data for 2 cvv.
	Fl	YMB	D,S	<3.2	3.2-4.0		4.2-5.5	6.0-7.0			Aust	1053	
	R1	YMB	F	<3.5	3.5-4.2	4.2	4.3-5.5	5.5-9.0			Thai	79	cv. SJ5; crit conc. corresponds to seed yield ≥1500 kg/ha.
	Late Fl	YMB	Lit				4.5-5.5				Ger	82	
	Pre-PS	YMB	F,S,D				4.26-5.5				USA	930	
	Early PF	YMB	S,D				4.25-5.0				USA	456	
	Early Aug	LB	S				3.6-4.7				USA	863	
	Pods (65 DAS)	LB	F				4.0-4.5				Ind	699	Criteria at max. yield
	R5 R7	All leaves	F		3.6-4.2 1.4-1.7	4.4	4.5-5.1 1.7-2.3				USA	243	cv. Williams; tentative crit. conc. from moisture stress treatments.
	Mat	Seed	F		6.14	6.4	6.67-6.75				USA	148	cv. Cutler 71
NO_3-N (mg/kg)	Late Fl (50 DAS) Pods (65 DAS)	LB	F				1900 1450				Ind	699	
P(%)	20 DAT	WS	Soil*		0.10-0.22		0.26				USA	124	cv. Century; P placement experiment. * Growth chamber
	25-33 DAT	WS	SC				0.33-0.40				Aust	75	Data for 2 cvv.
	Full Fl	WS	F		0.11-0.19		0.11-0.23				Aust	620	Authors indicate criteria of limited value (marginal conc. <80% max. grain yield; adequate conc. >80% max. grain yield; critical at 70% max. grain yield)
	49 DAS	WS	Soil			0.12 0.19					USA	510	Critical for non-mycorrhizal plants Critical for mycorrhizal plants

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	55 DAE	WS	Soil	0.14-0.21			0.27-0.72				USA	432	cv. McCall
	18 DAS	YMB	F	<0.35		0.35	>0.35				Aust	311	cv. Buchanan; flowering ended 53 DAS; critical at 95% max. yield
	Fl (31 DAS)			<0.4	0.4-0.45	0.4	>0.45						
	45 DAS			<0.39	0.39-0.41	0.39	>0.41						
	60 DAS			<0.34	0.34-0.38	0.34	>0.38						
	74 DAS			<0.25	0.25-0.29	0.25	>0.29						
	88 DAS			<0.21	0.21-0.24	0.21	>0.24						
	Veg	YMB	Soil			0.32					Aust	79	cv. Buchanan; crit conc. unclear due to Piper Steenbjerg curvature.
	R1					0.29							
	R3					0.32							
	R5-6					0.24							
	Early Fl	YMB	F			0.335					USA	805	cv. Beeson; data from 3 sites. Crit. conc. for 95% of maximum seed yield.
	Fl	YMB	D,S	<0.15	0.25		0.30-0.55	0.6-0.7		0.8-2.4	Aust	1053	Toxic, nutrient imbalance associated with Zn deficient crop.
	R1	YMB	F	<0.17	0.17-0.29	0.29	0.30-0.50	>0.50			Thai	79	cv. SJ5; crit conc. corresponds to seed yield ≥1500 kg/ha.
	Late Fl	YMB	Lit				0.35-0.6				Ger	82	
	Pre-PS	YMB	F,S,D				0.26-0.5				USA	930	
	R1-R3	YMB	F		0.34		0.39				USA	371	Adequate conc. corresponds to seed yield ≥3.5 t/ha.
	Early Pods	YMB	F,S,D			0.35					USA	604	
	Early PF	YMB	S,D				0.3-0.5				USA	456	
	27-42 DAT	LB	Perlite	0.13-0.17			0.38-0.59				USA	442	cv. Ransom; conc. in P adequate plants declined over time.
	Early Fl	LB	D		<0.l		>0.2				Aust	732	
	Pods						>0.15						
	Early Aug	LB	S				0.25-0.6				USA	863	
	49 DAS (R2)	LB	SC			0.43					USA	512	
	70 DAS (R4)					0.34							
	98 DAS (R6)					0.26							
	119 DAS (R8)					0.28							
	Pods	Upper LB	F			0.37					USA	614	

SOYBEAN (*Glycine max*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	18 DAS	YML	F		0.19-0.25	0.27	0.35				Aust	312	cv. Buchanan; critical conc. at 90% max. seed yield.
	31 DAS				0.21-0.31	0.37	0.40-0.45						
	45 DAS				0.21-0.31	0.35	0.38-0.41						
	59 DAS				0.16-0.27	0.32	0.33-0.38						
	73 DAS				0.13-0.20	0.23	0.25-0.29						
	87 DAS				0.15-0.19	0.19	0.21-0.24						
	42 DAE	YML	F		0.18-0.45	0.45	0.46-0.55				USA	178	cv. Clark 63; critical conc. same for N_2-fixing and N-supplied plants.
	R2	YML	F		0.185-0.245	0.275-0.33	0.345-0.406				Nig	700	Data from 5 trials.
	R2	YML	F,S			0.31	0.31-0.50	0.51-0.80			USA	71	Modified critical nutrient level procedure.
	17 DASAL began	Leaves	SC					0.58-0.92		1.08-2.91	USA	343	P conc. >1.86% was lethal.
	22 DASAL began	All leaves	SC							1.25-2.5	USA	342	Salinity-enhanced P toxicity in cvv. Clark and Kanrich.
	Mat	Seed	Perlite	0.33-0.36	0.37-0.41		0.54-0.69			0.68-0.75	USA	215	
	Mat	Grain	F		0.33-0.67	0.36	0.37-0.55				Aust	620	Authors indicate criteria of limited value (marginal conc. <80% max. grain yield; adequate conc. >80% max. grain yield; critical at 70% max. grain yield)
P(µmol/g fr. wt)	16 DAT	WS	FSC			23					Aust	279	cv. Fitzroy; corresponds to critical soln conc. of 0.8 µM.
K(%)	52 DAS	WS	SC			3.4					Swi	762	
	Veg (26 DAS)	YMB	Soil			2.0-2.2					Aust	72	cv. Buchanan
	R1					1.0-1.3						79	
	R3					0.5-0.9							
	R5-6 (55 DAS)					0.3-0.4							
	Early Fl	YMB	F	0.29-0.74	1.5		2.15-3.25				Aust	1051	
												1052	
	Early Fl	YMB	F			3.0					USA	883	
	Early PS					2.0							
	Fl	YMB	D,S	<0.8	1.0-1.5		1.7-3.2	4.0			Aust	1053	
	Fl	YMB	F		0.84-1.2	1.2	1.2-1.8				Peru	208	cv. Jupiter
	Late Fl	YMB	Lit				2.5-3.7				Ger	82	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	R1	YMB	F	<0.9	0.9-1.7	1.7	1.8-3.0	>3.0			Thai	79	cv. SJ5; crit. conc. corresponds to seed yield ≥1500 kg/ha.
	R1-R3	YMB	F		1.07		1.78				USA	371	Adequate conc. corresponds to seed yield ≥3.5 t/ha.
	1st Pods	YMB	F,S,D			2.2					USA	604	
	R3-4 (37DAS) R5-6 (55DAS)	YMB	Soil			0.88 0.39					Aust	73	cv. Buchanan; N_2 fixing plants
	Pre-PS	YMB	F,S,D				1.7-2.5				USA	930	
	Pre-PF	YMB	S,D				2.0-2.5				USA	456	
	20 cm tall Early Fl Early Pod Max. seed size	LB	F	1.35 0.91 0.51 0.29			2.25 1.99 0.81 0.52				USA	454	
	Early Aug	LB	S				1.35-2.3				USA	863	
	Pods	Upper LB	F				>1.7				USA	614	
	R1-R2	YML	F			1.76	1.78-2.35				USA	348	Crit. conc. for 90% of maximum seed yield; 3 cvv., each grown in a different soil.
	R2	YML	F,S			1.51	1.51-2.50	2.51-2.75			USA	71	Modified critical nutrient level procedure.
	R2 (Fl) R6 (PF)	YML	F		1.77 0.56	1.85 0.67	1.91-2.45 0.72-0.97				USA	615	Critical at 90% max. seed yield; cv. Bragg.
	Mat	Seed	Soil	1.11-1.51	1.74	1.78	1.77-1.88				Aust	874	cv. Lee; crit. conc. corresponds to 90% maximum fruit (seed and pod) yield.
	Mat	Seed	F		1.55-1.80	1.79	1.75-1.98				Bra	851	
S(%)	36 DAS 60 DAS	WS	Soil			0.15 0.185					Ind	47	Critical at 90% max. yield; critical N/S = 16.5
	U	WS	SC	0.20			0.33				USA	303	Adequate protein N:S ratio = 20. Moderate S def. symptoms in So treatment.
	Mat	WS	F				0.11-0.13				USA	970	Mean of 4 cvv.; N/S ranged from 25 to 20.
	Fl	YMB	D,S		0.15		0.2-0.4				Aust	1053	
	R1	YMB	F	<0.15	0.15-0.18	0.21	0.19-0.30	>0.30			Thai	79	cv. SJ5; crit. conc. corresponds to seed yield ≥1500 kg/ha.
	Late Fl	YMB	Lit				0.21-0.40				USA	457	
	R3 R5-6	YMB				0.18-0.20 0.17					Aust	79	cv. Buchanan

SOYBEAN (*Glycine max*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%) (ctd)	Fl	YML	F		0.16-0.24	0.23	0.27-0.32				Ind	15	Critical at 90% vegetat. growth; critical N/S = 12.
	Fl				0.16-0.21	0.22	0.23-0.32						Critical at 90% max. seed yield.
	42 DAS (R2)	LB	F				0.23-0.29				USA	970	cvv. Desoto, Douglas
	63 DAS (R2)						0.17-0.22						
	84 DAS (R5)						0.17-0.22						
	42 DAS (V9,V10)						0.22-0.28						cvv. Bay, Essex
	63 DAS (R2)						0.20-0.25						
	84 DAS (R6)						0.18-0.22						
	U	Leaves	F			0.33					Bra	571	
Ca(%)	20 DAT	WS	FSC	0.28							Aust	74	cv. Fitzroy
	21 DAT	WS	RSC	0.20	0.28-0.83		1.02-1.13				USA	665	Shoot conc. depressed by Al.
	20 DAT	YMB	FSC		0.77-1.26	1.22	1.68				Aust	74	cv. Fitzroy
	Fl	YMB	D,S		0.21-0.35		0.4-2.0	2.5-3.0			Aust	1053	
	Early Aug	LB	S				0.6-1.4				USA	863	
	Late Fl	YMB	Lit				0.60-1.5				Ger	82	
	Pre-PS	YMB	F,S,D				0.36-2.0				USA	930	
	1st Pods	YMB	F,S,D			0.4					USA	604	
	Early PF	YMB	S,D				0.5-1.5				USA	456	
Mg(%)	Fl	YMB	D,S		0.15-0.19		0.25-0.80	1.0-1.2			Aust	1053	
	Late Fl	YMB	Lit				0.30-0.70				Ger	82	
	Pre-PS	YMB	F,S,D				0.26-1.0				USA	930	
	1st Pods	YMB	F,S,D			0.3					USA	604	
	Early PF	YMB	S,D				0.3-0.8				USA	456	
	Early Aug	LB	S				0.3-0.55				USA	863	
Na(%)	Fl	YMB	D,S				<0.1	0.3		>0.5	Aust	1053	Toxic (or excess).
Cl(%)	26 DAS	WS	Soil				0.18-0.84		1.0	1.12-5.27	USA	710	cv. Bragg; data relate to shoot yield at maturity (73 DAS); plants with ≥2.16% Cl in WS died at 40-56 DAS.
	Fl	YMB	D,S				<1.2	1.5-2.0		2.6-5.0	Aust	1053	Toxic (or excess).

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	R6	3rd LB below A	F				0.07-0.14			>0.80	USA	712	
	15 DAS 80 DAS	YML	F				0.09-0.18 0.029-0.05			0.7-2.4 0.03-0.18	USA	1104	Study of 60 cvv., ranging from Cl- accumulators to excluders.
	17 DA salination	Leaves	SC				<0.003			0.53-8.63	USA	343	Cl^- conc. >2.84% was lethal.
	Mat	Seed	Soil						0.010-0.038	0.045-0.115	USA	559	Plants inoculated with *Glomus etunicatum*; crit. conc. varies with pH.
	Mat							0.008-0.014	0.014-0.024	0.025-0.065			Non-inoculated plants; crit conc. varies with pH.
Cu(mg/kg)	21 DAT	YEB	SC, Peat				Polyphenol oxidase assay				Mala	584	cv. Palmetto
	Veg	YMB				1.8-2.3					Aust	79	cv. Buchanan; occasional flowers only due to long day length.
	Fl init.	YMB	F			4-6					USA	569	Tentative criteria
	Fl	YMB	D,S		4-5		6-30	31-50			Aust	1053	
	R1	YMB	F	<1.7	1.7-2.2	4.0	2.3-5.0	>5.0			Thai	79	cv. SJ5; crit conc. corresponds to seed yield ≥1500 kg/ha.
	Late Fl	YMB	Lit				10-20				Ger	82	
	Pre-PS	YMB	F,S,D				10-30				USA	930	
	1st Pods	YMB	F,S,D			5					USA	604	
	Early PF	YMB	S,D				6-30				USA	456	
	Fl	YML	F				4.3-7.3				USA	719	
Zn(mg/kg)	31 DAS	WS	Soil						500	600-965	USA	738	Linear decline in growth at Zn conc. in shoots >318 mg/kg
	55 DAE	WS	Soil	9-10		18	20-50				USA	432	cv. McCall; critical for N-supplied and N_2-fixing plants.
	Veg	YMB	F		15						Aust	45	
	Veg	YMB				6-10					Aust	79	cv. Buchanan; occasional flowers only due to long day length.
	Early Fl	YMB	S,D	6-14	20		25-88				Aust	1052	Zn-susceptible cultivars. Adequate P/Zn ratio = 200-500; deficiency 1200-2200
	Fl	YMB	D,S	6-14	15-20		25-80				Aust	1053	
	35 DAS	YMB YMB+1				6 12					Aust	72	cv. Buchanan
	Late Fl	YMB	Lit				25-60				Ger	82	

SOYBEAN (*Glycine max*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Zn(mg/kg) (ctd)	Pre-PS	YMB	F,S,D				21-50				USA	930	
	1st Pods	YMB	F,S,D			15					USA	604	
	Pre-PF	YMB	S,D				20-50				USA	456	
	Late Fl	YMB+P	F		17-22						Aust	849	
	28 DAS	Trifoliate LB	Soil						370-860		USA	1060 1061	Criteria at 80% max. yield; cultivar differences
	Early Aug	LB	S				20-100				USA	863	
	35 DAS	3rd LB below A	Soil			18					Aust	429	Critical at 90% max. yield
	41 DAS	3rd LB below A	RSC			14					USA	682	Critical at 90% max. yield; slight Piper-Steenbjerg effect
	Early Fl	YML	Soil			22					USA	786	cv. Davis; critical conc. for 95% max. seed yield.
	Early Fl	YML	Soil			26					S Arab	19	
	Fl	YML	F		9-26	26	28-36				USA	719	Highest yields of 2 cultivars at approx. 26 mg Zn/kg and at P/Zn ratio of 115.
	R2	YML	F,S			21	21-50	51-75			USA	71	Modified critical nutrient level procedure.
	Mat	Seed	Soil		23-38	43	46-68				USA	786	cv. Davis; critical conc. for 95% max. seed yield.
Mn(mg/kg)	V6	WS	F,S			45					USA	321	Data from 30 sites
	37 DAE	WS	Soil				21-44			246-337	USA	627	cv. Bragg
	40 DAS	WS	Soil			14					USA	585	cv. Hutchinson
	42 DAS	WS	Soil		7.6-10.4	10.5	13.3-49.2				USA	610	cv. Bragg; critical conc. derived by reviewer.
	R6	WS	F	6-9							USA	1085	
	V4,V10 R2	YMB	F	<10 <10		16-17 17-22					USA	588	R2 growth stage more reliable for sampling than V4 or V10. Data from 38 sites.
	V5	YMB	F	4-8							USA	824	Strong seed yield responses to foliar Mn application.
	V6	YMB	Soil	11-20		22	23-47				Ind	49	cv. SL96; study with 15 soils.
	5 leaf 7 leaf Mid Fl	YMB	F			8 7 10					USA	694	Critical at 90% bean yield; cv. Ransom; YMB = blade below youngest leaf blade

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Fl	YMB	D,S	<15	15-25		30-100	150-250		750-1000	Aust	1053	
	R1, R2	YMB	F,S			17					USA	321	Data from 30 sites.
	36-46 DAS	YMB	RSC	<11						>173	USA	693	Seven cultivars compared
	Late Fl	YMB	Lit				30-100				Ger	82	
	R2	YMB	F	6-10	9-16	13.5-16.5	15-36				USA	587	Crit. conc. varies with soil.
	R2	YMB	F			15					USA	125	cv. Ransom; critical for seed yield.
	R2	YMB	F			12-13	15-55				USA	691	Critical at 90% max. bean yield; cv. Ransom
	R2	YMB	F			~18	29-35				USA	709	Eight cultivars compared; critical at 90% seed yield; variable data
	Pre-PS	YMB	F,S,D				21-100				USA	930	
	1st Pods	YMB	F,S,D			20					USA	604	
	Early PF	YMB	S,D				30-200			>500	USA	456	
	R2	YMB (terminal	F		19	20	21-48				USA	589	cv. Centennial
	R2	leaflet)			7-12	13	14-26						cv. Centennial; residual Mn expt.
	24 DAS	YMB, YMB+1, YMB+2		Determination of fluorescence ratio Fo/Fv							USA	7	cv. Bragg; Fo/Fv increased at leaf Mn conc. <10 mg/kg.
	Late Fl-Early PF	Youngest LB	F			20					USA	694	Critical at 90% bean yield; cv. Ransom
	Late PF					22							
	36 DAS	LB 2 & 3	RSC			10					USA	683	
	40 DAS	3rd LB below A (= YMB)	RSC			10			160		USA	681	Both criteria at 90% max. yield; cv. Bragg
	21 DAT	YOL	SC	10-13			43	221-306		402-648	Aust	388	cv. Bragg
				8-13			38	169-331		541-686			cv. Lee
	14 DAT	YML (first trifoliate)	SC	9.5-18.5			33-69	286-869		865-1180	Spa	521	Data for 4 cvv.
	18 DAT	YML	FSC						300		Aust	33	cv. Bragg; NO_3-N in nutrient soln.
	18DAT								180				cv. Fitzroy;NO_3-N in nutrient soln.
	18 DAT								170				cv. Lee; NO_3-N in nutrient soln.
	22 DAT	YML	SC						665		Aust	33	cv. Bragg; N_2-fixing plants
	22 DAT								570				cv. Fitzroy; N_2-fixing plants
	R1	YML	F		10.3-13.2	13.1-15.4	14.7-22.5				USA	320	cv. Essex; crit. conc. for seed yield.
	R2	YML	F,S			17	17-100	101-250			USA	71	Modified critical nutrient level procedure.

SOYBEAN (*Glycine max*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	Mat	YM Leaflet	F			18					USA	590	38 sites; critical is leaf conc. corresponding to avail. index that separates responsive sites.
	38 D after treats. imposed	YL Old leaves	Sand				103 144			1530 2780	Tai	1098	cv. Maple Arrow; treatments imposed at 39 DAS.
	Early Fl (R3) Early Fl (R3) Early Fl (R3) Early Fl (R3)	Leaves	Soil				136-286 151-310 129-202 128-220		193-367 201-261		USA	799	9 very tolerant genotypes 12 tolerant genotypes 9 sensitive genotypes 10 very sensitive genotypes
	U	Tls	SC	9-13			44-69			479-945	Spa	522	cv. Williams
	Mat	Seed	F		13.6-21.5		18.2-26.6				USA	320	cv. Essex
	Mat	Seed	F			16					USA	125	cv. Ransom
	Mat	Seed	F,S			20					USA	321	Data from 30 sites
Fe(mg/kg)	24 DAS	WS	Soil	<43							USA	151	
	37 DAE	WS	Soil	36-40			96-99				USA	627	cv. Lee
	Late Fl	YMB	Lit				51-350				USA	457	
	Pre-PS	YMB	F,S,D				51-350				USA	930	
	1st Pods	YMB	F,S,D			30					USA	604	
	Early PF	YMB	S,D				50-300				USA	456	
	19-20 DAS	YMB + buds	SC	30-33	40-50		49-88				USA	207	Study with 4 susceptible cvv.
	14 DAT	YML (1st trifoliate)	SC	51-121 78-133			62-80 74-181				Spa	521	cv. T-203 Data for 3 cvv.
	21 DAS	YML	Soil*				Chlorophyll concentration				USA	630	3 cvv. grown in 23 calcareous soils. *Growth room
	41 DAS	YML	F	35 Fe^{2+}			44-49 Fe^{2+}				Aust	410	cv. Forrest; no differences in seed yield at maturity.
Al(mg/kg)	20 DAS	WS	SC				<28	10-17		28-77	USA	1035	
	30DAE	WS	Soil							300-510	USA	16	cv. Wright
	75 DAS	WS	Soil				<84				USA	882	
	Early Fl	YMB	S,D				<200				USA	456	
B(mg/kg)	63 DAT	WS	SC		11-38	90	58-312		480	1110-1320	USA	676	Tentative critical conc.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Early Fl	YMB	F	<10						63	USA	1097	
	Fl	YMB	D,S		15-20		21-60	80-200			Aust	1053	
	Late Fl	YMB	Lit				25-60				Ger	82	
	Pre-PS	YMB	F,S,D				21-55				USA	930	
	Early PF	YMB	S,D				25-60				USA	456	
	R3	YMB	F			24					Thai	79	cv. NW1} Crit. conc. for 90% max.
	R3			<12	12-16	16	17-50	>50					cv. SJ5 } seed yield.
													Crit. at 90% maximal LB elongation rate
	1st Pods	YMB	F,S,D			25					USA	604	
	V2	Expanding LB	SC, F			12					Thai	79	Crit. at 90% maximal LB elongation rate
	28 DAS	YOL			4.9		31.3				Aust	493	cv. Buchanan; marginally deficient conc. at
		YOL+2			8.1		37.5						80% max. dry wt.
	11-16 DAT	Young leaf unfolding	SC	5.0-7.5		12	23-27				Aust	494	Critical at 90% of maximal LB elongation rate.
	Mat	Seed	F			12					Thai	818	cv. NW1
	Mat			≤8	9-13		≥14						19 cultivars grown.
Mo(mg/kg)	56 DAS	WS	Soil	0.04-0.12			0.18-0.31				Bulg	323	
	U	WS	Sand	0.19			3.2				USA	729	
	Fl	YMB	D,S	0.12	0.15-0.40		0.5-5.5	10			Aust	1053	
	R1-2	YMB				0.017-0.023					Aust/	79	
	R5-6					0.02					Thai	194	
	R1-2	YMB		<0.015	0.015-0.020	0.02	0.02-1.00	>1.00			Aust/ Thai	79 194	Crit. conc. for 90% max. seed yield.
	Late Fl	YMB	Lit				0.50-1.00				Ger	82	
	Pre-PS	YMB	F,S,D				1-5				USA	930	
	1st Pods	YMB	F,S,D			0.5					USA	604	
	Early PF	YMB	S,D				0.1-5				USA	456	
	Mat	Seed	F	<2.6							USA	382	Progeny of seed responded to Mo
	R1-2	Nodules				2					Aust	79	
	R5-6					2						194	
Ni(mg/kg)	56 DAS	WS	SC			0.002-0.004					USA	255	Critical Ni conc. estimated by authors.
As(mg/kg)	42 DAS	WS	Soil				0.4-0.5		0.54-1.3	1.3-13.7	USA	230	Critical conc. at 90% max. yield; data for 2 soils. No fruit set at ≥6.2 mg As/kg in WS.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
SOYBEAN (*Glycine max*) (ctd)													
Cd(mg/kg)	21 DAS	WS	Soil				0.02 - 1.5		1.7	2.8-50	USA	112	Mean data for 30 cvv. grown in 3 soils.
	28 DAS	WS	Soil				0.24-4.1		5.0	5.5-87	USA	613	cv. Amsoy; critical conc. for 90% max. growth derived from data for 9 soils.
	35 DAS	WS	Soil				2.4		7.0	7.1-26.3	USA	368	
	35 DAS	WS	SC						4.5	14.6-56.9	USA	123	cv. Lee; N_2-fixing plants; critical conc. derived by reviewer.
	42 DAS	Leaves	Sand/peat					2.2-2.9	3.2	3.2-24.9	USA	961	cv. Williams; critical conc. derived by reviewer.
SUGAR BEET, FODDER BEET (*Beta vulgaris*)													
N(%)	Veg	PYML YMB	Lit	1.1-1.5 1.9-2.9		1.6 2.5					USA	1010	
	50-60 DAS	ML	Lit				4.0-6.0				Ger	82	
	50-80 DAS	L	Lit	<4.3			4.30-5.00	>5.0			USA	457	
	Mat	Roots	F			0.82					Cyp	607	Diagnostic for fresh roots
	Mat	Roots Shoots	F			0.82 0.81					Cyp	607	Diagnostic for yield of sugar
	Mat	Roots Veg parts	F				≥1.8 ≥3.2				USA	865	Diagnostic for vegetative parts
	Mat	Whole plants	F			1.1					UK	344	Diagnostic for plant DW; Summary of 15 experiments
NO_3-N (mg/kg)	Veg	PYML	F			1000-2000					USA	172 328	Concs decreased exponentially during crop growth
	122 DAS	PYML	F				>22000				USA	1086	Predictive for root and sucrose yield
	As symptoms appear	PYML	F	70-200		1000	3500-35000				USA	1002 1007 1010 1015	Critical at 90% max. yield; 3-6 weeks before harvest crops should become N deficient to ensure optimal sugar accumulation
	As symptoms appear	PYML	F	Diphenylamine rapid field test used to detect N deficiency							USA	1003	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Leaf canopy formed	PYML	F	<7000							USA	625	Predictive for root and sucrose yield
	Veg	PYML YMB	Lit	70-200 0-400		1000 300					USA	1010	
	U	Storage root PYML	Lit	0-500 0-200		1000 1000	800-4000 350-35000				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	Veg	YML	Lit	<500							USA	1010	
P(%)	Mat	WS	F				>0.21				Ind	925	
	Veg	PYML YMB	Lit	0.06-0.12 0.10-0.18		0.12 0.18					USA	1010	
	Mat	B P Roots	F	<0.23 <0.16 <0.17							USA	723	Diagnostic for fresh root yield
	50-80 DAS	L	Lit	<0.45			0.45-1.10	>1.1			USA	457	
	50-60 DAS	ML	Lit				0.35-0.60				Ger	82	
PO_4-P (mg/kg)	Var	YMB		250-700			1000-8000				USA	1001	Critical at 90% max. yield PO_4-P extracted in 2% acetic acid
	25 DAS	Cotyledon	SC	200-700		1500	1600-13000				USA	927	Critical at 90% max. yield PO_4-P extracted in 2% acetic acid
	U	PYML YMB	Lit	150-400 250-700		750	750-4000 1000-8000				USA	1008 1010	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	Var	PYML	Soil	150-400		750	750-4000				USA	1001	Critical at 90% max. yield PO_4-P extracted in 2% acetic acid
	Seedl	Cotyledon PYML YMB	Lit	200-700 500-1300 500-1700		1500 1500 3000	1600-13000 1600-5000 3500-14000				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	25 DAS	Oldest LB Oldest P	SC	500-1700 500-1300		3200 1500	3500-14000 1600-5000				USA	927	Critical at 90% max. yield PO_4-P extracted in 2% acetic acid
	35 DAS	Oldest P	F			≤0.09					USA	398	PO_4-P extracted in 2% acetic acid
K(%)	Var	YMB	SC	0.3-0.6		1.0		1.0-6.0			USA	1004 1006 1011	

SUGAR BEET, FODDER BEET (*Beta vulgaris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	Var	YMB	SC	0.4-0.5		1.0		1.0-6.0			USA	1004 1006 1011	For Na conc >1.5%, critical at 90% max. yield
	U	PYML YMB	Lit	0.2-0.6 0.3-0.6		1.0 1.0	1.0-11.0 1.0-6.0				USA	1008 1010	Plant growth less below critical, Na > 1.5% Deficient = symptoms present Adequate = no symptoms
	U	PYML YMB	Lit	0.5-2.0 0.4-0.5		- 1.0	2.5-9.0 1.0-6.0				USA	1008	Plant growth less below critical, Na < 1.5% Deficient = symptoms present Adequate = no symptoms
	50-80 DAS	L	Lit	0.50-1.99			2.00-6.00	>6.0			USA	457	
	50-60 DAS	ML	Lit				3.8-7.0				Ger	82	
	50-60 DAS	ML	Lit				3.5-6.0				Ger	82	
	Var	PYML	SC	0.2-0.6		1.0		1.0-11.0			USA	1004 1006 1011	For Na conc >1.5%, critical at 90% max. yield
	Var	PYML	SC	0.5-2.0				2.5-9.0			USA	1004 1006 1011	For Na conc <1.5%, critical at 90% max. yield; Do not use PYML when Na < 1.5%
S(mg/kg)	Veg	YMB	Lit	400-750		750					USA	1010	
N/S	U	L	Lit			11					Ger	82	
SO_4-S (mg/kg)	U Veg	YMB PYML	SC, Lit	50-200 50-200		250 250	500-14000				USA	1004 1010	Critical at 90% max. yield, PYML unsuitable
	U	YMB	Lit	50-200		250	500-14000				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
Ca(%)	Veg	PYML YMB	Lit	0.04-0.10 0.1-0.4		0.1 0.5					USA	1010	
	U	PYML YMB	U	0.04-1.0 0.1-0.4		0.1 0.5	0.2-2.5 0.4-1.5				USA	84	Critical at 90% max. yield
	50-80 DAS	L	Lit	0.10-0.49			0.50-1.50	>1.5			USA	457	
	50-60 DAS	ML	Lit				0.6-1.5 0.7-2.0				Ger	82	Fodder Beet Sugar Beet

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	U	PYML	Lit	0.04-0.10		0.1	0.2-2.5				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
Mg(%)	Veg	PYML YMB	Lit	0.01-0.03 0.03-0.05							USA	1010	
	U	PYML	U	0.01-0.03			0.1-0.7				USA	1004 1006 1011	
	U	PYML YMB	Lit	0.01-0.03 0.025-0.05			0.1-0.7 0.1-2.5				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	50-80 DAS	L	Lit	0.05-0.24			0.25-1.00	>1.0			USA	457	
	50-60 DAS	ML	Lit				0.25-0.80				Ger	82	
	50-60 DAS	ML	Lit				0.3-0.7				Ger	82	
	U	YMB	U	0.025-0.05			0.1-2.5				USA	1011	
Na(%)	Var	PYML	F				0.02-9.0				USA	1004	
	U	PYML YMB	Lit				0.02-9.0 0.02-3.7				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	Var	YMB	F				0.02-3.7				USA	1005	
Cl(%)	Mat	WS Root	F	<1.5 <0.16							NZ	333	Diagnostic for fresh and dry shoots, root and percentage sugar
	Mat	WS Roots	F	<5			≥2.4 >2.8				NZ	560	Diagnostic for max. shoot and root FW
	Mat	WS Roots	F	<1.9							NZ	560	Diagnostic for max. root DW
	Mat	WS Roots	F			2.2	≥2.4				NZ	560	Diagnostic for max. sugar yield
	55 DAS	PYML	RSC	0.01-0.04		0.4	0.8-8.5				USA	1009	Critical at 90% max. yield
	U	PYML	Lit	0.01-0.04		0.4	0.8-8.5				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	Veg	PYML	Lit	0.01-0.04		0.4					USA	1010	
Cu(mg/kg)	Mat	WS	SC						17		UK	558	

SUGAR BEET, FODDER BEET (*Beta vulgaris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg) (ctd)	U	YMB	Lit	<2			>2				USA	1008 1010	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	50-60 DAS	ML	Lit				6-15				Ger	82	
	50-60 DAS	ML	Lit				7-15				Ger	82	
Zn (mmol/ kg FW)	30 DAS	WS	SC			<900					Ger	769	Carbonic anhydrase activity
Zn(mg/mL)	30 DAS 40 DAS	WS	SC			0.8 0.6					Ger	769	Zn conc. in aqueous leaf extraction (mg/L)
Zn(mg/kg)	30 DAS 40 DAS	WS	SC			18 16					Ger	769	
	42 DAS	WS	Soil							670	USA	108	Critical at 80% max. yield
	42 DAS	WS	Soil						100-150		UK	558	
	60 DAS	YMB	RSC	2-13		8-10	11-80				USA	850 1010	Same critical level for root DW and shoot FW Piper-Steenbjerg effect
	U	YMB	Lit	2-13		9	10-80				USA	1008 1010	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	50-80 DAS	L	Lit	5-9			10-80	>80			USA	457	
	50-60 DAS	ML	Lit				20-80				Ger	82	
Mn(mg/kg)	10th leaf	WS	Soil	<30		15	30-62				USA	274	Critical at 90% max. yield
	U	WS	Soil							>800	Ger	1117	Linked with soil acidity
	21 DAT	YMB	Soil, SC							>5000	USA	690	Critical at 90% max. yield
	Veg	YMB	Lit	4-20		10				>5500	USA	1010	
	U	YMB	Lit	4-20			25-360				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	U	YMB	U	4-20		10	25-360				Ger	1023	
	50-80 DAS	L	Lit	10-25			26-360	>360			USA	457	
	50-60 DAS	ML	Lit				35-100				Ger	82	
Fe(mg/kg)	50-80 DAS	L	Lit	50-59			60-140	>140			USA	457	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	30 DAT	YMB	RSC	20-55		55	60-140				USA	647	Critical at 90% max. yield
	Veg	YMB	Lit	20-55		55					USA	1010	
	U	YMB	Lit	20-55		55	60-140				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
B(mg/kg)	49 DAT	WS	SC	<250						>250	USA	676	Chlorotic tissue contained 800-1000 mg/kg B Necrotic tissue contained >1500 mg/kg B
	U	YMB	Lit	12-40		21	35-200				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	U	YMB	U	12-40		27	35-200				USA	1026	Critical at 90% max. yield
	Veg	YMB MB Old B	Lit	12-40 12-40 12-40		27				250 420 650	USA	1010	
	Veg	YML	Lit	<30			30 - 50				USA	26	
	50-80 DAS	L	Lit	20-30			31-200	201-800			USA	457	
	60-70 DAS	L	Soil					300-350			Ger	496	
	50-60 DAS	ML	Lit			5-50	35-100 35/40-100				Ger	82	Fodder Beet Sugar Beet
Mo(mg/kg)	U	YMB	U	0.01-0.15			0.2-20				USA	1006 1010	
	U	YMB	Lit	0.01-0.15			0.2-20				USA	1008	Plant growth less below critical Deficient = symptoms present Adequate = no symptoms
	50-80 DAS	L	Lit	0.10-0.19			0.20-2.0	2.1-20			USA	457	
	50-60 DAS	ML	Lit				0.2-1.0 0.25-1.00				Ger	82	Fodder Beet Sugar Beet
Cd(mg/kg)	7 DAT	Roots L	SC						≥35 >16		Yug	730	Diagnostic for DW in plant part sampled
	7 DAT	Roots L	SC						>374		Yug	730	Diagnostic for nitrate reductase activity in plant part sampled
	35 DAS	L	SC						70		UK	558	
Li(mg/kg)	28-42 DAS	L	Soil						5500		UK	558	

SUGAR CANE (*Saccharum* spp.)

Sampling is recommended during the 'boom' phase of growth, i.e. when stalk elongation is ≥ 2 cm/day (see reference 257). TVD = 'top visible dewlap', which is approximately the third leaf from the shoot apex (see reference 202). A section, 20 cm long (10 cm above and 10 cm below the midpoint of the TVD blade), is taken for chemical analysis (see reference 257). The midrib is discarded (see reference 336).

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	Rapid growth	TVD	F,S			1.8	2.0-2.6	>3.2			USA	57 252 316	
	3 months (plant)	TVD	F			2.4-2.5					Guy	257	Critical lower in droughted crops
	5 months (plant)					2.1							
	6 months (plant)					1.9							
	2 months (ratoon)					2.4-2.5							
	3 months (ratoon)					2.1							
	4.5 months (ratoon)					1.9							
	3-5 months	3rd LB below A	F			1.70					S Afr	889	
	3-9 months	TVD	F			1.7-1.9 1.6-1.8					S Afr	1095	Crit. conc. for plant crops. Crit conc. for ratoon crops.
	4 months	3rd & 4th LB below A	F				1.5-2.0				Bra	570	
	5-5.5 months	TVD	F			1.9					S Afr	336	
	5 months (ratoon)	3rd LB below A	F			1.95					Maur	369	
	6 months	TVD	F		1.5	1.6	1.7				USA	317	Mean data for 4 cvv.
	8 months				1.35	1.4	1.6						
	4 months (ratoon)				1.5-2.0	2.0	2.25						
	6 months (ratoon)				1.3-1.4	1.5	1.6						
	8 months (ratoon)				1.1-1.4	1.4	1.6						
	6-7 months (ratoon)	TVD	S			1.7					S Afr	21	
	7 months	TVD	S			1.65					S Afr	608	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	10.3 months plant	3rd LB below A	F	<1.7		1.6-2.0	1.9-2.5				Aust	185	
	7 months (ratoon)			<1.7		1.6-2.0	1.9-2.5					827	
	U	TVD	Lit	<1.2			2.0-2.6				USA	23	
	U			<1.0			1.5-2.0				PuRi		
	3-4 months	3rd leaf (200mm mid-section less midrib)					1.8				Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				1.9-2.1				Ger	82	
	3.8 months	Blades 3-6	F		1.35-1.80	1.79	1.75-2.12				Ind	1101	Critical conc. for 90% max. sugar cane yield derived by reviewer.
	4.8 months				1.22-1.75	1.72	1.67-2.03						
	7.2 months				1.02-1.60	1.64	1.59-1.95						
	3 months	Leaves	F	<1.4	1.4-1.6		1.6-2.0	2.0-5.0			PuRi	879	
	Early rapid growth	Leaves 3-6	F	<1.5		1.0	1.5-2.7				USA	886	Authors state N conc. should be preferably >2% N.
P(%)	Rapid growth	TVD	F,S			0.19	0.22-0.30	>0.34			USA	57 252 316	
	3-5 months	3rd LB below A	F			0.19					S Afr	889	Var. NCo367
						0.16							Var. N12
	3-6 months (plant)	TVD	F			0.18-0.21	0.21-0.35				Guy	257	
	2-4.5 months (ratoon)					0.18-0.21	0.21-0.35						
	3-9 months	TVD	F			0.19					S Afr	1095	
	4 months	3rd & 4th LB below A	F				0.24-0.3				Bra	570	
	5-5.5 months	TVD	F			0.18					S Afr	336	
	5 months (ratoon)	3rd LB	F			0.21					Maur	369	
	6-7 months (ratoon)	TVD	S			0.2					S Afr	21	
	7 months	TVD	S			0.19					S Afr	608	

SUGAR CANE (*Saccharum spp.*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	10.3 months (plant)	3rd LB below A	F	<0.18		0.15-0.23	0.21-0.3				Aust	185 827	
	7 months (ratoon)			<0.18		0.15-0.23	0.21-0.3						
	U	TVD	Lit	<0.19			0.22-0.30				USA	23	
	U			<0.10			0.18-0.25				PuRi		
	Early rapid growth	Sheath 3-6	F	<0.05		0.08	0.05-0.20				USA	886	
	3-4 months	3rd leaf (200mm mid-section less midrib)				0.19					Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				0.20-0.24				Ger	82	
	3 months	Leaves	F	<0.15	0.15-0.18		0.18-0.24	0.24-0.3			PuRi	879	
K(%)	Rapid growth	TVD	F,S			0.90	1.0-1.6	>2.2			USA	57 252 316	
	3-5 months	3rd LB below A	F			1.05 0.90					S Afr	889	All varieties except N14. Var. N14
	3-6 months (plant)	TVD	F			1.25	1.25-2.0				Guy	257	
	2-4.5 months (ratoon)					1.25	1.25-2.0						
	3-9 months	TVD	F			1.05					S Afr	1095	
	4 months	3rd & 4th LB below A	F				1.2-1.25				Bra	570	
	5-5.5 months	TVD	S			1.1					S Afr	608	
	5 months (ratoon)	3rd LB below A	F			1.25					Maur	369	
	3-5 months (ratoon)	3rd LB below A	F,S			1.1					Jam	436	
	6-9 months (plant)					0.98-1.08							

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	6-7 months (ratoon)	TVD	S			1.1					S Afr	21	
	10.3 months (plant)	3rd LB below A	F	<1.1		0.9-1.3	1.3-2.0				Aust	185 827	
	7 months (ratoon)			<1.1		0.9-1.3	1.3-2.0						
	U	TVD	Lit	<0.9			1.0-1.6				USA	23	
	U			<1.0			1.65-2.0				PuRi		
	Early rapid growth	Sheaths 3-6	F	<1.5		2.25	2.25-6.0				USA	886	
	3-4 months	3rd leaf (200mm mid-section less midrib)				1.11					Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				1.1-1.3				Ger	82	
	3 months	Leaves	F	<1.4	1.4-1.55		1.55-2.0	2.0-3.0			PuRi	879	
S(%)	35 DAS	WS	RSC			0.36					USA	289	Critical at 95-100% max. yield; Optimal N/S 10-15
	3-5 months	3rd LB below A	F			0.12					S Afr	889	
	7 months	TVD	S			0.13					S Afr	608	N/S <17
	Early rapid growth	Blades 3-6	F	<0.01			0.03-1.0				USA	886	
	35 DAS	Blades 3-6	F			0.24					USA	289	Critical at 95-100% max. yield; Optimal N/S = 10-15
	70 DAS					0.10							
	18 months			0.08			0.14						
	35 DAS	Sheaths 3-6	Soil			0.61					USA	289	Critical at 95-100% max. yield; Optimal N/S = 10-15
	70 DAS					0.08							
	18 months			0.07			0.23						
	3 months	3rd leaf (200mm mid-section less midrib)				0.13					Aust	167	N(%)/S(%) ratio >17 also used to identify S deficiency.
	8 months					0.10							
	4 months	Middle leaves (mid-portion less midrib)	Lit				0.25-0.30				Ger	82	Critical at 95-100% max. yield; Optimal N/S = 10-15
	U	Leaves	F			0.20					Bra	571	

SUGAR CANE (*Saccharum* spp.) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Ca(%)	Rapid growth 3 months (plant) 4.5-6 months (plant) 2-3 months (ratoon) 5 months (ratoon) 6 months (ratoon)	TVD	F	<0.13		0.13-0.15	0.18-0.35 0.14-0.18 0.15-0.2 0.16-0.2 0.2-0.24 >0.16				Guy	257	
	Rapid growth	TVD	F,S			0.20	0.20-0.45	>0.5			USA	57 252 316	
	3 months	3rd LB below A	F,S	<0.15			0.2-0.5				Aust	827 828	
	3-5 months	3rd LB below A	F			0.15					S Afr	889	
	5-5.5 months	TVD	F			0.18					S Afr	336	
	6-7 months	TVD	F			0.12					S Afr	21	
	7 months	TVD	F			0.15					S Afr	608	
	Early rapid growth	Sheaths 3-6	F	<0.1		0.15	0.1-2.0				USA	886	
	4 months	Middle leaves (mid-portion less midrib)	Lit			0.20	0.80-1.0				Ger	82	
	3-4 months	3rd leaf (200 mm mid-section less midrib)				0.20					Aust	167	
Mg(%)	Rapid growth	TVD	F,S			0.12	0.15-0.32	>0.35			USA	57 252 316	
	Rapid growth	TVD	SC	0.03-0.05		0.08	0.08-0.35				Guy	256	
	Rapid growth	3rd LB below A	F	<0.08			0.1-0.3				Aust	827 828	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	3 months (plant)	TVD	F				0.09-0.12				Guy	257	
	4.5-6 months (plant)						0.12-0.18						
	2-3 months (ratoon)						0.1-0.18						
	5 months (ratoon)						0.12-0.18						
	3-5 months	3rd LB below A	F			0.08					S Afr	889	
	5-7 months	TVD	F,S			0.08					S Afr	21 336 608	
	Early rapid growth	Sheaths 3-6	F	<0.1		0.1	0.15-1.0				USA	886	
	3-4 months	3rd leaf (200 mm mid-section less midrib)				0.08					Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				0.20-0.30				Ger	82	
Na(%)	Rapid growth	TVD	F							>0.04	Guy	257	
Cl(%)	Rapid growth	TVD	F				<0.5			0.6-1.0	Guy	256 257	
Cu(mg/kg)	Rapid growth	TVD	F,S	1	3.6		4-15				Guy	256 257	
	Rapid growth	TVD	F,S			3	4-8	>9			USA	57 252 316	
	3-5 months	3rd LB below A	F			3					S Afr	889	
	3-4 months	3rd leaf (200 mm mid-section less midrib)				2					Aust	167	
	6-7 months (ratoon)	TVD	S			3	4.2-12.2				S Afr	21 608	
	4 months	Middle leaves (mid-portion less midrib)	Lit				8-10				Ger	82	
	Rapid growth	Blades 3-6	F	<3.5		5	5-100				USA	886	

SUGAR CANE (*Saccharum spp.*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Cu(mg/kg) (ctd)	U	Leaf	S	<5							Aust	1013	
Zn(mg/kg)	Rapid growth	TVD	F,S				15-50				Guy	256 257	
	Rapid growth	TVD	F,S			15	16-32	>40			USA	57 252 316	
	3-5 months	3rd LB below A	F			12					S Afr	889	
	6-7 months (ratoon)	TVD	S			12					S Afr	21	
	7 months	TVD	S			14					S Afr	608	
	Rapid growth	Blades 3-6	F	<15		15	20-100				Tai	465	
	Rapid growth	Sheaths 3-6	F	<10		10	10-100				USA	886	
	3-4 months	3rd leaf (200 mm mid-section less midrib)				10					Aust	167 802	
	4 months	Middle leaves (mid-portion less midrib)	Lit				25-50				Ger	82	
Mn(mg/kg)	Rapid growth	TVD	F,S				12-100	>100			USA	252 316 57	
	Rapid growth	TVD	F,S	<15			20-200				Guy	256	
	3-5 months	3rd LB below A	F			15					S Afr	889	
	6-7 months (ratoon)	TVD	S			15					S Afr	21 608	
	Rapid growth	Blades 3-6	F	1-10		10	20-400				USA	886	Critical <10 if Fe/Mn >1
	3-4 months	3rd leaf (200 mm mid-section less midrib)				15					Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				100-250				Ger	82	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Fe(mg/kg)	U	WS		30			200				Ind	648	Callus derived seedlings grown in regeneration media.
	Rapid growth	TVD	F,S				50-105	>105			USA	57 252 316	
	Rapid growth	TVD	F,S	<5			5-100				Guy	256 257	Deficient if Fe/Mn <l; adequate if Fe/Mn >15
	7 months	TVD	S			50	49-915				S Afr	608	
	Rapid growth	Blades 3-6	F	<10		10	20-600				USA	886	Critical <10 if Fe/Mn >1
	3-4 months	3rd leaf (200 mm mid-section less midrib)				50					Aust	167	
B(mg/kg)	Rapid growth	TVD	F,S	<1			2-10				Guy	256 257	
	7 months	TVD	S			1	1.6-10				S Afr	608	
	Rapid growth	Blades 3-6	F	<1		1	2-30				USA	886	
	3-4 months	3rd leaf (200 mm mid-section less midrib)				1					Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				15-30				Ger	82	
Mo(mg/kg)	Rapid growth	TVD	F,S	0.03-0.05			0.08-1				Guy	256 257	
	Rapid growth	Blades 3-6	F	<0.05		0.05	0.05-4.0				USA	886	
	Rapid growth	Sheaths 3-6	SC,S	<0.05							Trin	130	
	3-4 months	3rd leaf (200 mm mid-section less midrib)				0.08					Aust	167	
	4 months	Middle leaves (mid-portion less midrib)	Lit				0.15-0.30				Ger	82	
Si(%)	5.5-6 months (plant)	TVD	F			3.0-3.3					USA	24	cv. CP72-1210; tissue Si conc. for max. yield; data from 2 sites.
	Rapid growth (1st ratoon)					1.0-1.1							
	Rapid growth (2nd ratoon)					0.26-1.2							

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
SUGAR CANE (*Saccharum spp.*) (ctd)													
Si(%) (ctd)	7 months (plant)	TVD	F		0.83-1.23		1.40-1.52				USA	246	cv. CP 63-588
	6.7 months (ratoon)				0.31-0.53		0.68-0.76						
	3-4 months	3rd leaf (200 mm mid-section less midrib)				0.7					Aust	167	
SUNFLOWER (*Helianthus annuus*)													
Growth stages of sunflower (e.g. R2, R3, R4) are described in reference 887.													
N(%)	Seedl	WS	Lit			5.21					Aust	107	
	R5.1					1.63							
	R5.1	WS	F				2.02				USA	192	Conc. at max. seed yield
	Fl	WS	F				≥3.5				Aust	958	Diagnostic for max. shoot and seed yield
	Mat						≥1.7					959	
	Buds visible (63 DAS)	YMB	F	< 4.7	4.7-5.4	5.1	>5.4				Aust	300	Critical at 95% max. yield; cv. Hysun 30
	Full Fl	YMB	F	< 4.5	4.5-5.0	4.8	>5.0				Aust	300	Critical at 95% max. yield; cv. Hysun 30
	R-2	YMB	SC	2.6	2.9-3.2	3.3	3.4				Aust	319	cv. Hysun 31
	R-2	YML	SC			3.3					Aust	319	
	Florets about to emerge	3rd + 4th LB below flower bud	Soil, D	<3.0	3.0-3.5	3.2	3.6-5.0				Aust	1051 1052	
	41 DAS	All LB	F				4.8				USA	594	Conc. at near max. yield
	55 DAS						4						
	69-83 DAS						3.3						
	97 DAS						2.1						
	R-1	L	Lit				5.20				Aust	107	
	R-2	YEL					3.30						
	R-5.1	YEL		1.38		2.79							
	R-5.1	L					4.00-5.50						
	R-5.1	L 5,6					3.08						
	Mat	Seed	F	2.4-2.5			3.3				USA	594	
	Mat	Seed	F				≥3.2				Aust	958 959	Diagnostic for max. shoot and seed yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N/S	Mat	Seed	Sand			16					Aust	409	Diagnostic for max. seed and oil yield
NO_3-N (mg/kg)	4th leaf stage	PYML	F	<17000							USA	414	Predictive for max. seed yield
P(%)	<30 cm high	WS	Soil			0.29					Pak	605	
	≤30 cm high	WS	Soil			0.29					Pak	784	Predictive for near max. seed yield
	42 DAS	WS	Soil	<0.39		0.39					Pak	567	Diagnostic at 95% of max. growth
	R-2	YEL	Lit	<0.33		0.20-0.32	0.25-0.56				Aust	107	
	Week 3	YEL				0.35							
	Week 10	YEL				0.20							
	R-5.1					0.24							
	R-5.1	L 5,6					0.37						
	Fl init.	YML	Soil			0.31					Pak	605	
	Full Fl	YMB	F	<0.28	0.28-0.33	0.32	>0.32				Aust	311	Critical at 95% max. yield; cv. Hysun 30
	Fl	YMB	F			0.25					Aust	430	Slight Piper-Steenbjerg curvature
	Fl	YMB	F			0.23					Aust	430	Critical at 90% seed yield
	Florets about to emerge	3rd + 4th LB below flower bud	Soil, D	<0.15	0.15-0.2	0.2	0.25-0.56				Aust	1051 1052	
	R2	YMB	SC			0.2					Aust	319	cv. Hysun 31
	27 DAS	YMB	F			0.32					Aust	950	Critical at 90% seed yield; cv. Hysun 10
	38 DAS					0.35							
	45 DAS					0.25							
	4 leaf pairs (49 DAS)					0.32							
	59 DAS					0.22							
	Late star (70 DAS)					0.24							
	Head	YMB	Soil			0.31					Pak	784	Predictive for near max. seed yield
	Mat	Seed				0.20							
	Mat	Seed	Soil			0.2					Pak	605	
PO_4-P (mg/kg)	44 DAS	LB pair 2	Sand			126					Aust	127	Critical at 90% max. yield expressed on fresh weight basis
		LB pair 3				135							
	51 DAS	LB pair 2	Sand			110					Aust	127	Critical at 90% max. yield expressed on fresh weight basis
		LB pair 3				115							
		LB pair 4				135							
K(%)	Florets about to emerge	3rd + 4th LB below flower bud	Soil, D	< 1.2	1.5-1.8	1.8	3.5-6.0				Aust	1051 1052	

SUNFLOWER (*Helianthus annuus*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	R-2	YMB	FSC	1.1	1.1-2.6	2.6	3.4-6.6				Aust	319	cv. Hysun 31
	R-2	YEL	Lit	1.8							Aust	107	
	R-2	YEL		1.1-2.4		2.4	3.4-6.6						
	R-1/R-2	YEL		0.17-1.09			1.28-2.70						
		Mature L					3.0						
	Week 8-14	L					6.3-6.7						
	R-5.1	L 5,6					3.91						
S(%)	R-2	YMB	SC	<0.29	0.29-0.37	0.43					Aust	319	cv. Hysun 31
	R-2	YEL	Lit	<0.29		0.43					Aust	107	
	Mat	S	Sand			0.04					Aust	409	Diagnostic for max. seed and oil yield
		L				0.19							
		Receptacle				0.09							
		Seeds				0.22							
Ca(%)	R-2	YEL	Lit			1.4	2.3-5.5				Aust	107	
	Week 6-14	L					2.1-3.6						
	R-5.1	L 5,6					2.18						
	Florets about to emerge	3rd + 4th LB below flower bud	D				2.3-3.5				Aust	1051 1052	
	R-2	YMB	SC	<0.3	0.3-1.4	1.4	1.6-1.9				Aust	319	cv. Hysun 31
Mg(%)	Florets about to emerge	3rd + 4th LB below flower bud	D				0.31-1.2				Aust	1051 1052	
	R-2	YMB	SC	<0.11	0.11-0.18	0.18	0.27-0.68				Aust	319	cv. Hysun 31
	R-2	YEL	Lit	<0.11		0.18	0.27-1.20				Aust	107	
	Week 6-14	L					0.57-0.70						
	R-5.1	L 5,6					0.32						
Na(%)	R-2	YMB	SC							>0.7	Aust	319	Na supplied as NaCl; symptoms observed > 1.2%Na
	R-2	YMB	SC							>1.5	Aust	319	Na supplied as Na_2SO_4; symptoms observed >1.5%Na
	R-2	YEL	Lit						0.7-1.6	0.7-3.7	Aust	107	
	Mat	Upper L								0.42-0.54			
Na(mmol/kg tissue water)	11 DAT	WS	SC						0.3		Aust	875	Diagnostic for transpiration rate
									0.5				Diagnostic for rel. growth rate
													Cl increased in proportion to Na

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Cl(%)	R-2	WS	Lit						0.005	0.005-0.0066	Aust	107	
	Florets about to emerge	3rd + 4th LB below flower bud	D				0.6-1.9			>2.5?	Aust	1051 1052	
Cl(mmol/kg tissue water)	11 DAT	WS	SC						20 73		Aust	875	Diagnostic for transpiration rate Diagnostic for rel. growth rate Na increased in proportion to Cl
Cu(mg/kg)	R-2 R-5.1	YEL L 5,6	SC Lit	<2.3	2.3-3.7	3.7	4.4-28 12.5			≥70	Aust	101 107	cv. Hysun 31
	Bud formation	Upper L	Soil	2-3			5-7.5				Pol	553	
Zn(mg/kg)	Florets about to emerge	3rd + 4th LB below flower bud	Soil, D	<17	18-20	20	40-100				Aust	1051 1052	
	R-2	YMB	SC	<10	10-13	13	13-23			>255	Aust	319	cv. Hysun 31
	Early Fl	YMB	F				>13				Aust	299	
	R-2 R-5.1	YEL L 5,6	Lit	<10		13	13-23 12.5		1150		Aust	107	
Mn(mg/kg)	Seedl	WS	Lit						5300		Aust	101	
	R-2 R-5.1	YEL L 5,6		<13	13-40	40	46-80 44.8		2205			107	cv. Hysun 31
	R-2 (42 DAT)	YMB WS	SC				65-2670		2205	>2205	Aust	856	cv. Hysun 31
	18-31 DAS	WS	FSC							5300	Aust	242	cv. Hysun 31
	Florets about to emerge	3rd + 4th LB below flower bud	D				41-850			>3000?	Aust	1051 1052	
Fe(mg/kg)	R-5.1	L 5,6	Lit				107				Aust	107	
B(mg/kg)	F l	YMB	F			29					S Afr	106	Critical at 90% max. normal heads
	R-2	YMB	SC							>1150	Aust	319	cv. Hysun 31
	R4-R5	YMB	F	<12	12-34	34	40-250			>250	S Afr	102	Critical at 90% max. seed yield (108)
	Seedl	L	Lit	<26							Aust	107	
	R-5.1	YEL		<13		29-34	31-250			1150			
	R-5.1	WS				46							
	R-5.1	L								>500			
	R-5.1	L 5,6					62.3						
	10 DAS	L	SC	10-14			39-44				Ger	166	
	Fl	4th LB from cotyledons	SC							>491	Spa	180	Toxic at 30% max. seed yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
SUNFLOWER (*Helianthus annuus*) (ctd)													
B(mg/kg) (ctd)	30 DAS	WS	F			46					S Afr	106	Critical at 90% max. normal heads
	42-49 DAS	Whole plant	Soil					≥148	185		NZ	902	
	Mat	Seed	F			15					S Afr	106	Critical at 90% max. normal heads
Mo(mg/kg)	Florets about to emerge	3rd + 4th LB below flower bud	D	<0.22			0.28-0.6				Aust	1051 1052	
TEA (*Camellia sinensis*)													
Plant parts referred to below are described in reference 1079.													
N(%)	Max. growth	2nd leaf of plucked shoot	F			5.16					Ind	56	
	At plucking At plucking	1st leaf +bud 3rd leaf	F			4.4 3.8					Ken	1080	Continual use of N fertilizer induced high Mn conc.
	U	3rd leaf	Lit				3.8-4.8				USA	457	
	At plucking	Mature leaves	F,S	< 2.6		3					PNG	271	
	Max. growth	Mature leaves	F				3.5-4.5				Aust	327	
P(%)	At plucking	3rd leaf	F			0.4-0.42					Ken	1084	
	U	3rd leaf	Lit				0.19-0.25				USA	457	
	At plucking	Mature leaves	F,S	<0.l		0.16					PNG	271	
	Max. growth	Mature leaves	F				0.3-0.4				Aust	327	
K(%)	At plucking At plucking	3rd leaf 1st leaf+ bud	F			1.57 1.75					Ken	1081	
	U	3rd leaf	Lit				1.8-2.0				USA	457	
	At plucking	1st leaf + bud and 3rd leaf (mean)	F	<1.6	1.6-2.0		>2.0				Ken	996	
	At plucking	Bud 3rd leaf Mat leaf	F		1.73 1.38 0.98		2.02-2.11 1.79-1.91 1.71-1.94				Sri L	929	
	Max. growth	Mature leaves	F				1.6-2.2				Aust	327	
	At plucking	Mature leaves	F,S	<0.8		1.0					PNG	271	
S(%)	U	3rd leaf	Lit				0.1-0.3				USA	457	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Max. growth	Mature leaves	F				0.1-0.3				Aust	327	
S04-S (mg/kg)	At plucking	Mature leaves	F,S	< 200		300					PNG	271	
Ca(%)	At plucking	1st leaf+ bud	F				~ 0.3				Ken	1082	Ca fertilizer induced K deficiency
	At plucking	3rd leaf					~ 0.5						
	U	3rd leaf	Lit				0.4-0.6				USA	457	
	At plucking	Mature leaves	F,S	<0.6		0.9					PNG	271	
	Max. growth	Mature leaves	F				0.4-0.5				Aust	327	
Mg(%)	At plucking	1st leaf + bud	F				0.07-0.23				Ken	1083	
	At plucking	3rd leaf					0.07-0.24						
	U	3rd leaf	Lit				0.15-0.3				USA	457	
	U	Leaves	S	0.1-0.15			0.26-0.49				E Afr	191	
	Max. growth	Mature leaves	F				0.18-0.25				Aust	327	
	At plucking	Mature leaves	F,S	<0.2		0.24					PNG	271	
Cl(%)	U	3rd leaf	Lit				0.003-0.005				USA	457	
Cu(mg/kg)	At plucking	Mature leaves	F,S	<9		12					PNG	271	
Zn(mg/kg)	U	3rd leaf	Lit				30-50				USA	457	
	At plucking	Mature leaves	F,S	<3		5					PNG	271	
Mn(mg/kg)	At plucking	Mature leaves	F,S	<50		100					PNG	271	
Fe(mg/kg)	U	3rd leaf	Lit				500-1000				USA	457	
	At plucking	Mature leaves	F,S	<60		120					PNG	271	
B(mg/kg)	U	3rd leaf	Lit				30-50				USA	457	
	At plucking	Mature leaves	F,S	<8		12					PNG	271	

TOBACCO (*Nicotiana tabacum*)

Extensive literature on plant analysis for tobacco is available (see references 310 and 597). Wide variations in nutrient concentration occur between leaves from different parts of the stalk.

Criteria for cured leaves are higher than those for uncured leaves, and differences also exist between leaf lamina and whole leaf samples. Criteria for quality are normally narrower than those for yield. Cultivar differences may also occur.

The data described below are given as guides for the nutritional status of tobacco.

N(%)	2 months	YMB	SC	3.40			5.80				Spa	234	Midrib was excised from leaf blade before analysis.
		YMB + 1		1.58			4.87						
		YMB + 2		1.05			2.17						
		YMB + 3		0.31			2.40						

TOBACCO (*Nicotiana tabacum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N(%) (ctd)	Fl	YMB	S,D				3:5-4.25				USA	456	
	2 months	Mid-rib of YMB	SC	2.20			4.50				Spa	234	
	Veg (40-80 DAE)	YML	S,D		3.5		4.0-5.4				Aust	1053	
	2.5 months	Laminae	F	1.06			1.23-1.86				Cyp	696	
	3 months			1.17			1.51-2.13						
	4.5 months			1.32			1.55-1.85						
	2 months	Leaf	SC							6.91	Spa	234	Authors claim symptoms of N toxicity.
	Early to mid-Fl	Leaves	F		3.6	4.0	4.3-5.1				USA	159	
	Mat	Leaves			3.1	3.5	3.9-4.7						
		Cured leaves			2.5	3.0	3.3-4.2						
	Mat	Leaves	F				2.0-5.0				USA	310	
	2.5 months	Midribs	F	0.57			0.65-1.00				Cyp	696	
	3 months			0.64			0.78-1.03						
	4.5 months			0.65			0.78-0.95						
	Mat	Cured leaves	F				4.45				USA	258	Yield ≥ 3.2 t/ha
NO_3-N (mg/kg)	2.5 months	Laminae	F	330			410-680				Cyp	696	
	3 months			630			700-780						
	4.5 months			380			420-460						
	2.5 months	Midribs	F	590			610-3500				Cyp	696	
	3 months			530			640-3500						
	4.5 months			430			510-880						
P(%)	Fl	YMB	S,D				0.27-0.5				USA	456	
	Veg (40-80 DAE)	YML	S,D		0.20-0.22		0.25-0.50				Aust	1053	
	Mat	Leaves	F	0.12-0.17			0.22-0.4				USA	310	
	Mat	Cured leaf lamina	F	0.1-0.18		0.2	0.2-0.3			0.32-0.42	Aust	298	
	Mat	Cured leaves	F				0.24				USA	258	Yield ≥ 3.2 t/ha
K(%)	Fl	YML	S,D				2.5-3.2				USA	456	
	Veg (40-80 DAE)	YML	S,D		2.0		2.5-5.0	5.8-6.8			Aust	1053	
	Mat	Leaves	Sand	0.42-1.08			2.44-3.17				Can	600	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mat	Leaves	F	0.4-1.0			2.5-7.5				USA	310	
	Mat	Cured leaf lamina	F	0.7-1.0	1.0-2.5	2.5	2.5-3.9				Aust	298	
	Mat	Cured leaves	F				4.81				USA	258	Yield ≥ 3.2 t/ha
	Mat	Cured leaves	Sand	0.1-0.5							Aust	548	
	Mat	Cured leaves	Sand		1.0-1.9		2.6-3.8				Aust	739	
S(%)	70 DAS	Leaves	Sand			0.2					USA	302	Critical protein N/S ratio = 6
	Mat	Leaves	F	0.1-0.15							USA	310	
	Mat	Leaves	F	0.11-0.18	0.18-0.22		0.15-0.65				USA	184	
	Mat	Cured leaf lamina	F			0.2	0.25-0.3	0.31-1.21			Aust	298	
	Mat	Cured leaves	Sand				0.4-1.4				Aust	743	
	Mat	Cured leaves	F				0.42				USA	258	Yield ≥ 3.2 t/ha
Ca(%)	Fl	YMB	S,D				1.5-3.5				USA	456	
	Veg (40-80 DAE)	YML	S,D				1.3-2.3	2.9-3.5			Aust	1053	
	30-45 cm height	Primary buds	F	0.42-0.50			0.48-0.54				USA	158	Data for 7 cvv; 3 susceptible and 4 not susceptible to Ca deficiency.
		YL		0.56-0.60			0.52-0.72						
	40 DAS	Non-deficient buds	F	0.37-0.39			0.53-0.54				USA	158	Data for 2 susceptible and 4 non-susceptible cvv.
		Leaves 1-4		0.77-0.82			0.85-0.96						
	Mat	Leaves	F	0.2-0.7			2.0-5.0				USA	310	
	Mat	Cured leaf lamina	F				2.2-6.1				Aust	298	
	Mat	Cured leaves	Sand		0.5-1.8		0.9-4.8				Aust	739	>2.2% Ca may affect quality; high Ca may induce K deficiency
	Mat	Cured leaves	F				3.33				USA	258	Yield ≥ 3.2 t/ha
Ca*	40 DAS	Leaves 1-4	F	0.08-0.10			0.19-0.29				USA	158	* "Free Ca", calculated as difference between total Ca and oxalate content.
Mg(%)	Fl	YMB	S,D				0.2-0.65				USA	456	
	Veg (40-80 DAE)	YML	S,D	0.11	0.18		0.25-0.90	1.2-1.4			Aust	1053	
	29 DAT	Leaves	Sand		0.27-0.36						Aust	741	
	38 DAT				0.24-0.8		0.33-1.56					742	
	45 DAT				0.18-0.72		0.48-1.81						

TOBACCO (*Nicotiana tabacum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mg(%) (ctd)	Mat	Leaves	F	0.12-0.2		0.24	0.24-1.8				USA	310	
	Mat	Leaves	Sand			0.2					Aust	741	
	Mat	Cured leaf lamina	S			0.2	0.2-0.5				Aust	298	High Mg conc. may induce K deficiency
	Mat	Cured leaf lamina	F				0.55-2.9				Aust	298	High Mg conc. may induce K deficiency
	Mat	Cured leaves	Sand	0.04-0.12	0.1-0.17	0.07-0.12	0.17-1.98				Aust	740	
	Mat	Cured leaves	Sand		0.1-0.3		0.3-2.7			4.3-6.3	Aust	739	
	Mat	Cured leaves	F				0.49				USA	258	Yield ≥ 3.2 t/ha
Na(%)	Veg (40-80 DAE)	YML	S,D				0.01-0.15	0.4-0.6		0.8	Aust	1053	
	Mat	Cured leaves	F				0.009				USA	258	Yield ≥ 3.2 t/ha
Cl(%)	Veg (40-80 DAE)	YML	S,D				<2.5	3.0-3.5		>3.5	Aust	1053	Toxic - leaf quality lowered when Cl^- conc. >3.5%.
	28 DAT	All leaves	FSC					5.1			USA	1018	No Cl^- toxicity symptoms.
	Mat	Cured leaf lamina	S				0.5-1.0			1.1-9.3	Aust	298	
	Mat	Cured leaf	F							4-5	USA	310	
	Mat	Cured leaves	F				0.96				USA	258	Yield ≥ 3.2 t/ha
Cu(mg/kg)	Fl	YMB	S,D				15-60				USA	456	
	Veg (40-80 DAE)	YML	S,D		2-3		4-55				Aust	1053	
	Mat	Leaves	F				10				USA	310	
	Mat	Cured leaf lamina	F				4-30				Aust	298	
Zn(mg/kg)	Fl	YMB	S,D				20-80				USA	456	
	Veg (40-80 DAE)	YML	S,D				20-70				Aust	1053	
	4.2-6 months	Leaves	F				22-79				Can	359	Data are means of 5 leaf harvests (primings).
	Mat	Leaves	F				25-50				USA	310	
Mn(mg/kg)	Seedl	WS	F				93-1019			823-3430	Aust	298	
	Fl	YMB	S,D				30-250				USA	456	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Fl	YMB	F		30-56		33-156				USA	537	
	Veg (40-80 DAE)	YML	S,D				35-350	450-850		1290-1420	Aust	1053	
	67 DAT	Leaves	Soil				277-1395			9000	Aust	549	>2000 mg/kg Mn affects quality
	Var	Leaves	Var				160			933-11000	USA	184	
	Veg	Leaves (all) Leaves (all)	SC				33 41	397 449-877		797	USA	1043	cv. KY 14 cv. T.I.1112
	42 DAT	Leaves	Sand							700-1200 2000-3500 5000-8000	USA	857	D/N temp 22/18°C } cv. D/N temp 26/22°C } Coker D/N temp 30/26°C } 347.
	Mat	Cured leaves	F				115				USA	258	Yield ≥ 3.2 t/ha
	Mat	Cured leaves	Sand							7000	Aust	451	
	Mat	Cured leaves	F				500-2000				USA	310	
Fe(mg/kg)	45 DAT	WS	F	33-36			91-130				USA	184	
	Fl	YMB	S,D				50-200				USA	456	
	Mat	YMB	F	63-70			68-140				USA	184	
B(mg/kg)	Fl	YMB	S,D				20-50				USA	456	
	Veg (40-80 DAE)	YML	S,D		15-20		25-55				Aust	1053	
	Mat	Leaves	F	<6			20-50			800	USA	310	
	4.2-6 months	Leaves	F				40-92		98	134	Can	359	Data are means of 5 leaf harvests (primings).
	Budding Mat	Cured leaves Cured leaves	F				32-70 23-58				Aust	535	
Mo(mg/kg)	45 DAT	WS	F		0.31-0.35	0.40	0.41-1.54				USA	911	Crit. conc. for cured leaf yield at maturity.
	50 DAT	WS	F			0.38					USA	910	Burley tobacco
	Veg (40-80 DAE)	YML	S,D		<0.4		0.4-3.7				Aust	1053	
	U	Upper leaves Lower leaves	Pyrex glass cullet-wool	0.17 0.13			6.6 10.6				USA	729	
	Mat	Cured leaves	F				0.56				USA	258	Yield ≥ 3.2 t/ha
	Mat	Cured leaves	F		1.1-6.6		11.4-22.1				USA	489	
	Mat	Cured leaves	S	<0.2	0.2-0.4		0.4-1.0	1.0-8.0			USA	488	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
TRITICALE (*X Triticosecale*)													
NO_3-N (mg/kg)	Early Till	Basal S	F	1200			9500-12500				Aust	707	
P(%)	Mat	Grain	F			~0.2					Aust	500	
N/S	30-65 DAS	WS	Soil				<25				USA	277	Variable data.
Mn(mg/kg)	22 DAS	WS	Soil	11-15							Aust	579	Conc. associated with reduced growth in two cvv.
	25 DAS	WS	SC							1100-3200	USA	634	Toxic range associated with plant yield reduction in four cvv.
Zn(mg/kg)	70 DAS	WS	Soil	19			31-46				Ind	916	Four levels of Zn applied.
WHEAT (*Triticum aestivum* and *Triticum durum*)													
FS = Feeke's scale of cereal growth (see reference 511). ZS = Zadok's scale of cereal growth (see reference 1110).													
N(%)	FS2	WS	F			7.39					Aust	592	Diagnostic critical values quoted have been derived from a range of experiments in Western Australia by relating N% in WS to relative shoot yield at sampling.
	FS3					5.64							
	FS4					5.30							
	FS5					4.19							
	FS6					2.86							
	FS7					2.88							
	FS9					2.57							
	FS10					1.81							
	FS10.5					1.79							
	FS11					1.41							
	Mat					1.39							
	FS2	WS	F			6.66					Aust	592	Predictive criteria derived from relationships between N% in WS and relative grain yield.
	FS3					5.39							
	FS4					5.45							
	FS5					5.15							
	FS6					3.08							
	FS7					3.12							
	FS9					2.44							
	FS10					1.37							
	FS10.5					1.69							
	FS11					1.47							
	Mat					1.28							
	22 DAS	WS	RSC			3.1					USA	967	Critical at near max. shoot yield.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	FS 2 -4	WS	F				>3.0				USA	862	
	FS 6						>2.75						
	FS 7						>2.25						
	FS 8						>2.0						
	FS 9						>1.25						
	FS 4	WS	F			4.5-4.8					USA	236	Critical at max. grain yield for winter wheat.
	FS 5-6	WS	Lit				3.0-5.0				Ger	82	Winter wheat
	FS 5-6						4.0-5.5						Summer wheat
	FS 7-8						2.3-3.8						Winter wheat
	FS7-8						3.0-4.5						Summer wheat
	FS 5	WS	F			3.2					USA	1016	Criticals at near max. grain yield for winter red wheat. Shoot and stem NO_3-N values were highly variable. N and NO_3-N values at FS 3 correlated poorly with grain yield.
	FS 7					2.7							
	FS 3	WS	F	<4.2	4.9-5.2		5.2-5.6				USA	253	Deficient at 40% max. yield; marginal 80-90% max. yield; adequate 90-100% max. yield
	FS 5-6			<3.4	3.7-4.2		4.2-5.1						
	FS 9-10			<2.0	2.2-2.4		2.4-3.5						
	FS 10.5-10.5.1			<1.5	1.6-1.8		1.8-2.6						
	FS 3	WS	F			4.4					USA	853	Criticals at 90% max. grain yield for winter wheat.
	FS 4					3.9							
	FS 5					3.5							
	FS 6					2.7							
	FS 10.1	WS	Lit	1.0-1.99			2.0-3.0	>3.0			USA	457	Spring wheat
	Late Till	WS	F				>4.0				Aust	199	
	4 leaf stage	WS	RSC			0.63					UK	1115	Conc. expressed on tissue water basis. Critical derived where NO_3 begins to accumulate in shoots.
	ZS 30	WS	F			3.97					USA	37	Critical N content in WS was 95 kgN/ha at ZS30 which was judged to be a good indicator of N required at ZS30 to maximise grain yield. This criterion was later tested on 39 farms (see 885).
	Up until Fl	WS	RSC	Maximum and minimum N concentration between emergence and flowering are developed.							Aust	25	
	Pollination	WS	F			1.2					Fin	725	Critical N uptake/plant = 15 mg.
	Early double ridge stage	WS	F			4.3					Fin	725	
	FS 10	WS	F,S			2.6					USA	604	
	FS 10.1	WS	F,S	<1.5	1.5-2.0		2.1-3.0	>3.0			USA	205	

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%) (ctd)	Stigmatic branches on carpel formed	WS	F			2.8					Fin	725	Critical N uptake/plant = 13 mg.
	U	WS	F	N status of winter wheat is best assessed by shoot yield and N content of shoots.							UK	61	
	Various	WS	F	In situ nitrate reductase tests calibrated as a means of assessing N status of winter wheat.							Ind Fra	3 1026	
	Mid to late Till	YMB	F,S	<3.4	3.4		3.5-5.4	5.5-6.5		>6.5	Aust	1052 1053	
	22 DAS	YMB	RSC	The merit of measuring chlorophyll fluorescence in YMB using a portable fluorometer was judged to be doubtful given that similar recordings were obtained for N,P and K deficiencies in wheat seedlings.							USA	967	
	36 DAS	YMB	Soil			4.5					Aust	846	Critical value decreases at elevated atmospheric CO_2 levels.
	FS 5	YMB	F	The merit of measuring chlorophyll in YMB using a portable chlorophyll meter to assess plant N status has been evaluated.							USA	282 286 801	Winter wheat
	FS 5 FS 7	2 uppermost YMBs	F			3.8 3.5					USA	1016	Criticals at near max. grain yield for winter red wheat. Shoot and stem NO_3-N values were highly variable. N and NO_3-N values at FS 3 correlated poorly with grain yield.
	2-3 leaf	YEB	F,S				4.0-6.5				Aust	732	
	FS 9-1 0 FS 10.5-10.5.1	YEB, YEB + 1	F	<3.6 <3.0	3.9-4.1 3.4-3.6		4.1-5.0 3.6-4.5				USA	253	
	Pre-Head	Upper LB	S,D				2.0-3.0				USA	456	
	4 leaf stage	Leaf 4	RSC			0.77					UK	1115	Conc. expressed on tissue water basis. Critical derived where NO_3 begins to accumulate in shoots.
	FS 10	Flag leaf	F			4.4-4.7					USA	236	Critical range at 100% max. grain yield for winter wheat.
	Stigmatic branches on carpel formed	Leaves	F			3.0					Fin	725	
	Pollination	Leaves	F			2.3					Fin	725	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Till	LB	F	<3.8	3.9-4.2		4.3-5.2	>5.2			CIS	335	Deficient <70% max. yield; marginal 70-100% max. yield.
	Shoot			<3.0	3.1-3.5		3.6-4.4	>4.4					
	Fl			<2.4	2.4-2.6		2.7-3.0	>3.0					
	Just before heading	Two uppermost leaves	Lit	1.25-1.74			1.75-3.0	>3.0			USA	457	Winter wheat
	Fl	1st + 2nd blades below flag leaf	Lit			2.6±0.2					Fra	547	
	FS 1.5	Leaves	Sand			5.35					Aust	404	Critical values at 90% max. shoot yield.
	FS 5	Leaves				4.75						405	Atmospheric CO_2 enrichment reduced these criteria substantially.
	FS 10.3	YL				4.25							
	FS 1.5	Basal S				3.04							
	FS 5	Basal S				2.8							
	FS 10.3	Basal S				2.2							
	Mat	Grain	F			2.3					Aust	858	
	Mat	Grain	F	<1.6	1.6-2.0	2.0	>2.0				Aust	963	
	Mat	Grain	F	<1.56	1.56-2.11		1.78-2.3				UK	1073	Data assessment from several field experiments with winter wheat.
	Mat	Grain	F			11.1-12.0					USA	334	Critical range of protein % at max. grain yield for winter wheat.
	Mat	Grain	F	8-10		11-12					NZ	583	Values are protein % at 14% grain moisture for max. grain yield of 6 cvv.
	Mat	Grain	F			11.2					Fin	725	Unit is protein % in grain of four cvv. of spring wheat.
	Mat	Grain	F	An increasing proportion of grain had a non-vitreous appearance at protein levels <9%.							Can	169	
	Mat	Grain	Lit	Deposition of starch and protein in wheat endosperm is reviewed.							Aust	447	
NO_3-N (mg/kg)	4 leaf stage	WS	RSC			140					UK	1115	Conc. expressed on tissue water basis (mg/L). Critical derived when NO_3 begins to accumulate in shoots.
	Till	Basal S	F	Cultivar differences in basal stem NO_3-N conc. are unlikely to influence interpretation criteria.							Cyp	702	
	35 DAS	Basal S	F			9630					Aust	248	Diagnostic critical values for near max. shoot yield.
	42 DAS					6600							
	63 DAS					6600							
	77 DAS					2930							
	35 DAS	Basal S	F			9630					Aust	248	Predictive critical values for near max. grain yield.
	42 DAS					7060							
	63 DAS					6910							
	77 DAS					2660							

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
NO_3-N (mg/kg) (ctd)	FS 2 FS 5 FS 6 FS 10 FS 10.5	Basal S	F			2000 2000 1000 1000 500	3000-4000 2500-3500 1000-1500 500-1000 200-500	6000 5000 4000 3000 2000			USA	499	Criteria for durum wheat (*T. turgidum*). See reference for Basal S sampling protocol.
	FS 3 FS 4 FS 5 FS 6	Basal S	F			2420 2010 2190 1960					USA	853	Criticals at 90% max. grain yield. Basal S is stem between root and collar of 1st living leaf (lower 5 cm sampled). Whole shoot N recommended for diagnosing N status of wheat.
	FS 1.5 FS 5 FS 10.3	Basal S	Sand			7500 6200 6400					Aust	404 405	Critical at 90% max. shoot yield. Atmospheric CO_2 enrichment reduced these criteria substantially.
	49 DAS (5 leaf stage)	Basal S	Soil			1200					Aust	1032	Critical at 90% max. shoot yield.
	FS 3-4 (56 DAS)	Basal S	F	<4000	4000-6000		6000-9000	>10000			Aust	707 704	Predictive criteria for near max. grain yield
	Joint (77 DAS)	Basal S	F				>3000				Aust	704	Predictive criteria for grain yield
	Till-FI	Basal S	Soil			1000					Aust	706	Minimum conc. at 90% max. shoot yield
	Late Till-FI	Basal S	F				2000				USA	307	Predictive criteria for grain yield
	Until ear emergence	Basal S	F	Diphenylamine rapid field test developed for assessing N status of wheat.							Ger	1050	
	49-77 DAS	Basal S	F	Effects of rotation on this plant N test were assessed over 2 years.							Aust	705	
	Till	Basal S	F	In situ field tests have been developed and calibrated in other countries (see 111, 703, 890, 891, 1089, 1090, 1091) using sap NO_3 - sensitive test strips to assess N status of wheat (mainly winter wheat).							Aust	248 373	
	Spring (Feb-June)	Basal S sap	F			~200					UK	220	Units are mg NO_3-N/mL sap in winter wheat
	FS 1.5 FS 5 FS 10.3	Leaves	Sand			4000 2200 1700					Aust	404	Criticals at 90% max. shoot yield. Atmospheric CO_2 enrichment reduced these criteria substantially.
P(%)	8-19 DAS	WS	Soil							1.1-2.1	Aust	1049	
	8-19 DAS	WS	Soil							>1.0	Aust	87	
	14 DAT	WS	SC	0.11-0.12			0.25-0.67				USA	263	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	2-3 leaf stage	WS	F							>0.84	Aust	542	
	6th leaf stage	WS	RSC			0.31					Can	347 713	Critical P increased as root temperature decreased from 25°C to 10°C
	21 DAS 36 DAS	WS	Soil	0.17-0.48 0.11-0.36			0.79-1.04 0.53-0.65				Aust	557	
	28 DAS	WS	Soil			0.8-0.9					Aust	115	Critical estimated at near max. shoot yield.
	≤40 DAS 41-60 DAS 61-90 DAS 90+ DAS	WS	F, Soil			0.91±0.15 0.55±0.03 0.44±0.05 0.23±0.03					Aust	120	Critical (± s.e.) at 90% max. shoot or grain yield.
	44 DAS	WS	Soil			0.28					Ger	259	Critical at 80% max. shoot yield.
	ZS12-13.5/21 ZS14.5/2+ ZS15.5/2+ ZS16.5/2+ ZS17.5/2+ ZS31	WS	F			0.59-0.70 0.48-0.58 0.38-0.45 0.27-0.33 0.23-0.27 0.18-0.22					Aust	249	Critical ranges at near max. shoot yield and cover the derived critical values and their 95% confidence limits.
	FS 5-6 FS 5-6 FS 7-8 FS 7-8	WS	Lit				0.3-0.6 0.35-0.6 0.25-0.5 0.3-0.5				Ger	82	Winter wheat Summer wheat Winter wheat Summer wheat
	≤30 cm tall	WS	Soil			0.28					Pak	783	Critical at 95% max. yield.
	Late Till	WS	F		0.16-0.2	0.2	>0.2				Aust	85	
	FS 10	WS	F,S			0.3					USA	604	
	FS 10.1	WS	S				0.15-0.3				Aust	732	
	FS 10.1	WS	F,S	<0.15	0.15-0.2		0.21-0.5	>0.5			USA	1044	
	FS 10.1	WS	Lit	0.15-0.19			0.2-0.5	>0.5			USA	457	Spring wheat
	Just before heading	Uppermost two leaves	Lit	0.11-0.2			0.21-0.5	0.51-0.8			USA	457	Winter wheat
	FS 1	YEB	F,S				0.3-0.8				Aust	732	
	ZS12-13.5 /21 ZS14.5/2+ ZS15.5 /2+ ZS16.5 /2+ ZS17.5 /2+ ZS31	YEB	F			0.48-0.55 0.44-0.47 0.32-0.38 0.24-0.3 0.22-0.27 0.21-0.25					Aust	249	YEB = 1st-3rd blade on main culm. YEB = 4th blade on main culm. YEB = 5th blade on main culm. YEB = 6th blade on main culm. YEB = 7th blade on main culm. Above critical ranges cover critical values at max. shoot yield and their 95% confidence limits

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	8-19 DAS	YEB	Soil							1.8-2.7	Aust	1049	
	36 DAS	YMB	Soil			0.39					Aust	846	Critical value increased at elevated atmospheric CO_2 levels.
	Until Fl	YEB	F		Presence of an acid phosphatase isozyme in YEB indicates P deficiency.						Aust	205 602	
	Mid to late Till	YMB	F,S	<0.24	0.24-0.29		0.3-0.5	0.6-0.7		>0.7	Aust	1052 1053	
	Fl init.	YMB	Soil			0.3					Pak	783	Critical at 95% max. yield.
	Till Shoot Fl	LB	F	<0.31 <0.28 <0.22	0.32-0.34 0.29-0.31 0.23-0.24		0.35-0.49 0.32-0.4 0.25-0.34	>0.49 >0.4 >0.4			CIS	335	Deficient <70% max. yield; marginal 70-100% max. yield
	Pre-Head	Upper LB	F,S				0.2-0.4				USA	456	
	Fl	1st+2nd blades below flag leaf	Lit	0.25	0.26-0.33	~0.34	0.34-0.36	>0.36			Fra	547	
	2 tillers	Oldest LB	F							>1.37	Aust	542	
	Mat	Grain	F			0.18-0.2					Aust	249	Critical range at 90% max. grain yield (4 sites). Critical range at max. grain yield is 0.21-0.24%P.
	Mat	Grain	F		0.25-0.5	~0.37	0.37-0.53				Aust	1068	Grain P conc. vary with grain yield.
	Mat	Grain	F		<0.25	~0.4					Aust	534	Critical at 100% max. grain yield
	Mat	Grain	F		0.15-0.19		0.20-0.29				Aust	119	
	Mat	Grain	F, Soil			0.27±0.02					Aust	120	Critical (± s.e) at 90% max. grain yield.
	Mat	Grain	Soil			0.22					Pak	783	Critical at 95% max. yield.
	Mat	Grain	F		0.29-0.31		0.33				NZ	169	
		Grain	F		Early plant vigour results when seeds of high P conc. are sown on P deficient soils						Aust	118 226 834	
PO_4-P (mg/kg)	ZS14.7/24	YEB	F			~133					Aust	249	Critical at 90-100% max. yield.
	ZS14.7/24	YEB+1	F			~127					Aust	249	Critical at 90-100% max. yield.
	ZS16.3/25	YEB	F			~82					Aust	249	Critical at 90-100% max. yield.
	ZS16.3/25	YEB+1	F			~64					Aust	249	Critical at 90-100% max. yield.
	ZS17.5/26	YEB	F			~73					Aust	249	Critical at 90-100% max. yield.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	ZS17.5/26	YEB+1	F			~54					Aust	249	Critical at 90-100% max. yield.
	FS 6-7	(YMB + YMB+1)	F		<80		>90				Fin	860	Mid section of blade analysed.
	4-6 leaf stage	Basal S	F			240-550					Aust	373	Critical at 90% max. shoot yield. Units are mg/L sap collected.
	FS 2 FS 6 FS 10	Basal S	F			2000 1200 500					USA	498	Preliminary criteria for irrigated *T. turgidum*. Basal S extracted in 2% acetic acid. Consult reference for Basal S separation protocol.
	37-49 DAS	Mature LB	Sand			155-200					Aust	127	Critical at 90% max. shoot yield
K(%)	22 DAS	WS	RSC			3.9					USA	967	Critical at near max. shoot yield.
	30 DAE 45 DAE	WS	RSC			3.8 4.1					Ind	773	Predictive criticals at 90% max. grain yield.
	FS 2 FS 3 FS 7 FS 10.1 FS 11	WS	F	<3.5 <3.0 <1.8 <1.3	3.5-4.5 3.0-3.5 1.8-2.3 1.3-1.6	4.1 3.2 2.0 1.5 0.9	>4.1 >3.5 >2.3 >1.6 >1.0				Aust	211	Criticals at 95% max. yield.
	FS 5-6 FS 7-8 FS 5-6 FS 7-8	WS	Lit				3.5-5.5 3.3-4.5 3.3-4.5 2.9-3.8				Ger	82	Winter wheat Winter wheat Summer wheat Summer wheat
	FS 10	WS	F,S			1.8					USA	604	
	FS 10.1	WS	S				1.5-2.5				Aust	732	
	FS 10.1	WS	F,S	<1.25	1.25-1.49		1.5-3.0	>3.0			USA	1044	
	FS 10.1	WS	Lit	1.25-1.49			1.5-3.0	>3.0			USA	457	Spring wheat
	2-3 leaf	YEB	S				2.5-6.0				Aust	732	
	Mid to late Till	YMB	F,S	<1.5	1.5-2.3		2.4-4.0	4.1-5.5		>6.0	Aust	1052 1053	
	75 DAE 105 DAE	Uppermost 2 leaves	RSC			3.2 2.1					Ind	773	Predictive criticals at 90% max. grain yield.
	Just before heading	Uppermost 2 leaves	Lit	1.0-1.5			1.51-3.0	3.01-5.0			USA	457	Winter wheat
	Till Shoot Fl	LB	F	<2.8 <2.6 <2.0	2.9-3.6 2.7-3.0 2.1-2.2		3.4-4.2 3.1-3.6 2.3-3.2	>4.2 >3.6 >3.2			CIS	335	Deficient <70% max. yield; marginal 70-100% max. yield
	Pre-Head	Upper LB	S,D				1.5-3.0				USA	456	
	45 DAS	Leaves	F	2.65	3.79		3.93				Ind	995	Three levels of K applied.

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	Awns just visible	Flag leaf	Soil		0.15		0.41				Ger	504	Data are for sap expressed from moderately K deficient and adequate plants.
	Fl	1st + 2nd blades below flag leaf	Lit	1.6-1.9	1.9-2.5	2.5-2.8		>2.8			Fra	547	Critical at or near max. grain yield.
	4-6 leaf stage	Basal S	F			>0.16					Aust	373	Critical at 90% max. shoot yield. Units are mg/L sap collected.
	Mat	Grain	F	0.41	0.47		0.53				Ind	995	Three levels of K applied.
Na/K	Till Mat	WS Grain	Soil						0.5 <0.15		Ind	193	Critical ratios for assessing cultivar tolerance to salinity.
S(%)	FS 2 FS 5 Early joint	WS	F			0.3 0.28 0.15					Aust	951	Criticals at 90% max. yield
	FS 2-3 (21 DAS) FS 7-8 (44 DAS)	WS	Soil			0.29 0.11					Aust	843	Criticals at near max. shoot yield. Data for FS 2-3 is variable.
	FS 4-5 FS 5-6	WS	Soil			0.26 0.27					Aust	745	Critical S values lower in N deficient plants.
	35 DAS	WS	Sand	0.06-0.11			0.18				USA	636	Three levels of S applied to 35 wheat cvv. Values quoted are cv. means.
	FS 9	WS	F			0.18					USA	562 564	
	FS 9-10	WS	F			0.11					USA	563	Critical at 90% max. grain yield.
	FS 10.1	WS	F,S				0.15-0.4	>0.4			USA	1044	
	FS 10.1	WS	Lit		<0.15		0.15-0.4	>0.4			USA	457	Spring wheat
	FS 10.1	WS	F	0.06			0.1-0.15				USA	675	Winter wheat
	Fl	WS	F	0.08			0.12				USA	791	N/S ratio recommended for diagnosing S deficiency in winter and spring wheats.
	FS 2-3 (21 DAS) FS 7-8 (44 DAS)	YEB	Soil			0.31 0.14					Aust	843	Critical at near max. shoot yield. Data for FS 2-3 is variable.
	FS 4-5 FS 5-6	YEB	F			0.28 0.32					Aust	745	Critical values are lower in N deficient plants. Critical reducible S in YEB at FS 6-7 was 0.42% S.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mid to late Till	YMB	F,S		<0.15		0.15-0.4	>0.4			Aust	1052 1053	
	Stem elongation	Younger leaves	F, S, Soil			0.29					Ger	375	Critical at 95% max. grain yield in winter wheat.
	FS 7	Upper 2 leaves	F	0.11			0.25-0.5				USA	1058	
	FI	Green leaves	F	0.14			0.23				USA	791	N/S ratio recommended for diagnosing S deficiency in winter and spring wheats.
	16-24 days after FI	Immature grain	Sand	0.08-0.1			0.19-0.2				Aust	179	
	Mat	Grain	Sand	0.05			0.17-0.18				Aust	28	Five cvv. grown at 3 levels of S supply.
	Mat	Grain	F, Soil			0.12					Aust	777	S deficiency if N/S ratio >17; critical at 90% max. yield
	Mat	Grain	F, Soil		Gluteraldehyde rapid test developed for detecting S deficient grain.						Aust	631	
N/S	30&65 DAS	WS	Soil	30-55			<22				USA	277	Two levels of S applied.
	FS 4-10	WS	F	19-33			13-16				USA	791	N/S ratio recommended for diagnosing S deficiency in winter and spring wheat.
	FS 9	WS	F			19					USA	562	
	FS 9-10	WS	F			16.5					USA	563	Critical at 90% max. grain yield.
	FS 10.1	WS	F	21			9-16				USA	675	Winter wheat
	FS 7-8 (44 DAS)	YEB	Soil			19					Aust	843	Critical at 90% max. shoot yield.
	FI	Green leaves	F	25			14				USA	791	N/S ratio recommended for diagnosing S deficiency in winter and spring wheats.
	16-24 days after FI	Immature grain	Sand	30-38			17-19				Aust	179	
	Mat	Grain	Sand	43			15-16				Aust	28	Five cvv. grown at 3 levels of S supply.
	Mat	Grain	F	23			<17				USA	564	
SO_4-S (mg/kg)	FS 2 FS 5 Early joint	WS	F			460 360 190					Aust	951	
	4-6 leaf stage	Basal S	F			>200					Aust	373	Critical at 90% max. shoot yield. Units are mg SO_4-S/L sap collected.
SO_4-S/S(%)	FS 2-Early Joint	WS	F			13					Aust	951	Critical at 90% max. yield
Ca(%)	FS5-6 FS7-8	WS	Lit				0.4-1.0 0.35-1.0				Ger	82	Winter and summer wheats

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Ca(%) (ctd)	FS 10	WS	F,S			0.25					USA	604	
	FS10.1	WS	Lit		<0.2		0.2-0.5	>0.5			USA	457 1044	Spring wheat
	2-3 leaf FS 2 FS 6	YEB	S	<0.15	0.15-0.25 0.15-0.2 0.12-0.2		0.3-0.8				Aust	732	
	Mid to late Till	YMB	F,S		<0.18		0.21-0.4	0.6-0.7			Aust	1052 1053	
	Just before Till	Uppermost 2 leaves	Lit		0.1-0.2		0.2-1.0	>1.0			USA	457	Winter wheat
	31DAS	Unemerged blade	RSC	0.36			0.71				Can	244	Deficient value for salinity-induced Ca deficiency.
Mg(%)	FS 5-6 FS 7-8 FS 5-6 FS 7-8	WS	Lit				0.12-0.25 0.1-0.23 0.2-0.3 0.15-0.25				Ger	82	Winter wheat Winter wheat Summer wheat Summer wheat
	FS 10	WS	Soil			0.13					Ger	1072	Critical at 95% max. yield
	FS 10	WS	F,S			0.15					USA	604	
	FS10.1	WS	Lit		<0.15		0.15-0.5	>0.5			USA	457 1044	Winter wheat
	FS 1-6	YEB	F,S	<0.05	0.05-0.15		0.15-0.4				Aust	732	
	Early Till	YEB	SC			0.086					Aust	892	Critical at max. shoot yield. YEB analysis recommended.
	Mid to late Till	YMB	F,S	<0.11	0.11-0.12		0.13-0.3				Aust	1052 1053	
	Pre-Head	Upper LB	F,S				0.15-0.5				USA	456	
	Just before heading	Uppermost 2 leaves	Lit		0.1-0.15		0.16-1.0	>1.0			USA	457	Winter wheat
	FI	1st + 2nd blades below flag leaf	Lit	<0.1	0.1-0.15		>0.15				Fra	547	Marginal range linked to K status of wheat.
Na(%)	FI	WS	Soil				~0.02	>0.35			Aust	412	Suggested as a guide to salinity existing in the root zone.
	Mid to late Till	YMB	F,S				<0.5	0.6-0.7		>0.8	Aust	1053	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mat	Grain	Soil				~0.005	>0.08			Aust	412	Suggested as a guide to salinity existing in the root zone.
Cl(%)	Boot - heading	WS	F	Cl conc. in shoots did not reliably predict positive yield responses to applied Cl							Can	619	
	FS10-10.1	WS	F			0.3					USA	254	Critical associated with small yield increases to applied Cl in winter wheat
	FS10.1	WS	F			0.15					USA	280	Critical at 96% max. grain yield.
	Fl	WS	Soil				<0.19			>2.0	Ind	189	
	Mid to late Till	YMB	F,S				<2.0	2.0-2.8		>3.0	Aust	1053	
Cu(mg/kg)	16 DAS	WS	Sand							>18	UK	224	
	28 DAS	WS	RSC						75		NZ	1059	Critical defined where yield decreased.
	60 DAS	WS	Soil		~6		7-13				Ind	506	
	FS 5-6 FS 7-8	WS	Lit				7-15 5-10				Ger	82	Winter and summer wheats
	FS 6 FS 10	WS	F			4.0 3.2					Can	475	Criticals at 90% max. yield.
	FS10.1	WS	Lit		<5		5-25	>25			USA	457	Spring wheat
	Pre-Fl	WS	Soil			5.6					Pak	478	
	Early heading	WS	Soil	1.3-2.9	3.0-4.9						Can	596	Lower Cu conc. in marginal range at 85% max. shoot yield.
	Fl	WS	F			~3					China	965	Critical associated with sterile florets.
	Seedl-senescence	YEB	Soil, F,S	<1.3	1.3-2.0		>2.1				Aust	314	Diagnostic criteria (see reference for details)
	FS 10-10.1	YEB	Soil, F,S	<1.6	1.6-2.1		>2.2				Aust	314	Predictive criteria (see reference for details)
	FS 10.5.1	YEB	Soil, F,S	<1.6	1.7-1.9		>2.0				Aust	314	Monitoring criteria (see reference for details)
	Until Fl	YEB	Soil	<1.3		1.3	>1.3				Aust	144 145 543 841 937	Critical at 90% max. shoot yield
	ZS 50 ZS 59	YEB	F		1.5 1.1		1.7-3.5				Aust	143	Applied N decreased Cu conc. in YEB.
	Late Till	YEB	F, Soil	Cu conc. in YEB used to estimate the residual value of previously applied Cu.							Aust	146	
	Mid-Till	YEB + younger LB	Soil	<1.0			1.5-2.0				Aust	649	
	35 DAS	YMB	SC	ELISA technique used to diagnose Cu deficiency.							USA	782	

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg) (ctd)	Mid to late Till	YMB	F,S		2-4		5-50				Aust	1052 1053	
	FS 10	Flag leaf	F			2.5					Can	475	Critical at 90% max. yield.
	Just before heading	Uppermost 2 leaves	Lit		3-5		5-50	51-70			USA	457	Winter wheat
	60 DAS	3rd leaf	Soil			8.8					Ind	867	Critical at 90% max. shoot yield.
	Mat	Grain	Soil			1.0	>1.0				Aust	649	
	Mat	Grain	Soil		<1.1						Aust	397	Authors indicate grain Cu is unsatisfactory.
	Mat	Grain	F			2.5					Aust	492	
	Mat	Grain	F			1.5					Can	475	Deficiency symptoms observed in crops with grain Cu of 1.3-1.8 mg/kg.
	Mat	Grain	F			1.2					Aust	143	Critical at near max. grain yield. Applied N depressed Cu conc. in grain.
	Mat	Grain	Soil			1.0					Aust	147	Critical at max. grain yield.
Zn(mg/kg)	23 DAS	WS	Soil			15-25					Aust	991	
	33 DAS	WS	Soil						560		USA	108	Critical at 80% max. shoot yield
	40 DAS	WS	Soil	8	8.2		30				Aust	947	Values based on plant symptoms for 3 levels of applied Zn.
	45 DAS	WS	Soil	<18		20	22-390				Aust	768	
	45 DAS	WS	F		24-28		30-45				Ind	992	Three levels of Zn applied.
	60 DAS	WS	Soil		13-21		19-84				Pak	877	
	Till	WS	F		8.9-10.8		9.4-12.5				Aust	338	Ranges for 6 cvv. grown on a marginally Zn-deficient soil.
	FS 5-6 FS 7-8	WS	Lit				25-70 20-70				Ger	82	Winter and summer wheats
	ZS45	WS	F				14-27				Can	357	Ranges found in Zn adequate crops.
	Pre-Fl	WS	Soil			14.5					Pak	478	
	FS 10.1	WS	Lit		<15		15-70	>70			USA	457 1044	Spring wheat
	Fl	WS	Soil			16	17-51				Aust	218	Critical at 90% max. shoot yield. Analysis of YMB recommended.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	ZS 75	WS	F			~5					Aust	835	Diagnostic critical at near max. shoot yield.
	Veg	YEB	Soil			8-10					Aust	3 541	
	Mid Till	YEB	F	<16	16-24	18	24-90				Aust	1077	Critical at 90% max. shoot yield
	ZS16	YEB	Soil			11					Aust	142	Critical at 90% max. shoot yield.
	52 DAS	YEB	Soil	4-6			17-25				Aust	229	The merit of the carbonic anhydrase assay is also evaluated.
	ZS 75	YEB	F			~7					Aust	835	Diagnostic critical at near max. shoot yield.
	ZS 15.5/2 ZS 75	YEB	F			~17 ~7					Aust	835	Predictive criticals at near max. grain yield.
	Mid to late Till	YMB	F,S	<14	14		15-70				Aust	1052 1053	
	Fl Fl	YMB YMB+1	Soil			16 14	17-30 15-40				Aust	218	Critical at 90% max. shoot yield. Analysis of YMB recommended.
	45 DAS	2nd and 3rd upper leaf blade	F	13-23	18-35	19	28-40				Ind	50	
	Just before heading	Uppermost 2 leaves	Lit	11-20			21-70	71-150			USA	457	Winter wheat
	Early Fl	Flag leaf	Soil			17					USA	786	Critical at 95% max. shoot yield.
	Flag leaf stage	Flag leaf	F	16	19-21		21-22				Ind	897	Ranges related to grain yield responses to applied Zn.
	Mat	Grain	F	25	28-29		28-32				Ind	897	Ranges related to grain yield responses to applied Zn.
	Mat	Grain	F		15-16		19-21				Ind	992	Three levels of Zn applied.
	Mat	Grain	Soil			5-10					Aust	20 541	
	Mat	Grain	Soil							>66	Pak	972	
	Mat	Grain	F			~10					Aust	835	Critical at near max. grain yield.
	Mat	Grain	F	14-25	17-29		22-33				Ind	50	
	Mat	Grain	Soil			15					USA	786	Critical at 95% max. grain yield.
	Mat	Grain	F				21-34				Can	357	Ranges found in Zn adequate crops.
	Mat	Grain	F	7.6-13.0			23-30				Aust	338	Ranges for 8 cvv. grown at one Zn-deficient site.
Mn(mg/kg)	Young plants	WS	S						160		Ger	1117	Critical for acidic soils (pH < 4.7).

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	18-31 DAS	WS	FSC							280	Aust	242	
	21 DAS	WS	Soil, RSC						Mg/Mn 20	Mg/Mn 1.1-6.5	UK	337 517 518	Critical ratios for shoot yield reductions. Toxic ratio for symptoms. Shoot growth reduced where Mn conc. exceeded 100 mg/kg Mn in unlimed soil.
	22 DAS	WS	Soil		9-12						Aust	579	Conc. associated with plant symptoms and reduced growth in 7 cvv.
	25 DAS	WS	Soil	6			37-116				Aust	1076	Three levels of Mn applied.
	26 DAS	WS	Soil			11					Aust	577	Critical at 90% max. shoot yield.
	37 DAS	WS	SC						380		USA	485	Critical at 90% max. shoot yield. Severe symptoms >700 mg/kg.
	3 leaf stage	WS	SC			35			475		USA	272	Criticals at 90% shoot yield.
	Mid Till	WS	F	11			23				Aust	1075	Two levels of Mn applied.
	Mid Till-S elongation	WS	F			11-13					Aust	339	YEB recommended for sampling.
	FS 5-6 FS 7-8	WS	Lit				35-100 30-100				Ger	82	Winter and summer wheats
	FS 10.1	WS	Lit		5-24		25-100	>100			USA	457	Spring wheat
	Veg	YEB	SC			10					Aust	540	Correlated with photosynthetic O_2 evolution.
	26 DAS	YEB	Soil			11					Aust	577	Critical at 90% max. shoot yield.
	30 DAS	YEB	Soil			12-17					Aust	578	Critical range derived for 3 cvv at 90% max. shoot yield. Criteria using chlorophyll a fluorescence = 13-15 mg/kg.
	33 DAS	YEB	SC			13			380		USA	685	Criticals at 90% max. yield; YEB recommended for sampling.
	33 DAS	YEB+1	SC			39			900		USA	685	Criticals at 90% max. yield; YEB recommended for sampling
	33 DAS	YEB+2	SC			82			1100		USA	685	Criticals at 90% max. yield; YEB recommended for sampling.
	Mid Till-S elongation	YEB	F			10-12					Aust	339	YEB recommended for sampling.
	Mid Till-S elongation	YEB+1	F			12-14					Aust	339	YEB recommended for sampling.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mid Till-S elongation	YEB+2	F			15-17					Aust	339	YEB recommended for sampling.
	35 DAS (early Till)	YEB	F			11					Aust	248	Critical at near max. shoot yield. Criteria using chlorophyll fluorescence = 14 mg/kg.
	26 DAT (early Till)	YMB	RSC			13			384		USA	686	Criticals at 90% max. shoot yield.
	35-42 DAS	YMB	RSC			~12					Aust	502	Critical relates to chlorophyll a fluorescence.
	Mid to late Till	YMB	F,S	<12	12-24		25-300	300-600		700	Aust	1052 1053	Toxicity symptoms observed.
	Just before heading	Uppermost 2 leaves	Lit		10-15		16-200	201-350			USA	457	Winter wheat
	Shoots 20-40 cm high	Uppermost 40% shoot	F			11					USA	565	Critical at ~90% max. grain yield.
	25-40 DAS FI	Upper 2 leaf blade Flag leaf	F			10 10					Aust	503	Critical related to leaf fluorescence characteristics.
	Var	LB	F			Rapid peroxidase enzyme field test developed.					Irel	674	
	Mat	Grain	F				21-34				Can	356	Ranges in crops which did not respond to applied Mn.
	Mat	Grain	F		11.7-15.4		18.2				Ind	653	
	Mat	Grain	Soil		<15.5	19.4				>24	China	616	Critical at max. grain yield.
Fe(mg/kg)	FS 10.1	WS	Lit		<25		25-100	>100			USA	457	Spring wheat
	Just before heading	Uppermost 2 leaves	Lit		<10		10-300	301-500			USA	457	Winter wheat
	Pre-Head	Upper LB	F,S				25-100				USA	456	
B(mg/kg)	28 DAS	WS	RSC						400		NZ	1059	Critical defined for yield decrease.
	35 DAS	WS	SC							257-1226	Aust	641	Associated with reduced shoot growth in different genotypes. Range associated with symptoms was 106-1226 mg B/kg.
	ZS26	WS & YEB	F	It is suggested that leaching of B from foliage by rain may invalidate plant tests for diagnosing B toxicity.							Aust	643	
	FS 5-6 FS 7-8	WS	Lit				6-12 5-10				Ger	82	Winter and summer wheats
	Boot stage	WS	Soil				10-307				Ind	575	B conc. in shoots depressed by increased salinity levels at all levels of applied B.

WHEAT (*Triticum aestivum* and *Triticum durum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
B(mg/kg) (ctd)	FS 10	WS	Soil	<5			6-10			>16	Can	352	
	FS 10	WS	F							>13	Can	352	
	FS 10.1	WS	Lit		<6		6-10	>10			USA	457	Spring wheat
	Fl	WS	Soil				43			57-567	Aust	412	
	35 DAS	YEB	SC							281-812	Aust	641	Associated with reduced shoot growth in different genotypes. Ranges associated with symptoms was 123-812 mg B/kg.
	FS 1-6	YEB	F,S				3-25				Aust	732	
	Spike emergence	Y leaf	Sand				73	450		1009	USA	92	Three levels of B applied at 4 osmotic potentials.
	Early head emergence	Leaf below Y leaf	Sand						55		USA	93	
	28 DAS	YMB	RSC						122-282		Aust	186	Critical range at 90% max. shoot yield for 5 wheat genotypes.
	Mid to late Till	YMB	F,S	<2	2-4		5-10	11-20		30-100	Aust	1052 1053	
	Booting	1st tiller	Soil	Considerable genotypic tolerance to B toxicity and B conc. in tillers was established.							Aust	716	
	Booting	Flag leaf	F, Sand	<3			7-24				Thai	816	Definitive diagnosis of B deficiency (3-7 mg/kg) is not possible under field conditions.
	Mat	Straw	Soil	5-8			14-21			>34	Can	352	
	Mat	Grain	F	A more than two-fold genotypic variation in grain B conc. is described for wheat grown on a soil with a B-toxic subsoil.							Aust	718	
	Mat	Grain	Soil				2.0			9-37	Aust	412	
		Grain	Soil	Grain B conc. up to 20 mg/kg did not affect early seedling emergence, growth nor B conc. in shoots.							Aust	644	
Mo(mg/kg)	Veg	WS	F,S		<0.l						Aust	313	
	FS 5-8	WS	Lit				0.1-0.3				Ger	82	Winter and summer wheats
	FS 10	WS	Soil				0.09-0.18				Can	352	
	FS 10.1	WS	Lit		<0.09		0.09-0.18	>0.18			USA	457	Spring wheat
	Until FS 10	YEB	Soil, F	<0.05	0.05-0.1	0.075	>0.l				Aust	844	
	Unknown	YEB	Soil	<0.02	0.04-0.06						Aust	832	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Mid to late Till	YMB	F,S	<0.05	0.05-0.09		0.1-0.5	0.6-0.7			Aust	1052 1053	
	Veg	LB	SC		Nitrate reductase enzyme assay developed for diagnosing Mo deficiency.						Aust	775	
	Mat	Grain	F,S		<0.1						Aust	313	
	Mat	Grain	Soil				0.16-0.2				Can	352	
Al(mg/kg)	28 DAT	WS	RSC						2.2		USA	687	Critical at 90% max. shoot yield.
	28 DAT 28 DAT	WS YMB	RSC						2.2 3.2		USA	687	Criticals at 90% max. shoot yield.
	28 DAT	YMB	RSC						4		USA	688	Critical at 10% reduction in photosynthetic activity.
	Pre-Head	Upper LB	F,S				<200				USA	456	
Ni(mg/kg)	35 DAS	WS	RSC	0.037			0.084				USA	156	
	56 DAS	WS	Soil						63-113		Ind	913	Critical range at 90% max. shoot yield. Critical varies with plant N status.

WINGED BEAN (*Psophocarpus tetragonolobus*)

N(%)	42 DAS	WS	Sand	1.72-1.92			2.55-4.02				USA	214	
	25-33 DAT	WS	SC				3.88-4.42				Aust	75	Data for 2 cvv.
P(%)	25-33 DAT	WS	SC				0.35-0.42			0.93-1.66	Aust	75	Data for 2 cvv.
	42 DAS	WS	Sand				0.27-0.36				USA	214	
K(%)	42 DAS	WS	Sand				3.33-3.68				USA	214	
Ca(%)	42 DAS	WS	Sand				0.37-0.56				USA	214	
Mg(%)	42 DAS	WS	Sand				0.15-0.18				USA	214	
Cu(mg/kg)	42 DAS	WS	Sand				12-15				USA	214	
Zn(mg/kg)	42 DAS	WS	Sand				76-113				USA	214	
Mn(mg/kg)	25-33 DAT	WS	SC				218-225	498-1333			Aust	75	cv. UPS 31
	42 DAS	WS	Sand				29-49				USA	214	
Fe(mg/kg)	42 DAS	WS	Sand				60-76				USA	214	
Mo(mg/kg)	42 DAS	WS	Sand				5-10				USA	214	

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SUMMARISED INTERPRETATION GUIDELINES FOR DIAGNOSING NUTRIENT DISORDERS IN AGRONOMIC CROPS

The main tabular compilation in this chapter provides a diverse array of published plant tests for diagnosing nutrient deficiencies, excesses, toxicities and imbalances in field crop species. These tests involve sampling different plant parts at various stages of growth for different nutrients or nutrient fractions.

The purpose of the tables produced below is to summarise this body of information into sets of interpretation guidelines, which appear appropriate for detecting many nutritional disorders in major field crops grown in Australia. The particular growth stages and plant parts are identified in the tables.

The interpretation guidelines for diagnosing deficiencies are selected from the range of critical deficiency concentrations derived largely from field and glasshouse soil culture experiments conducted throughout the world. Occasionally, solution culture data have been used. The guidelines for diagnosing nutrient excesses, toxicities or imbalances have been derived in a number of ways; they include concentrations associated with a 10% yield decline, and concentrations associated with the presence of toxicity symptoms and yield depressions due to nutrient imbalance. In cases where no appropriate experimental data were found, the guidelines have been derived from Weir and Cresswell (1994). In these cases, guidelines for diagnosing deficiencies were obtained by coupling the top end of their 'Low' range with the bottom end of their 'Normal' range, while guidelines for toxicities and imbalances were based on their 'Excess or toxic' range.

The stated ranges correspond to the marginal zones of deficiency and toxicity as defined in Figure 4.3 (Chapter 4). They would normally relate to plants which are not exhibiting symptoms. However, in the case of toxicities, plants showing a 10% yield reduction may or may not show symptoms. An 'adequate' nutrient status would be expected where concentrations exceed the quoted guideline values for deficiencies, but are less than the guideline values for toxicities given below.

Diagnostic criteria have only been presented in these guidelines. Predictive criteria for these and other crops are provided in the main tabular compilation.

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TABLE 1 Interpretation guidelines for diagnosing nutrient deficiencies in cereal crops.

	BARLEY	MAIZE		OATS	RICE	SORGHUM	WHEAT
Growth stage	**Mid-late tillering FS 3-5 ZS 14/23-ZS30**	**Tasselling**	**Silking**	**Mid-late tillering FS 3-5 ZS 14/23-ZS30**	**Mid-Max tillering FS 3-5**	**GS 3-5**	**Mid-late tillering FS 3-5 ZS 14/23-ZS30**
Plant part	**YEB (YMB)**	**Ear leaf**	**Ear leaf**	**YEB (YMB)**	**Y blade (YMB)**	**YMB, YEB**	**YEB (YMB)**
Element							
N(%)	3.4–3.5[1]	2.6–3.3	2.6–3.1	3.4–3.5[1]	2.2–3.0	2.8–3.2	3.4–3.5[1]
NO_3- N (mg/kg)	6000–15000[2,3]	2200–2800[3]					3000–7000[2,3]
P(%)	0.24–0. 53[2]	0.24–0.25[1]	0.22–0.27	0.29–0.3[1]	0.1–0.2	0.23–0.25	0.22–0.47[2]
K(%)	2.3–2.4[1]	1.6–2.4	1.2–1.7	2.3–2.4[1]	1.0–1.5	1.3–2.2	2.3–2.4[1]
S(%)	>0.15	0.16–0.2	0.16–0.24	>0.15		0.15–0.20	0.14–0.32[2]
N/S		~17	14–17	14–20			~17
Ca(%)	0.18–0.21[1]	0.2–0.4	0.2–0.21	0.18–0.21[1]	0.1–0.16	0.30–0.34	0.18–0.21[1]
Mg(%)	0.12–0.13[1]	0.15–0.25	0.1–0.21	0.12–0.13[1]	0.12–0.15	0.16–0.20	0.12–0.15
Na(%)	<0.5[1]	<0.3[1]		<0.5[1]	<0.02[1]		<0.5[1]
Cl(%)	<2.0[1]	<0.1[1]		<2.0[1]	<0.6[1]		<2.0[1]
Cu(mg/kg)	1.2–2.8[6]	5–6[1]	5–6[1]	1.0–2.0	5–8	2.0–2.7	1.3–3.0[6]
Zn(mg/kg)	14–20	14–25	13–25	14–15[1]	17–25	18–20	16–20[5]
Mn(mg/kg)	11–15	19–20[1]	11–20	24–25[1]	40[1]	15	10–15
Fe(mg/kg)		20–30[1]			70–90[4]	55–90	
B(mg/kg)	4–5[1]	4–6		4–5[1]	5–6	1–2	3–5
Mo(mg/kg)	0.09-0.1[1]	0.2[1]		0.09–0.1[1]	0.2	0.15–0.30	0.08–0.1

[1] Critical nutrient range documented by Weir and Cresswell (1994).

[2] Between these stages of growth, nutrient criteria change reasonably rapidly, generally decreasing with advancing plant age (consult main Table compilation).

[3] Nitrate-N concentrations in basal stems sampled at the specified stages of growth.

[4] 40–50 mg/kg Fe^{2+} appears to be a consistent range.

[5] <11 mg/kg Zn is used to diagnose Zn deficiency in wheat grown in Western Australia; 20-25 mg/kg Zn may be appropriate for durum wheats.

[6] In crops of high N status, an upper limit of 5 mg/kg Cu may apply.

TABLE 2 Interpretation guidelines for diagnosing nutrient excess, toxicities or nutrient imbalances in cereal crops.

	BARLEY, OATS, WHEAT	MAIZE		RICE	SORGHUM
Growth stage	**Mid-late tillering FS 3-5 ZS14/23-ZS30**	**Tasselling**	**Silking**	**Mid-late tillering FS 3-5**	**GS 3-5**
Plant part	**YEB (YMB)**	**Ear leaf**	**Ear leaf**	**Y blade (YMB)**	**YMB, YEB**
N(%)	>6.5[1]	>3.9	>3.75	>5.5[1]	
P(%)	0.7–2.7	>0.8[1]	>0.5	>0.55[1]	0.81[1]
K(%)	>6.0[1]	>2.5–4.0	>2.5	>3.5[1]	
S(%)		>0.8[1]			
Ca(%)		>0.9[1]	>0.9		1.2–1.5[1]
Mg(%)		>0.85[1]	>0.55	>0.3?	0.9–1.2[1]
Na(%)	>0.8[1]	>0.5[1]		>0.5	
Cl(%)	>3.0[1]	>1.8[1]		>2.5?[1]	0.20–0.71[3]
Cu(mg/kg)		>50[1]	>50	>25	68
Zn(mg/kg)		>150[1]	>100	>50?	60–64[3]
Mn(mg/kg)	>380	3000[2]	>200	>800	280[3]
Fe(mg/kg)			>350	>300	450–700
B(mg/kg)	>40	>60[1]	>35		170[3]

[1] Ranges documented by Weir and Cresswell (1994).
[2] Showing toxicity symptoms.
[3] Critical toxicity concentrations associated with 10% yield reduction.

TABLE 3 Interpretation guidelines for diagnosing nutrient deficiencies in pulse crops.

	FIELD PEA	LUPIN	NAVY BEAN	PEANUT	SOYBEAN
Growth stage	**Prior to flowering**	**Prior to flowering**	**Prior to flowering**	**Pre-Fl or Fl**	**Early Fl**
Plant part	**YMB (YML)**	**YMB (YML)**	**YMB (YML)**	**YMB (YML)**	**YMB**
N(%)	3.4–3.5[1]	2.8–3.2[1]	5	3.0–3.5	4.1–4.2
P(%)	0.27–0.30[1]	0.19–0.24[1]	0.34	0.19–0.30[3]	0.29–0.34
K(%)	1.8–2.0[1]	1.4–1.6[1]	2.2	1.2–1.6	1.2–1.7
S(%)	0.22–0.29			0.20	0.20–0.23
N/S				13–15	16.5
Ca(%)	0.7–0.9[1]		1.5	1.20–1.25	0.4–0.9
Mg(%)	0.2[1]	0.17–0.24[1]	0.29–0.30	0.30	0.19–0.25
Cu(mg/kg)	4–6[1]	1.0–1.2	6–7	5–6	4–6
Zn(mg/kg)	19–24[1]	15–25	11–20	20–25	20–25
Mn(mg/kg)	15–30[1]	30	49–50	25–50	17–25
Fe(mg/kg)		18–20[1]	49–50	50	50
B(mg/kg)	20–25[1]	5–9[1]	19–24	22–25	20
Mo(mg/kg)				0.10–0.13	0.5[2]

[1] Critical nutrient range documented by Weir and Cresswell (1994).
[2] A critical Mo concentration of approx. 0.02 mg/kg has been reported for soybean grown in solution culture (Bell *et al.* 1990).
[3] Diagnostic criteria for P appear to differ with cultivar.

TABLE 4 Interpretation guidelines for diagnosing nutrient excess, toxicities or nutrient imbalances in pulse crops.

	FIELD PEA	LUPIN	NAVY BEAN	PEANUT	SOYBEAN
Growth stage	**Prior to flowering**	**Prior to flowering**	**Prior to flowering**	**Pre-Fl or Fl**	**Early Fl**
Plant part	**YMB (YML)**	**YMB (YML)**	**YMB (YML)**	**YMB (YML)**	**YMB**
N(%)	5.5–5.8[1]	6.0–7.0[1]	3.3		
NO_3-N(mg/kg)			3000		
P(%)					0.85[5]
K(%)	0.55–0.65[1]			1.11–1.65[4]	
Ca(%)				1.70–2.05	
Mg(%)	0.5–0.7[1]				
Na(%)	0.3–0.4[1]	0.35–0.4[1]	0.7[3]		> 0.5[1]
Cl(%)	1.6–1.8[1]				0.7–5.0
Cu(mg/kg)			15–30[3]		
Zn(mg/kg)	100[1]			240[5]	370–860[5]
Mn(mg/kg)	400–500[1]	1200–1400		512–2920[5]	160–665[5]
B(mg/kg)				150[5]	480[5]
Mo(mg/kg)					
Cd(mg/kg)			5–30[3]		1.7–7.0[3,5]

[1] Ranges documented by Weir and Cresswell (1994).
[2] Showing toxicity symptoms.
[3] Concentration range in whole shoots.
[4] Yield depression at high K due to nutrient imbalance.
[5] Critical toxicity concentrations associated with 10% yield reduction.

TABLE 5 Interpretation guidelines for diagnosing nutrient deficiencies in oilseed crops.

	CANOLA/MUSTARD	LINOLA	SUNFLOWER
Growth stage	**Prior to flowering**	**Prior to flowering**	**Prior to flowering**
Plant part	**YMB (YML)**	**YMB (YML)**	**YMB (YML)**
N(%)	5.2–7.0[1,2]	2.8–3.2	2.8–5.1
NO_3-N(mg/kg)	1200–16500[2,3]		
P(%)	0.28–0.32	0.2–0.61[4]	0.21–0.35
K(%)	1.9–2.8[1]	1.8–2.2[1]	1.8–2.4
S(%)	0.35–0.47		0.43
N/S	19–30		
Ca(%)	1.2–1.4[1]	0.8–1.0[1]	1.4
Mg(%)	0.19–0.21[1]		0.18
Cu(mg/kg)	3–4[1]	4–6[1]	3.7
Zn(mg/kg)	15–22[2]		13
Mn(mg/kg)			40
B(mg/kg)	20–22[1]		29–34

[1] Critical nutrient range documented by Weir and Cresswell (1994).
[2] Between these stages of growth, nutrient criteria change reasonably rapidly, generally decreasing with advancing age (consult main Table).
[3] Nitrate-N concentrations in petioles of youngest mature leaves (PYML).
[4] Concentration range in whole shoots.

TABLE 6 Interpretation guidelines for diagnosing nutrient excess, toxicities or nutrient imbalances in oilseed crops.

	CANOLA	LINOLA	SUNFLOWER
Growth stage	**Prior to flowering**	**Prior to flowering**	**Prior to flowering**
Plant part	**YMB (YML)**	**YMB (YML)**	**YMB (YML)**
N(%)	5.5–6.5[1]	2.9–6.0[3]	
K(%)	0.60–0.65[1]		
S(%)	5.5–6.5[1]		
Ca(%)		1.6–2.2[1]	
Mg(%)		0.65–0.95[1]	
Na(%)	0.5–0.7[1]	0.9–1.1[1]	0.7–1.6
Cu(mg/kg)	16[1,2]	25–90[1]	
Zn(mg/kg)		18–20[1]	1150
Mn(mg/kg)	250–300[1]		2205–5300[2]
B(mg/kg)	84	19–25[1]	1150
Mo(mg/kg)	0.55–1.6[1]		

[1] Ranges documented by Weir and Cresswell (1994).
[2] Concentration range in whole shoots.

TABLE 7 Interpretation guidelines for diagnosing nutrient deficiencies in other crops.

	COTTON	SUGAR BEET	SUGAR CANE[3]	TOBACCO
Growth stage	**Early FI**	**Prior to flowering**	**Active growing season**	**Vegetative (40-80 DAE)**
Plant part	**YMB (YML)**	**YMB (YML)**	**TVD**	**YML**
N(%)	3.3–3.5	2.5	1.8–2.0	3.5–4.0[1]
NO_3-N(mg/kg)	12,000–13,000[2]	1000–2000[2]		410–700
P(%)	0.24–0.26	0.18	0.19–0.20	0.22–0.25[1]
K(%)	1.4–1.5	1	0.90–1.11	2.0–2.5[1]
S(%)	0.20–0.25	0.075	0.12–0.13	0.2
N/S	13		17	
Ca(%)	2.00–2.25	0.5	0.18–0.20	1.3–1.5
Mg(%)	0.30		0.08–0.10	0.20–0.25
Cu(mg/kg)	4–5		2–3	3–4[1]
Zn(mg/kg)	20–25	9	10–12	20[1]
Mn(mg/kg)	20–25	10	15	30–35
Fe(mg/kg)	40–50	55	50	50
B(mg/kg)	20	27	1–2	20–25[1]
Mo(mg/kg)	0.5		0.08	0.4[1]
Si(%)			0.7	

[1] Critical nutrient range documented by Weir and Cresswell (1994).
[2] Nitrate-N concentrations in petioles of youngest mature leaves (PYML).
[3] Values given are for plant crops; where information is available, values for ratoon crops are generally similar.

TABLE 8 Interpretation guidelines for diagnosing nutrient excess, toxicities or nutrient imbalances in other crops.

	COTTON	SUGARCANE	TOBACCO
Growth stage	**Early Fl**	**Active growing season**	**Vegetative (40–80 DAE)**
Plant part	**YMB (YML)**	**TVD**	**YML**
P(%)	0.91[1]		
Mg(%)	1.4–1.5[1,2]		
Na(%)	0.6[1]	> 0.04	0.8[1]
Cl(%)	2.2–4.3[1]	0.6–1.0	> 3.5[1]
Cu(mg/kg)	8.5[3]		
Zn(mg/kg)	200–850		
Mn(mg/kg)	230–1460[3]		800–9000
B(mg/kg)	80[3]		
Mo(mg/kg)	900		

[1] Ranges documented by Weir and Cresswell (1994).
[2] Toxic concentration associated with low leaf K.
[3] Critical toxicity concentrations associated with 10% yield reduction.

PASTURES

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6. PASTURE SPECIES

A. Pinkerton, F.W. Smith and D.C. Lewis

INTRODUCTION

Criteria, useful for interpreting plant analysis data for most of the pasture species used in temperate and tropical regions of Australia, are presented in the following table. The criteria have been derived largely from experiments, surveys, or experience within Australia, but have been supplemented by data from other countries. Some species grown primarily as crops can also be grazed or used as fodder. Information about these species may be found in the chapter for temperate and sub-tropical crops. The data assembled in this chapter refer to criteria for assessing the nutritional status of pasture and fodder plants and do not refer to the nutritional requirements of animals grazing them.

A number of points should be noted when using the table, viz:

- Sampling times have been adjusted to be relevant to Australian conditions. For example, for temperate species, growing seasons have been arranged from the "autumn break" in southern Australia through winter to spring and summer.
- Unless otherwise stated, critical values for deficiencies or toxicities refer to 90 or 95% of maximum yield.
- Criteria established from field experiments are often means or ranges of values derived over a number of years in which moisture stress may in some years have limited yields at some harvests. In such cases, it would be unwise to use these values for predictive purposes.
- HI-reducible S has been regarded as equivalent to SO_4-S. For some species, criteria for sulfur status have been established by analysis for oxidised sulfur, S^{6+} determined using X-ray fluorescence spectrometry. These criteria are similar to SO_4-S values, and fulfil the same function in a nutritional sense. Thus, where SO_4-S values are available for these species, S^{6+} data are not presented.
- In some publications, critical values have not been stated by the original authors. In these cases where good data sets were available the chapter authors have calculated criteria and entered the data into the table.
- Where information is not available for a nutrient or a species, a useful guide can often be obtained by extrapolation of the criteria for a genetically related species which *is* included in the table. However, when doing so, heed should be taken of the cautions stated in Chapter 1.

Many colleagues contributed to this compilation of diagnostic criteria. We are particularly grateful for the contributions from Prof C.J. Asher, Dr D. Bouma, Dr R.C. Bruce, Associate Professor D.G. Edwards, Prof J.F. Loneragan, Dr N.E. Marcar, Mr M.G. Mason, Dr K.I. Peverill, Mr G.H. Price, Mr G.E. Rayment, Dr D.J. Reuter, Prof A.D. Robson, Dr M.G. Rogers, Mr R.G. Weir and Dr N. Wilhelm. We are also indebted to Mrs C. Murray and the staff of the CSIRO Black Mountain Library for assistance in locating relevant literature for this Chapter.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
***Andropogon gayanus* (Gamba Grass)**													
P(%)	35 DAS	WS	Soil			0.27					Aust	97	cv. QI 57497
	35 DAS	YEB	Soil			0.24					Aust	97	cv. QI 57497
K(%)	56 DAS	WS	Soil			1.30					Nig	189	
***Aristida armata* (Wiregrass)**													
P(%)	26 DAS	WS	Soil			0.26					Aust	13	
***Bothriochloa pertusa* (Indian Couch or Bluegrass)**													
P(%)	35 DAS	WS	Soil			0.31					Aust	97	
	35 DAS	YEB	Soil			0.35					Aust	97	
***Brachiaria brizantha* (Arm Grass)**													
P(%)	50 DAS	WS	Soil			0.13					Bra	43	cv. Marandu
	80 DAS	WS	Soil			0.12					Bra	43	cv. Marandu
***Brachiaria decumbens* (Signal Grass)**													
P(%)	50 DAS	WS	Soil			0.11					Bra	43	
	80 DAS	WS	Soil			0.09					Bra	43	
***Brachiaria humidicola* (Koronivia Grass)**													
P(%)	48 DAS	WS	Soil			0.33-0.50					Bra	68	Critical concn depends on soil type
***Brachiaria ruziziensis* (Ruzi Grass)**													
P(%)	48 DAS	WS	Soil			0.14-0.29					Bra	68	Critical value depends on soil type

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
***Bromus diandrus* (Great Brome Grass)**													
S(%)	58 DAE	YOL	Soil			0.14					Aust	64	
Bromus inermis (Smooth Brome Grass)													
S(N/S)	Late Spring	WS	Field			20					USA	86	
***Bromus wildenowii* (Prairie Grass)**													
P(%)	35-63 DAE	WS	Sand			0.29-0.31					NZ	41	cv. Grasslands Matua
K(%)	35-63 DAE	WS	Sand			3.1-3.7					NZ	41	cv. Grasslands Matua
***Buchloe dactyloides* (Buffalograss)**													
B(mg/kg)	12 weeks after clipping	WS	Peat						>2571		USA	75	cv. Taxoka; Critical for yield; Toxicity symptoms appeared at 406 mg/kg leaf B
Mo(mg/kg)	12 weeks after clipping	WS	Peat						>3090		USA	75	cv. Taxoka; Critical for yield; Toxicity symptoms appeared at 1280 mg/kg leaf Mo
***Cenchrus ciliaris* (Buffel Grass)**													
P(%)	35 DAS	WS	Soil			0.20					Aust	97	cv. Biloela
	26 DAT	WS	Soil			0.19					Aust	13	cv. USA
	57 DAE	WS	Soil	<0.22	0.22-0.27	0.25	0.27-0.35				Aust	10	cv. Gayndah
	Veg	WS	Soil	<0.20		0.23-0.26	0.29-0.38				Cub	108	cvv. Verde Guantanamo, Numbank, Malopo Q-860
	Veg	WS	Soil		0.18	0.19	0.20-0.22				Cub	108	cv. Formidable
	Pre-Fl	WS	Soil			0.16					Aust	176	cv. Biloela
	35 DAS	YMB	Soil			0.19					Aust	97	cv. Biloela
K(%)	Veg	WS	Soil			3.09					Cub	113	cv. Formidable
S(%)	28 DAE	WS	Soil	<0.07	0.07-0.12		>0.12				Aust	180	cv. Gayndah
Mn(mg/kg)	51 DAE	WS	Sand						>1000		Aust	177	cv. Biloela

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Centrosema pubescens (Centro)													
P(%)	48 DAE	WS	Soil			0.17				Bra	68		
	60 DAE	WS	Soil			0.23				Cub	47		
	Pre-Fl	WS	Soil	<0.14	0.14-0.18	0.16	0.18-0.30			Aust	8		
	Pre-Fl	WS	Soil	<0.17			>0.23			Mala	71		
K(%)	Pre-Fl	WS	Soil	<0.6	0.6-0.8	0.75	0.8-1.5	>1.5		Aust	9		
	Pre-Fl	WS	Soil				1.35-1.88			Mala	71		
S(%)	5 harvests at 6 week intervals	WS	Soil			0.21-0.24				S I	195		cv. Common
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4-5		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
Zn(mg/kg)	Pre-Fl	WS	Soil			20				Aust	12		Piper-Steenbjerg effect in very deficient plants
Mn(mg/kg)	21-35 DAE	WS	FSC						>1400	Aust	56		
	51 DAE	WS	SC						>1600	Aust	6		
Chloris barbata (_inflata_) (Purple-top Rhodes or Chloris)													
P(%)	35 DAS	WS	Soil		0.37					Aust	97		
	35 DAS	YEB	Soil		0.42					Aust	97		
Chloris gayana (Rhodes Grass)													
NO_3-N (mg/kg)	Early Autumn	WS	SC			1900				Isr	89		
	Summer	WS	SC			1300				Isr	89		
P(%)	35 DAS	WS	Soil			0.19-0.25				Aust	97		cv. Callide
	57 DAE	WS	Soil	<0.20	0.20-0.24	0.22	0.24-0.34			Aust	10		cv. Pioneer
	Veg	WS	Soil			0.20				Cub	109		cv. Callide
	Veg	WS	Soil			0.24				Cub	109		cv. 161
	35 DAS	YEB	Soil			0.21-0.23				Aust	97		cv. Callide
K(%)	28 DAE	WS	Soil				>0.5			Aust	175		cv. Pioneer; Values dependent upon Na concn
	Veg	WS	Soil			3.42				Cub	113		cv. Callide

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
S(%)	28 DAE	WS	Soil	<0.07	0.07-0.12		>0.12			Aust	180		cv. Pioneer
Mn(mg/kg)	51 DAE	WS	Sand						>700	Aust	177		cv. Pioneer
B(mg/kg)	42 DAE	WS	Sand/soil/ash						>150	Aust	2		

Chrysopogon fallax (Golden-beard Grass)

P(%)	35 DAS	WS	Soil			0.30				Aust	97		
	35 DAS	YEB	Soil			0.29				Aust	97		

Cynodon dactylon (Green Couch or Bermudagrass)

N(%)	28-35 DAC	WS	Lit	<1.5		1.8-2.2	2.5-3.0	>3.4		USA	82		cv. Coastal; Values vary with season
	28-35 DAC	WS	Lit	<1.7		2.0-2.5	2.6-3.2	>3.6		USA	82		cvv. Common, Midland; Values vary with season
P(%)	28-35 DAC	WS	Lit	<0.16		0.18-0.24	0.24-0.30	>0.40		USA	82		cv. Coastal; Values vary with season
	28-35 DAC	WS	Lit	<0.22		0.24-0.28	0.28-0.34	>0.40		USA	82		cvv. Common, Midland; Values vary with season
	Hay, cut at 6 week intervals	WS	F				>0.14			USA	35		
K(%)	Veg	WS	Soil			3.64				Cub	113		cv. 68
	28-35 DAC	WS	Lit	<1.3		1.3-1.5	1.5-1.8	>2.2		USA	82		cv. Coastal; Values vary with season
	28-35 DAC	WS	Lit	<1.5		1.6-1.8	1.9-2.2	>2.4		USA	82		cvv. Common, Midland; Values vary with season
	4-5 cuts in each of 2 seasons	WS	F			2.20				USA	48		cv. Coastal
	Hay, cut at 6 week intervals	WS	F				>1.0			USA	35		
S(%)	30 cm high	WS	F			0.20-0.21				USA	81		cvv. Coastal, Alicia
	28-35 DAC	WS	Lit	<0.10		0.14-0.16	0.15-0.20	>0.30		USA	82		cv. Coastal; Values vary with season
	28-35 DAC	WS	Lit	<0.12		0.14-0.18	0.18-0.24	>0.32		USA	82		cvv. Common, Midland; Values vary with season
S(N/S)	30 cm high	WS	F			10				USA	81		cvv. Coastal, Alicia

Dactylis glomerata (Cocksfoot or Orchard Grass)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	21-28 DAC	WS	Lit	<2.4		2.7-3.0	3.2-3.5	>4.2			USA	82	
	Cut in Summer	WS	F			4.8					Fra	88	cv. Floreal; Crop grown under irrigation
	1st Fl	WS above 5 cm	Lit				2.80-4.00				Ger	22	
P(%)	Veg	WS	F	<0.25			>0.30				Jap	85	
	21-28 DAC	WS	Lit	<0.18		0.20-0.24	0.23-0.28	>0.35			USA	82	
	1st Fl	WS above 5 cm	Lit				0.30-0.50				Ger	22	
K(%)	35-63 DAE	WS	Sand			1.5-2.2					NZ	41	cv. Wana; Plants trimmed 21 DAE
	21-28 DAC	WS	F	<2.0		2.3-2.5	2.6-3.0	>3.5			USA	82	
	1st Fl	WS above 5 cm	Lit				2.50-3.50				Ger	22	
S(%)	21-28 DAC	WS	Lit	<0.12			0.25				USA	82	
SO_4-S (mg/kg)	Showing symptoms	WS	Soil, S			450					Jap	96	cv. Aonami
Ca(%)	1st Fl	WS above 5 cm	Lit				0.60-1.20				Ger	22	
Mg(%)	1st Fl	WS above 5 cm	Lit				0.15-0.30				Ger	22	
Cu(mg/kg)	1st Fl	WS above 5 cm	Lit				6-15				Ger	22	
Zn(mg/kg)	1st Fl	WS above 5 cm	Lit				20-50				Ger	22	
Mn(mg/kg)	1st Fl	WS above 5 cm	Lit				40-100				Ger	22	
Mo(mg/kg)	1st Fl	WS above 5 cm	Lit				0.15-0.50				Ger	22	
B(mg/kg)	Veg	WS	Soil						34-63		NZ	167	cv. Grasslands Apanui
	1st Fl	WS above 5 cm	Lit				6-12				Ger	22	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Danthonia richardsonii (Wallaby Grass)													
P(%)	62 DAS	WS	Sand			0.41-0.51					Aust	133	cv. Taranna; Critical value increases with N supply
	93 DAS	WS	Sand			0.23					Aust	133	cv. Taranna
	62 DAS	YEB	Sand			0.32-0.42					Aust	133	cv. Taranna; Critical value increases with N supply
	93 DAS	YEB	Sand			0.17-0.18					Aust	133	cv. Taranna
PO_4-P (mg/kg)	62 DAS	YEB	Sand			170-220					Aust	133	cv. Taranna; Units in fresh weight; H_2SO_4 extract; Critical value increases with N supply
	93 DAS	YEB	Sand			80					Aust	133	cv. Taranna; Units in fresh weight; H_2SO_4 extract
Desmodium intortum (Greenleaf Desmodium)													
N(%)	Pre-Fl	LB+P	D	2.3	2.7		3.5-5.0				Aust	196	
P(%)	45 DAE 64 DAE 73 DAE	WS	Soil			0.33 0.18 0.16					Aust	77	
	Pre-Fl	WS	Soil	<0.19	0.19-0.24	0.22	0.24-0.35				Aust	8	
	Pre-Fl	WS	F			0.17-0.20					Aust	142	
	Pre-Fl	LB+P	D	0.16	0.20-0.24		0.25-0.40				Aust	196	
K(%)	Pre-Fl	WS	Soil	<0.6	0.6-0.8	0.72	0.8-1.5	>1.5			Aust	9	
	Pre-Fl	LB+P	D	0.36	0.5-0.6		0.8-2.0				Aust	196	
S(%)	Pre-Fl	WS	Soil	<0.13	0.13-0.20	0.17	0.20-0.30				Aust	4	
	Pre-Fl	LB+P	D		0.13-0.18		0.20-0.40				Aust	196	
SO_4-S (mg/kg)	Symptoms showing	WS	Soil, F			260					Jap	86	cv. Greenleaf; Critical for 60% maximum yield
Ca(%)	Pre-Fl	LB+P	D				1.0-2.0				Aust	196	
Mg(%)	Pre-Fl	LB+P	D				0.25-0.60				Aust	196	
Cu(mg/kg)	Pre-Fl	LB+P	D	4-5			8-60				Aust	196	
Zn(mg/kg)	Pre-Fl	WS	Soil			19					Aust	12	Piper-Steenbjerg effect in very deficient plants
	Pre-Fl	LB+P	D		<20		20-70				Aust	196	
Mn(mg/kg)	Pre-Fl	LB+P	D				40-350	675			Aust	196	
Cl(%)	Pre-Fl	LB+P	D					2.0	2.3-4.2		Aust	196	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Desmodium uncinatum (Silverleaf Desmodium)													
N(%)	Pre-Fl	LB+P	D	2.3	2.7		3.5-5.0				Aust	196	
P(%)	Pre-Fl	WS	Soil	<0.21	0.21-0.25	0.23	0.25-0.35				Aust	8	
	Pre-Fl	LB+P	D	0.16	0.2-0.24		0.25-0.40				Aust	196	
K(%)	84 DAE	WS	F	<0.5			0.9-1.14				Aust	5	
	Pre-Fl	WS	Soil	<0.5	0.5-0.8	0.8	0.8-1.5	>1.5			Aust	9	
	Pre-Fl	LB+P	D	0.36	0.5-0.6		0.8-2.0				Aust	196	
S(%)	Pre-Fl	WS	Soil	<0.14	0.14-0.20	0.17	0.20-0.30				Aust	4	
	Pre-Fl	LB+P	D		0.13-0.18		0.20-0.40				Aust	196	
Ca(%)	Pre-Fl	LB+P	D				1.0-2.0				Aust	196	
Mg(%)	Pre-Fl	LB+P	D				0.25-0.60				Aust	196	
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5				Aust	11	Piper-Steenbjerg effect in very deficient plants
	Pre-Fl	LB+P	D		4-5		8-60				Aust	196	
Zn(mg/kg)	Pre-Fl	LB+P	D		<20		20-70				Aust	196	
Mn(mg/kg)	51 DAE	WS	SC						>1160		Aust	6	
	Pre-Fl	LB+P	D				40-350	675			Aust	196	
Cl(%)	Pre-Fl	LB+P	D					2.0	2.3-4.2		Aust	196	
Dichanthium annulatum (Sheda Grass)													
P(%)	35 DAS	WS	Soil			0.26					Aust	97	CPI 50819
	35 DAS	YEB	Soil			0.29					Aust	97	CPI 50819
Digitaria ammophila (Silky Umbrella Grass)													
P(%)	26 DAS	WS	Soil			0.28					Aust	13	
Digitaria ciliaris (Summer Grass)													
P(%)	35 DAS	WS	Soil			0.21					Aust	97	
	35 DAS	YEB				0.20							

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Digitaria eriantha (_decumbens, smutsii_) (Pangola or Tall (Woolly) Finger Grass)													
P(%)	45 DAE	WS	Soil	<0.14	0.14-0.18	0.16	0.18-0.26			Aust	10		
	60 DAS	WS	F	<0.18						PuRi	194		
	28-35 DAC	WS	Lit	<0.10		0.12-0.16	0.16-0.24	>0.28		USA	82		
	Pre-Fl	WS	F	<0.1		0.15-0.17	0.2-0.25			Cub	106		cvv. Comun, Transvaal, PA-32
	Pre-Fl					0.19							cv. Peluda
K(%)	60 DAS	WS	F	<1.0-1.5			>1.5			PuRi	194		
	28-35 DAC	WS	Lit	<1.1		1.2-1.4	1.6-2.0	>2.2		USA	82		
S(%)	28 DAE	WS	Soil	<0.07	0.07-0.12		>0.12			Aust	180		
	28-35 DAC	WS	Lit	<0.12		0.15-0.20	0.20-0.25	>0.30		USA	82		
Mg(%)	60 DAS	WS	F	<0.20						PuRi	194		
Elytrigia pontica (Tall Wheat Grass)													
Cl(mol/m^3)	Veg	WS	Sand						>150	Aust	103		cv. Largo; Units in plant water; Critical for 50% reduction in shoot weight
Festuca arundinacea (Tall Fescue)													
N(%)	Cut in Summer	WS	F			4.8				Fra	88		cv. Clarine; Crop grown under irrigation
	U	WS	F				2.8-3.4			USA	199		
NO_3-N (mg/kg)	U	WS	F		700-1000					USA	199		
P(%)	35-42 days after clipping	WS	Lit	<0.24		0.26-0.32	0.34-0.40	>0.45		USA	82		
	U	WS	F	<0.24		0.24-0.32	0.32-0.40	>0.45		USA	199		cv. Alto; 50% maximum yield with 0.19%
K(%)	35-42 days after clipping	WS	Lit	<2.2		2.4-2.8	2.8-3.2	>3.8		USA	82		
	U	WS	F	<2.2		2.5	2.8	3.0-3.5		USA	199		2.0% critical for cv. Kentucky-31; 4.0% regarded as excessive
SO_4-S (mg/kg)	Symptoms showing	WS	F			880				Jap	96		cv. Kentucky-21; Critical for 60% maximum yield

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Festuca pratensis (Meadow Fescue)													
P(%)	1st Fl	WS above 5 cm	Lit				0.30-0.50			Ger	22		
K(%)	1st Fl	WS above 5 cm	Lit				2.10-3.50			Ger	22		
Ca(%)	1st Fl	WS above 5 cm	Lit				0.60-1.20			Ger	22		
Mg(%)	1st Fl	WS above 5 cm	Lit				0.15-0.50			Ger	22		
Cu(mg/kg)	1st Fl	WS above 5 cm	Lit				6-12			Ger	22		
Zn(mg/kg)	1st Fl	WS above 5 cm	Lit				20-50			Ger	22		
Mn(mg/kg)	1st Fl	WS above 5 cm	Lit				35-100			Ger	22		
Mo(mg/kg)	1st Fl	WS above 5 cm	Lit				0.15-0.50			Ger	22		
B(mg/kg)	1st Fl	WS above 5 cm	Lit				6-12			Ger	22		
Glycine tabacina (Glycine or Native Pea)													
S(%)	Fl	WS	Soil				0.29			Aust	93		
S(N/S)	Fl	WS	Soil				20			Aust	93		Ratio > critical indicates deficiency
Heteropogon contortus (Black or Bunched Speargrass)													
P(%)	35 DAS	WS	Soil				0.29			Aust	97		
	35 DAS	YEB					0.24						
Hordeum leporinum (Barley Grass)													
S(%)	58 DAE	YEB	Soil				0.13			Aust	64		

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
***Hyparrhenia rufa* (Jaragua Grass)**													
P(%)	108 DAS	WS	Soil			0.31-0.40					Bra	44	
***Indigofera spicata* (Creeping Indigo)**													
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5				Aust	11	Piper-Steenbjerg effect in very deficient plants
***Lablab purpureus* (*Dolichos lablab*) (Lablab Bean)**													
N(%)	Pre-Fl	YML	D	1.9	2.5-3.0		3.5-5.3				Aust	196	
P(%)	Veg	WS	Soil			0.16					Cub	110	cv. Rongai
	Pre-Fl	YML	D		0.20-0.23		0.25-0.40	0.5			Aust	196	
K(%)	Pre-Fl	YML	D	<0.8	0.9		1.0-1.8				Aust	196	
S(%)	Pre-Fl	YML	D				0.21-0.35				Aust	196	
Ca(%)	Pre-Fl	YML	D				1.2-1.7				Aust	196	
Mg(%)	Pre-Fl	YML	D				0.24-0.55	0.65	0.7		Aust	196	Toxicity associated with imbalance in K-deficient crop
Cu(mg/kg)	Pre-Fl	YML	D				8-20				Aust	196	
Zn(mg/kg)	Pre-Fl	YML	D				30-70				Aust	196	
Mn(mg/kg)	Pre-Fl	YML	D				50-200				Aust	196	
B(mg/kg)	Pre-Fl	YML	D				30-50				Aust	196	
Mo(mg/kg)	Pre-Fl	YML	D		0.14		0.3-1.0				Aust	196	
***Lathyrus sylvestris* (Flatpea)**													
P(%)	6-12 weeks after sowing	WS	Soil			0.21					USA	200	cv. Lathco
***Lespedeza cuneata, stipulacea, striata* (Sericea, Korean, Common Lespedeza)**													
N(%)	Early Fl, Hay	WS	F				2.75-3.00				USA	124	
P(%)	Early Fl, Hay	WS	F				0.18-0.25				USA	124	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Lespedeza cuneata, stipulacea, striata (Sericea, Korean, Common Lespedeza) (ctd)													
K(%)	Early Fl, Hay	WS	F				0.90-1.20				USA	124	
Ca(%)	Early Fl, Hay	WS	F				1.00-1.30				USA	124	
Mg(%)	Early Fl, Hay	WS	F				0.20-0.25				USA	124	
Leucaena leucocephala (Leucaena)													
N(%)	75 DAS	YMB	Soil				4.5				Aust	171	cv. Cunningham; N-supplied
	84 DAS	YMB	Soil				4.1				Aust	156	cv. Cunningham; N-supplied
P(%)	45 DAE	WS	Soil				0.09-0.10				USA	102	Applies also to *Leucæna retusa*
	84 DAS	YMB	Soil				0.25 0.21				Aust	156	cv. Cunningham; Inoculated cv. Cunningham; N-supplied
K(%)	84 DAS	YMB	Soil				0.20				Aust	156	cv. Cunningham; N-supplied
Ca(%)	84 DAS	YMB	Soil				0.49 0.38				Aust	156	cv. Cunningham; Inoculated cv. Cunningham; N-supplied
S(%)	84 DAS	YMB	Soil				0.24				Aust	156	cv. Cunningham; N-supplied
Mn(mg/kg)	51 DAE	WS	SC						>550		Aust	6	
	84 DAS	YMB	Soil						>325		Aust	156	cv. Cunningham
Lolium multiflorum (Italian Ryegrass)													
K(%)	35 DAS	WS	Soil				1.9 1.3 0.8				UK	21	Biophysical functions in low-Na soils Biophysical functions in high-Na soils Biochemical functions All values for cv. Landras Westerwolths
	Late veg	YEB	SC				3.5 0.8				USA	74	cv. Tifton No.1; Critical when Na <0.3% cv. Tifton No.1; Critical when Na >2.4%
SO_4-S (mg/kg)	Showing symptoms	WS	Soil, F				650				Jap	96	cv. Waseyutaka; Value critical for 60% maximum yield
Mn(mg/kg)	U	WS	Soil				25-250		>500		Bel	45	
Cu(mg/kg)	U	WS	Soil				6-15		>20		Bel	45	
Zn(mg/kg)	U	WS	Soil				25-150		>400		Bel	45	
B(mg/kg)	U	WS	Soil				18-30		>190		Bel	45	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Na(mol/m^3)	Veg	WS	Sand						>130	Aust	103		Units in plant water; Critical for 50% reduction in shoot weight
Cl(mol/m^3)	Veg	WS	Sand						>85	Aust	103		Units in plant water; Critical for 50% reduction in shoot weight
Ni(mg/kg)	U	WS	Soil				0-8		>80	Bel	45		

Lolium perenne (Perennial Ryegrass)

N(%)	84 DAE	WS	Soil			2.8-2.9				NZ	67		
	49-105 DAE	WS	Sand			3.2				NZ	182		cv. Grasslands Nui; 4.4% for 99% maximum yield
	4-5 cuts at 6 week intervals	WS	F	<1.9		2.1-2.2	2.3-2.7			UK	73		Figures are means for ageing and newly sown swards at 8 sites
	1st Fl	WS above 5 cm	Lit				3.00-4.20			Ger	22		
	Veg	YMB	D				3.5-4.5	5.0-6.0		Aust	196		Leaves randomly plucked
	Fl	Leaf	F, S	<2.0			2.5-4.0			Aust	130		
NO_3-N (mg/kg)	49-105 DAE	WS	Sand			500				NZ	182		cv. Grasslands Nui; 1000mg/kg for 99% maximum yield
P(%)	Veg	WS	F	<0.30	0.30-0.34		0.35-0.40	>0.40		NZ	42		
	7-21 DAS	WS	Soil			0.34				NZ	60		
	34-50 DAS	WS	Soil			0.33				Ger	59		cv. Printo; Critical for 80% maximum yield
	35, 49, 63 DAS	WS	Sand	0.13		0.29-0.38	0.9			NZ	41		cv. Yatsyn; Yields bulked for 3 cuts
	49-105 DAE	WS	Sand			0.21				NZ	182		cv. Grasslands Nui; 0.44% for 99% maximum yield; High N supply
	Various	WS	F			0.20				UK	138		cv. Grasslands Huia
	1st Fl	WS above 5 cm	Lit				0.35-0.50			Ger	22		
	Veg	YMB	D	0.13	0.18-0.21		0.25-0.55	0.60-0.75		Aust	196		Leaves randomly plucked
	Year after sowing	YMB	F			0.28				UK	137		
	Fl	Leaf	F, S	<0.20			0.20-0.40			Aust	130		
K(%)	Veg	WS	F	<1.7	1.7-1.9		2.0-2.5	>2.5		NZ	42		
	35 DAS	WS	Soil			2.8 0.8-1.0				Aust	119		No Na supplied Na supplied; Monovalent cation requirement = 580-1200 me/kg cv. Grasslands Nui

Lolium perenne (Perennial Ryegrass) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	21-27 days after clipping	WS	Sand			4.8 1.4					Aust	118	No Na supplied Na supplied
	82 DAT	WS	Soil			0.6					UK	15	Critical for 95% maximum yield when Ca approx. 0.8% DM
	49-105 DAE	WS	Sand			2.8					NZ	182	cv. Grasslands Nui; 3.8% for 99% maximum yield; High N supply
	Various	WS	F			1.0-1.5					UK	138	cv. Grasslands Huia
	1st Fl	WS above 5 cm	Lit				2.50-3.50				Ger	22	
	Veg	YMB	D	0.8-1.3	1.4-1.6		2.0-4.8	7.0			Aust	196	Leaves randomly plucked
	Fl	Leaf	F, S	<1.0			1.5-3.0				Aust	130	
S(%)	Veg	WS	F	<0.22	0.22-0.26		0.27-0.32	>0.32			NZ	42	
	84 DAE	WS	Soil			0.23					NZ	67	
	49-105 DAE	WS	Sand			0.18					NZ	182	cv. Grasslands Nui; 0.25% for 99% maximum yield; High N supply
	3 cuts	WS	Soil	<0.18		0.20	0.24-0.41				UK	29	cv. S23
	Various	WS	Soil, F	<0.20							UK	162	
	Veg	YMB	D		0.18-0.22		0.25-0.45	0.55-0.65			Aust	196	Leaves randomly plucked
	Fl	Leaf	F, S	<0.18			0.20-0.40				Aust	130	
S(N/S)	U	WS	F			15-17					NZ	99	Ratio > critical indicates S deficiency
	Various	WS	Soil, F	>15							UK	162	
SO_4-S (mg/kg)	Symptoms showing	WS	Soil, F			160					Jap	86	cv. Friend; Critical for 60% maximum yield
	Various	WS	Soil				500				UK	162	Adequate for optimum yields at later cuts
	6 cuts in 2 years	WS	F			500					UK	163	
SO_4-S/S x100	6 cuts in 2 years	WS	F			30					UK	163	
	Various	WS	Soil, F	<20		29	28.5-44				UK	162	
Ca(%)	Veg	WS	F	<0.20	0.20-0.24		0.25-0.30	>0.30			NZ	42	
	70 DAS; 42 DAC	WS	Soil			≤0.5					UK	16	Critical Ca concn depends on P and Zn concns

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Various	WS	F			0.2				UK	138		cv. Grasslands Huia
	1st Fl	WS above 5 cm	Lit				0.60-1.20			Ger	22		
	Veg	YMB	D				0.20-0.60			Aust	196		Leaves randomly plucked
	Fl	Leaf	F, S	<0.25			0.25-0.60			Aust	130		
Mg(%)	Veg	WS	F	<0.13	0.13-0.15		0.16-0.20	>0.20		NZ	42		
	49-105 DAE	WS	Sand			0.07				NZ	182		cv. Grasslands Nui; 0.10% for 99% maximum yield; High N supply
	1st Fl	WS above 5 cm	Lit				0.20-0.50			Ger	22		
	Veg	YMB	D	<0.13	0.14		0.20-0.40			Aust	196		Leaves randomly plucked
	Fl	Leaf	F, S	<0.15			0.20-0.35			Aust	130		
Cu(mg/kg)	Veg	WS	F	<4	4.0-5.0		6.0-7.0	>7		NZ	42		
	12-15 cm long leaves	WS	Sand						>21	UK	51		cv. S23
	48, 70, 80 DAS	WS	Soil						>40	UK	28		cv. S23
	1st Fl	WS above 5 cm	Lit				6-12			Ger	22		
	Veg	YMB	D	4-5			6-15			Aust	196		Leaves randomly plucked
	Fl	Leaf	F, S	<4			5.0-12.0			Aust	130		
Zn(mg/kg)	Veg	WS	F	<10	10.0-13.0		14-20	>20		NZ	42		
	5 leaf stage	WS	Sand						>221	UK	51		cv. S23
	48,70,80 DAS	WS	Soil						>375	UK	28		cv. S23
	4-5 months	WS	Soil						>560	Neth	172		Critical for 20% reduction in yield; >370 mg/kg critical when in combination with other toxicities
	1st Fl	WS above 5 cm	Lit				20-50			Ger	22		
	Veg	YMB	D		10-13		15-70			Aust	196		Leaves randomly plucked
	Fl	Leaf	F, S	<15			15-50			Aust	130		
Mn(mg/kg)	40-61 DAS	WS	Sand						>1110	NZ	183		cv. Grasslands Nui
	1st cut	WS					50-200		1000-2000	Ger	84		
	1st Fl	WS above 5 cm	Lit				40-100			Ger	22		
	Veg	YMB	D		16		30-400	650-1290		Aust	196		Leaves randomly plucked

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Lolium perenne (Perennial Ryegrass) (ctd)													
Mn(mg/kg) (ctd)	Fl	Leaf	F, S				50-300				Aust	130	
Fe(mg/kg)	Veg	WS	F	<40	40-49		50-60	>60			NZ	42	Be careful of Fe contamination from soil or grinding
B(mg/kg)	Veg	WS	F					>15			NZ	42	
	Veg to 6 months	WS	Soil						39		NZ	167	cv. Grasslands Ruanui
	1st Fl	WS above 5 cm	Lit				6-12				Ger	22	
	Veg	YMB	D		5		10-20				Aust	196	Leaves randomly plucked
	Fl	Leaf	F, S	<3			5.0-15.0				Aust	130	
Mo(mg/kg)	Veg	WS	F	<0.15	0.15-0.29		0.30-0.40	>0.40			NZ	42	
	1st Fl	WS above 5 cm	Lit				0.15-0.50				Ger	22	
	Veg	YMB	D		0.11		0.25-3.7	8.1			Aust	196	Leaves randomly plucked
	Fl	Leaf	F, S	<0.2			0.3-0.4				Aust	130	
Na(mol/m^3)	Veg	WS	Sand						>205		Aust	103	cv. Vic. Cert.; Units in plant water; Critical for 50% reduction in shoot weight
Na(%)	Veg	YMB	D					0.7-1.5	1.8-2.3		Aust	196	Leaves randomly plucked; High Na values associated with K deficiency, not salinity
Cl(mol/m^3)	Veg	WS	Sand						>150		Aust	103	cv. Vic. Cert.; Units in plant water; Critical for 50% reduction in shoot weight
Cl(%)	Veg	YMB	D					2.0-2.6	3.6		Aust	196	Leaves randomly plucked
Lolium rigidum (Wimmera or Annual Ryegrass)													
P(%)	46 DAS	WS	Soil			0.41					Aust	158	
S(%)	58 DAE	YEB	Soil			0.14					Aust	64	
Na(mol/m^3)	Veg	WS	Sand						>200		Aust	103	cv. Wimmera; Units in plant water; Critical for 50% reduction in shoot weight
Cl(mol/m^3)	Veg	WS	Sand						>150		Aust	103	cv. Wimmera; Units in plant water; Critical for 50% reduction in shoot weight

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Lotononis bainesii (Lotononis)													
P(%)	Pre-Fl	WS	Soil	<0.15	0.15-0.19	0.17	0.19-0.35			Aust	8		cv. Miles
K(%)	Pre-Fl	WS	Soil	<0.6	0.6-0.9	0.9	0.9-1.5	>1.5		Aust	9		cv. Miles
S(%)	Pre-Fl	WS	Soil	<0.13	0.13-0.20	0.15	0.20-0.30			Aust	4		cv. Miles
Zn(mg/kg)	Pre-Fl	WS	Soil			22				Aust	12		cv. Miles; Piper-Steenbjerg effect may occur in very deficient plants
Mn(mg/kg)	51 DAE	WS	SC						>1320	Aust	6		cv. Miles
Lotus corniculatus (Birdsfoot Trefoil)													
P(%)	Late Autumn	WS	F			0.21				NZ	50		
	Late Spring-Early Autumn					0.23							
	42 DAS	WS	Soil			0.31				USA	157		cvv. Fergus, Maitland
	6-12 weeks after sowing	WS	Soil			0.24				USA	200		cv. Empire
Lotus pedunculatus (Maku or Greater Lotus)													
P(%)	55 DAS	WS or YOL	Sand			0.30-0.31				Aust	133		cv. Grasslands Maku
	80 DAS					0.27-0.28							
	Late Autumn	WS	F			0.27				NZ	50		cv. Grasslands Maku
	Late Spring-Early Summer					0.30							
PO_4-P (mg/kg)	55 DAS	YOL	Sand			110				Aust	133		cv. Grasslands Maku; Units in fresh weight; H_2SO_4 extract
	80 DAS					86							
K(%)	49 DAS	WS	Sand	<2.0		2.46	3.2-6.1			Aust	131		cv. Grasslands Maku
	84 DAS			<1.2		1.98	3.7-5.4						
	49-84 DAS	YOL				1.84-1.85							
Mn(mg/kg)	39 DAS	WS	Sand				100-389	718	760-1638	Aust	54		cv. Grasslands Maku
		YOL					116-351	612	650-1232				
Macroptilium atropurpureum (Siratro, Atro, Purple Bean)													
P(%)	28 DAS	WS	Soil			0.29-0.32				Aust	178		Critical at 30°C; Critical value rises with rising temperature
	35 DAS					0.29-0.32							

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Macroptilium atropurpureum (Siratro, Atro, Purple Bean) (ctd)													
P(%) (ctd)	35 DAS	WS	Soil			0.3				Aust	97		
	37 DAE	WS	SC	0.19		0.32	0.35-0.39			Aust	36		
	42 DAS	WS	Soil			0.23-0.25				Aust	178		Critical at 30°C; Critical value rises with rising temperature
	Pre-Fl	WS	Soil			0.26				Cub	110		
	Pre-Fl	WS	Soil	<0.20	0.20-0.25	0.24	0.25-0.35			Aust	8		
	41 DAE 59 DAE 77 DAE	WS	Soil			0.3 0.15 0.09				Aust	77		
K(%)	Pre-Fl	WS	Soil	<0.6	0.6-0.8	0.75	0.8-1.5	>1.5		Aust	9		
S(%)	5 harvests at 6 week intervals	WS	Soil			0.21-0.24				S I	195		cv. Siratro
	Pre-Fl	WS	Soil	<0.15	0.15-0.20	0.17	0.20-0.30			Aust	4		
	Var	WS	F			0.13-0.15				Aust	139		
	Var	Tips of runners	F			0.16				Aust	139		Tips include 5-6 expanded leaves
SO_4-S (mg/kg)	Symptoms showing	WS	SC			60				Jap	86		Critical for 60% maximum yield
Zn(mg/kg)	Pre-Fl	WS	Soil			24				Aust	12		
Mn(mg/kg)	21-35 DAE	WS	FSC						>320	Aust	56		
	51 DAE	WS	Soil						>810	Aust	6		
Macroptilium lathyroides (Phasey Bean)													
P(%)	27 DAE	WS	SC	0.21		0.51	0.55-0.56			Aust	36		
	Pre-Fl	WS	Soil	<0.17	0.17-0.20	0.20	0.20-0.30			Aust	8		cv. Murray
K(%)	Pre-Fl	WS	Soil	<0.6	0.6-0.8	0.75	0.8-1.5	>1.5		Aust	9		
S(%)	Pre-Fl	WS	Soil	<0.10	0.10-0.17	0.15	0.17-0.25			Aust	4		
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
Mn(mg/kg)	51 DAE	WS	SC						>840	Aust	6		cv. Murray

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Medicago minima (Woolly Burr Medic)													
P(%)	Fl	WS	Soil			0.28					Aust	93	var. Minima
S(%)	Fl	WS	Soil			0.30					Aust	93	var. Minima
N/S	Fl	WS	Soil			20					Aust	93	var. Minima; Ratio > critical indicates deficiency
Medicago murex (Murex Medic)													
P(%)	Veg-Start Fl Full-Fl Veg-Start Fl Full Fl	WS YOL 	F			0.27 0.17 0.40 0.20					Aust	133	cv. Zodiac
P(mg/kg)	49-70 DAS (Veg-Pre-Fl)	YOL	Sand			260					Aust	133	cv. Zodiac; Units in fresh weight; H_2SO_4 extract
	49 DAS (Veg, Late Autumn)	YOL	F			125					Aust	133	cv. Zodiac; Units in fresh weight; H_2SO_4 extract
	Pre-Fl to Early Fl, Early Spring	YOL	F			90-150					Aust	133	cv. Zodiac; Units in fresh weight; H_2SO_4 extract
	Spring, Full Fl	YOL	F			68					Aust	133	cv. Zodiac; Units in fresh weight; H_2SO_4 extract
K(%)	43-66 DAS	WS	Sand	<2.6		3.32-3.38	3.8-5.9				Aust	131	cv. Zodiac
	Veg, Winter	WS	F		1.1	1.6-1.7	2.0-3.75				Aust	132	cv. Zodiac
	Veg-Early Fl, Spring	WS or YOL	F		0.7	1.0-1.4	1.5-3.4				Aust	132	cv. Zodiac
	Pod set, Late Spring	WS	F		0.6	0.7	1.1-2.4				Aust	132	cv. Zodiac
	43-66 DAS	YOL	Sand	<2.3		2.53-2.8	2.8-4.0				Aust	131	cv. Zodiac
	Early Veg, Autumn	YOL	F			2.75					Aust	132	cv. Zodiac
	Veg, Winter	YOL	F			1.5-2.0	2.2-3.4				Aust	132	cv. Zodiac
	43-66 DAS	PYOL	Sand	<4.5		5.17-5.66	6.5-8.1				Aust	131	cv. Zodiac
	Early Veg Veg, Winter Veg-Early Fl, Spring	PYOL	F		4.7 1.8 1	5.58 2.2-2.5 1.6-1.9	6.0-8.0 3.0-4.5 2.1-4.6				Aust	132	cv. Zodiac

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Medicago murex (Murex Medic) (ctd)													
S(%)	42 DAS	WS	Sand	<0.19	0.22	0.24	0.29-0.35			Aust	134		cv. Zodiac
	67 DAS			0.14		0.17	0.22-0.39						
	42-67 DAS	YOL		<0.20	0.21	0.23-0.26	0.31-0.38						
SO_4-S (mg/kg)	42 DAS	WS or YOL	Sand	<123		174-185	438-997			Aust	134		cv. Zodiac
	67 DAS	WS		<102	136	164	278-1514						
	67 DAS	YOL		<76	89	112	274-798						
SO_4-S/S x100	42 DAS	WS or YOL	Sand			7.7-8.3				Aust	134		cv. Zodiac
S(N/S)	42-67 DAS	WS	Sand			20				Aust	134		cv. Zodiac
Mn(mg/kg)	32 DAS	WS	Sand				63-169	406	430-4313	Aust	54		cv. Zodiac
	32 DAS	YOL	Sand				65-131	274	290-3162	Aust	54		cv. Zodiac
Medicago polymorpha (denticulata) (Burr or Annual Medic)													
N(%)	Pre-Fl	Mat LB	D	<2.7	3.0-3.2		3.5-5.5			Aust	196		
P(%)	34 DAS	WS	Soil			0.61				Aust	25		var. brevispina, cv. Circle Valley
	40 DAS	WS	Soil, F			0.65				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	46 DAS	WS	Soil			0.41				Aust	158		
	48 DAS	WS	Sand			0.57				Aust	133		var. brevispina, cv. Santiago
	60 DAS	WS	Soil, F			0.54				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	74 DAS	WS	Sand			0.44				Aust	133		var. brevispina, cv. Santiago
	80 DAS	WS	Soil, F			0.43				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	100 DAS					0.32							
	Fl	WS	Soil			0.28				Aust	93		var. vulgaris
	48 DAS	YOL	Sand			0.68				Aust	133		var. brevispina, cv. Santiago
	74 DAS					0.48							
	Pre-Fl	Mat LB	D		0.21		0.26-0.45			Aust	196		
	Mat	Seed	Soil, F			0.37-0.84				Aust	26		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
PO_4-P (mg/kg)	48 DAS 74 DAS	YOL	Sand			346 220				Aust	133		var. brevispina, cv. Santiago; Units in fresh weight; H_2SO_4 extract
K(%)	44 DAS 66 DAS	WS	Sand	<1.5 <0.9		1.89 1.26	2.1-4.6 2.4-3.6			Aust	131		var. brevispina, cv. Santiago
		YOL				2.02 1.41							
		YOB		<1.4 <1.1		1.72 1.33	2.8-3.5 2.2-3.0						
		PYOL		<3.0 <1.5		3.10 2.06	5.3-6.6 2.2-5.2						
	Pre-Fl	Mat LB	D				1.5-4.0			Aust	196		
S(%)	Pre-Fl	WS	Soil	<0.16	0.16-0.20	0.20	0.20-0.30			Aust	4		
	Pre-Fl	Mat LB	D	0.11	0.16-0.20		0.25-0.60			Aust	196		
S(N/S)	Fl	WS	Soil			20				Aust	93		var. vulgaris; Ratio > critical indicates deficiency
Ca(%)	Pre-Fl	Mat LB	D			0.8-1.2				Aust	196		
Mg(%)	Pre-Fl	Mat LB	D	0.17		0.20-0.55				Aust	196		
Cu(mg/kg)	Pre-Fl	Mat LB	D	<4	4		6-25			Aust	196		
Zn(mg/kg)	Pre-Fl	Mat LB	D		17		25-60			Aust	196		
Mn(mg/kg)	32 DAS 32 DAS	WS YOL	Sand				75-214 75-194		440-2678 400-2162	Aust	54		cv. Serena
	Pre-Fl	Mat LB	D				35-250			Aust	196		
B(mg/kg)	Pre-Fl	Mat LB	D				25-50			Aust	196		
Mo(mg/kg)	Pre-Fl	Mat LB	D	<0.13	0.14-0.30		0.45-1.00			Aust	196		
Na(%)	Pre-Fl	Mat LB	D					0.45	1.0	Aust	196		
Cl(mg/kg)	Pre-Fl	Mat LB	D					1.8		Aust	196		

Medicago sativa (*Lucerne* or *Alfalfa*)

N(%)	Full bud	WS	F				>3.0			Can	17		
	1st Fl	WS	F				>2.5			USA	173		
	Early Fl	WS	F, S	<3.0			3.5-5.0			Aust	130		
	Hay	WS	F	<2.8	2.8-2.9		3.0-3.5	>3.5		NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<3.5	3.5-4.0		4.2-5.5	5.6-6.0		Aust	196		
	Veg	Top 15 cm	F	<4.0	4.0-4.4		4.5-5.0	>5.0		NZ	42		

Medicago sativa (*Lucerne* or *Alfalfa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%) (ctd)	Start Fl	Top 15 cm	Lit				3.5-5.0			Ger	22		
P(%)	Pre-Fl	WS	Soil	<0.21	0.21-0.26	0.24	0.26-0.35			Aust	8		cv. Hunter River
	1st Fl	WS	F				>0.26			USA	173		
	Early Fl	WS	F,S	<0.20			0.25-0.40			Aust	130		
	Hay	WS	F	<0.20			0.20-0.25	0.25-0.45	>0.45	NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<0.20	0.20-0.23		0.25-0.50	0.6		Aust	196		
	Veg	Top 15 cm	F	<0.20	0.20-0.25		0.26-0.70		>0.70	NZ	42		
	1st Fl	Top 15 cm	Lit				0.30-0.60			Ger	22		
	(Branching, Budding and Flowering)	Leaves Stems	S	<0.27 <0.25			0.35-0.43 0.21-0.35	0.55-0.63 0.45-0.57		Bulg	129		
K(%)	Full bud	WS	F	<1.0			>2.0			Can	17		
	Pre-Fl	WS	Soil	<1.0	1.0-1.3		1.3-2.0	>2.0		Aust	9		cv. Hunter River
	1st Fl	WS	F				>2.50			USA	173		
	Early Fl	WS	F, S	<1.75			2.0-3.5			Aust	130		
	Hay	WS	F	<1.3	1.3-1.4		1.5-1.8	>1.8		NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<1.0	1.0-1.4		1.5-3.5	3.8-4.5		Aust	196		
	Hay	Mid-S	F			0.65-0.75				USA	105		
	Veg	Top 15 cm	F	<1.8	1.8-2.4		2.5-3.8	>3.8		NZ	42		
	1st Fl	Top 15 cm	Lit				2.50-3.80			Ger	22		
	(Branching, Budding and Flowering)	Leaves Stems	S	<1.29 <1.23			2.74-3.08 2.63-2.89	4.11-4.50 3.29-3.33		Bulg	129		
S(%)	Pre-Fl	WS	F			0.28				Aust	92		
	3 annual cuts	WS	Soil			0.20-0.23				Gre	193		
	1st Fl	WS	F				>0.25			USA	173		
	Early Fl	WS	Soil	<0.17	0.17-0.21	0.20	0.21-0.30			Aust	4		cv. Hunter River
	Early Fl	WS	F, S	<0.20			0.25-0.40			Aust	130		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Early Fl	WS	F			0.12-0.15				USA	164		cv. Ranger
	Early Fl	WS	Soil			0.25				SAfr	123		
	Hay	WS	F	<0.18			0.18-0.23	>0.23		NZ	42		
	Hay	WS	F			0.20				NZ	100		
	58 DAE	YOL	Soil			0.19				Aust	64		cv. Hunter River
	Early-Fl (10%)	Mid-S leaves	D	<0.20	0.20-0.22		0.23-0.60	>0.60		Aust	196		
	Veg	Top 15 cm	F	<0.20	0.20-0.25		0.26-0.50	>0.50		NZ	42		
S(N/S)	U	WS	Soil			14				Can	18		
	Early Fl	WS	Soil			11.2				SAfr	122		
Ca(%)	1st Fl	WS	F				>1.80			USA	173		
	Early Fl	WS	F, S	<0.7			1.0-2.0			Aust	130		
	Hay	WS	F	<0.4	0.4-0.5		0.5-0.8	>0.8		NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<1.0	1.0-1.4		1.5-3.2	>3.5		Aust	196		
	Veg	Top 15 cm	F	<0.25	0.25-0.50		0.51-3.0	>3.0		NZ	42		
	1st Fl	Top 15 cm	Lit				1.0-2.50			Ger	22		
Mg(%)	1st Fl	WS	F				>0.30			USA	173		
	Early Fl	WS	F, S	<0.20			0.25-0.50			Aust	130		
	Hay	WS	F	<0.10	0.10-0.11		0.12-0.15	>0.15		NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<0.18	0.18-0.22		0.25-0.50	0.65-0.85		Aust	196		
	Veg	Top 15 cm	F	<0.20	0.20-0.30		0.31-1.0	>1.0		NZ	42		
	1st Fl	Top 15 cm	Lit				0.30-0.80			Ger	22		
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
	1st Fl	WS	F				>11			USA	173		
	Early Fl	WS	F, S	<4			5.0-15.0			Aust	130		
	Hay	WS	F	<4			5.0-9.0	>9		NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<4	4		5-30	40-50		Aust	196		
	Veg	Top 15 cm	F	<6	6.0-10.0	10			>50	NZ	42		
	1st Fl	Top 15 cm	Lit				6-15			Ger	22		
Zn(mg/kg)	67 DAS	WS	Soil				27-97	140	>200	USA	24		cv. Vernal; 295 mg/kg for 20% reduction in yield

Medicago sativa (*Lucerne* or *Alfalfa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Zn(mg/kg) (ctd)	Pre-Fl	WS	Soil			16					Aust	12	cv. Hunter River; Piper-Steenbjerg effect in very deficient plants
	1st Fl	WS	F				>20				USA	173	
	Early Fl	WS	F, S	<15			15-40				Aust	130	
	Hay	WS	F	<10	10.0-11.0		12.0-18.0	>18			NZ	42	
	Early Fl (10%)	Mid-S leaves	D		15-18		20-50	60-90			Aust	196	
	Veg	Top 15 cm	F	<11	11.0-20.0	20.0			>100		NZ	42	
	1st Fl	Top 15 cm	Lit				25-70				Ger	22	
Mn(mg/kg)	35 DAS	WS	Sand				48	123	192-1735		Aust	54	cv. Siriver
	40-61 DAS	WS	Sand						>340		NZ	183	cv. Wairau
	62 DAE	WS	SC						380		Aust	6	cv. Hunter River
	Veg	WS	F	<20	20-24		25-30	>30			NZ	42	
	1st Fl	WS	F				>25				USA	173	
	Early Fl	WS	Sand						>175		Can	127	Four clonal lines
	Hay	WS	F	<20	20-24		25-35	>35			NZ	42	
	35 DAS	YOL	Sand				51	129	182-2011		Aust	54	cv. Siriver
	Early Fl (10%)	Mid-S leaves	D		20-24		25-190	200-350	450-2900		Aust	196	
	Veg	Top 15 cm	F	<20	20-30	30			>250		NZ	42	
	1st Fl	Top 15 cm	Lit				30-100				Ger	22	
Fe(mg/kg)	1st Fl	WS	F				>30				USA	173	
	Hay	WS	F	<40	40-44		45-60	>60			NZ	42	Be careful of Fe contamination from soil or grinding
B(mg/kg)	Veg to 6 months	WS	Soil			17-18					NZ	166	cv. Wairau
	Late bud	WS	F			20					Can	126	
	1st Fl	WS	F				>25				USA	173	
	30% in Bloom	WS	Soil						>850-975		USA	63	cvv. Ladak, Rambler, Riley
	Var	WS	S	<17			17-64				NZ	168	In deficient plants B content lower in upper parts of plant than lower parts
	Hay	WS	F	<20	20-24		25-35	>35			NZ	42	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Veg	Top 15 cm	F	<20	20-30	30			>100	NZ	42		
	1st Fl	Top 15 cm	Lit				35-80			Ger	22		
	Early Fl	Tips	F, S	<20			25-60			Aust	130		
Mo(mg/kg)	6 months	WS	F						>300	Ger	57		
	1st Fl	WS	F				>0.5			USA	22		
	Early Fl	WS	F, S	<0.2			>0.2			Aust	130		
	Hay	WS	F	<0.10	0.10-0.14		0.15-0.30	>0.30		NZ	42		
	Early Fl (10%)	Mid-S leaves	D	<0.3	0.4		0.5-5.0	6-10	>10	Aust	196		Deficiency range associated with low total nitrogen
	Veg	Top 15 cm	F	<0.5	0.5-0.9					NZ	42		
	1st Fl	Top 15 cm	Lit				0.50-2.0			Ger	22		
	Early Fl	Leaf	F			0.5				Aust	148		
Na(%)	Veg	WS	SC						0.4	Aust	151		50% reduction with 1.6%
	Var	WS	F				0.12	0.12	0.51	USA	76		Toxic and high values associated with K deficiency
	Early Fl (10%)	Mid-S leaves	D					0.5-0.6	0.8-1.5	Aust	196		
Cl(%)	Veg	WS	F						1.2	Aust	151		50% reduction with 1.8%
	Early Fl (10%)	Mid-S leaves	D					1.5-1.7	1.8-2.8	Aust	196		

Medicago truncatula (Barrel Medic)

N(%)	Pre-Fl	Mat LB+P	D	<2.7	3.0-3.2		3.5-5.5			Aust	196		
P(%)	123 DAS	WS	F			0.14-0.18	0.23			Aust	39		cv. Jemalong
	Fl	WS	Soil			0.26				Aust	93		cv. Jemalong
	49 DAE	YOL	F			0.39				Aust	143		cv. Jemalong
	63 DAE					0.40-0.43							
	77 DAE					0.35-0.38							
	91 DAE					0.43-0.47							
	Early Fl					0.37-0.43							
	Pre Fl	Mat LB+P	D		0.21		0.26-0.45			Aust	196		
K(%)	42 DAS	WS	Sand	<2.3		3.69	4.2-5.7			Aust	131		cv. Paraggio
	65 DAS			<1.9		2.52	3.6-5.2						
	Pre-Fl	WS	Soil	<0.8	0.8-1.1	1.0	1.1-1.8	>1.8		Aust	9		cv. Jemalong

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Medicago truncatula (Barrel Medic) (ctd)													
K(%) (ctd)	42 DAS	BYOL	Sand	<2.2		3.01	3.1-4.0			Aust	131		cv. Paraggio
	65 DAS			<1.9		2.42	2.8-3.7						
	42 DAS	PYOL		<3.5		4.96	6.7						
	65 DAS			<3.0		4.06	4.8-6.8						
	Pre-Fl	Mat LB+P	D				1.5-4.0			Aust	196		
S(%)	Pre-Fl	WS	Soil	<0.16	0.16-0.20	0.20	0.20-0.30			Aust	4		cv. Jemalong
	Fl	WS	Soil			0.24				Aust	93		cv. Jemalong
	58 DAE	YOL	Soil			0.19				Aust	64		cv. Jemalong
	Pre-Fl	Mat LB+P	D	0.11	0.16-0.20		0.25-0.60			Aust	196		
S(N/S)	Fl	WS	Soil			20				Aust	93		cv. Jemalong; Ratio > critical indicates deficiency
Ca(%)	Pre-Fl	Mat LB+P	D				0.8-1.2			Aust	196		
Mg(%)	Pre-Fl	Mat LB+P	D		0.17		0.20-0.55			Aust	196		
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
	Pre-Fl	Mat LB+P	D	<4	4		6-25			Aust	196		
Zn(mg/kg)	Pre-Fl	Mat LB+P	D		17		25-60			Aust	196		
Mn(mg/kg)	62 DAE	WS	SC						>560	Aust	6		cv. Jemalong
	Pre Fl	Mat LB+P	D				35-250			Aust	196		
B(mg/kg)	Pre Fl	Mat LB+P	D				25-50			Aust	196		
Mo(mg/kg)	Pre Fl	Mat LB+P	D	<0.13	0.14-0.30		0.45-1.00			Aust	196		
Na(%)	Pre Fl	Mat LB+P	D					0.45	1	Aust	196		
Cl(%)	Pre Fl	Mat LB+P	D					1.8		Aust	196		
Melinis minutiflora (Molasses Grass)													
P (%)	57 DAE	WS	Soil	<0.16	0.16-0.20	0.18	0.20-0.30			Aust	10		
Neonotonia wightii (Glycine)													
P(%)	40 DAE	WS	SC	0.2		0.32	0.35-0.45			Aust	36		cv. Tinaroo
	48 DAE	WS	Soil			0.19-0.21				Bra	68		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Pre-Fl	WS	Soil	<0.21	0.21-0.25	0.23	0.25-0.35			Aust	8		cv. Cooper
	Pre-Fl	WS	Soil	0.15			0.22-0.25			Aust	83		
K(%)	Pre-Fl	WS	Soil	0.6			0.8			Aust	83		
	Pre-Fl	WS	Soil	<0.6	0.6-0.9	0.8	0.9-1.5	>1.5		Aust	9		cv. Cooper
S(%)	Pre-Fl	WS	Soil	<0.15	0.15-0.22	0.17	0.22-0.30			Aust	4		cv. Cooper
	Pre-Fl	WS	Soil	0.07			0.17			Aust	83		
Zn(mg/kg)	Pre-Fl	WS	Soil			22				Aust	12		cv. Tinaroo; Piper-Steenbjerg effect in very deficient plants
Mn(mg/kg)	51 DAE	WS	SC						>560	Aust	6		cv. Tinaroo
	Pre-Fl	WS	Soil	30					>560	Aust	83		Symptoms appeared at 30 mg/kg Mn

Ornithopus compressus (Yellow Serradella)

P(%)	34 DAS	WS	Soil			0.62				Aust	25		cv. Tauro
	40 DAS	WS	F, Soil			0.62				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	46 DAS	WS	Soil			0.41				Aust	158		
	47 DAS	WS or YOL	Sand			0.45				Aust	133		cv. Avila
	60 DAS	WS	F, Soil			0.56				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	75 DAS	WS	Sand			0.42				Aust	133		cv. Avila
	80 DAS	WS	F, Soil			0.50				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	100 DAS	WS	F, Soil			0.44				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	120 DAS	WS	F, Soil			0.38				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	140 DAS	WS	F, Soil			0.31				Aust	26		Critical value, derived from regression of critical value with DAS, varies with season and conditions
	75 DAS	YOL	Sand			0.52				Aust	133		cv. Avila
	Mat	Seed	F, Soil			0.42-0.51				Aust	26		

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Ornithopus compressus (Yellow Serradella) (ctd)													
PO_4-P	47 DAS	YOL	Sand			101					Aust	133	cv. Avila; Units in fresh weight; H_2SO_4 extract
(mg/kg)	75 DAS	YOL	Sand			134					Aust	133	cv. Avila; Units in fresh weight; H_2SO_4 extract
K(%)	44 DAS	WS	Sand	<2.7		3.0	3.6-6.0				Aust	131	cv. Avila
	80 DAS			<1.7		2.13	2.4-6.0						
	44 DAS	YOL		<2.4		2.66	3.3-5.6						
	80 DAS			<1.6		1.89	3.6-4.9						
	44 DAS	PYOL		<4.8		5.44	6.1-9.8						
	80 DAS			<2.4		3.02	3.2-7.3						
Mn(mg/kg)	37 DAS	WS	Sand				85-209	571	1080-3159		Aust	54	cv. Avila
		YOL					71-170	424	720-2231				
Panicum maximum (Green Panic or Guinea Grass)													
P(%)	50 DAS	WS	Soil			0.12					Bra	43	
	57 DAE	WS	Soil	<0.18	0.18-0.22	0.20	0.22-0.32				Aust	10	cv. Petrie
	60 DAS	WS	F	<0.18							PuRi	194	
	80 DAS	WS	Soil			0.10					Bra	43	
	108 DAS	WS	Soil			0.29-0.45					Bra	44	
	Veg	WS	Soil			0.20-0.21 0.23					Cub	107	cvv. Australian Common, Likoni and Makueni cv. Uganda
K(%)	61 DAS	WS	F	<1.0-1.5			>1.5				PuRi	194	
	Veg	WS	Soil			3.36					Cub	113	cv. Likoni
S(%)	28 DAE	WS	Soil	<0.07	0.07-0.12		>0.12				Aust	180	cv. Petrie
SO_4-S (mg/kg)	18-32 DAE	WS	Soil	<120			>120				Aust	179	cv. Petrie; Adequate if >12% of total-S is SO_4-S
Mg(%)	60 DAS	WS	F	<0.20							PuRi	194	
Mn(mg/kg)	51 DAE	WS	Sand						>1000		Aust	177	cv. Petrie
Paspalum dilatatum (Paspalum or Dallis Grass)													
N(%)	28 DAC	WS	F			2.34					USA	149	Critical at 86% maximum yield
P(%)	57 DAE	WS	Soil	<0.22	0.22-0.27	0.25	0.27-0.35				Aust	10	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
K(%)	21-35 DAS	WS	Lit				2.1-2.4			USA	149		
S(%)	28 DAE	WS	Soil	<0.07	0.07-0.12		>0.12			Aust	180		
Mn(mg/kg)	51 DAE	WS	Sand						>1000	Aust	177		

Paspalum notatum (Bahia Grass)

S(%)	Various	WS	F			0.16				USA	115		cv. Pensacola

Paspalum plicatulum (Plicatulum)

P(%)	35 DAS	WS YEB				0.25 0.20				Aust	97		cv. Rodd's Bay

Pennisetum clandestinum (Kikuyu Grass)

N(%)	21 days regrowth	WS	F			3.5				Aust	120		
P(%)	45 DAE	WS	Soil	<0.20	0.20-0.24	0.22	0.24-0.35			Aust	10		
K(%)	42 DAS 65 DAS 42 DAS 65 DAS	WS YMB 	Sand	<2.7 <1.3 <2.3 <1.2		3.54 1.46 3.1 1.97	4.1-5.3 2.4-3.8 3.7-4.8 1.6-3.4			Aust	131		cv. Whittet
S(%)	28 DAE	WS	Soil	<0.07	0.07-0.12		>0.12			Aust	180		cv. Whittet
Mn(mg/kg)	Pre-Fl	WS	Soil							Aust	141		cv. Whittet; No toxicity symptoms at 1870 mg/kg

Pennisetum purpureum (Elephant Grass)

P(%)	Veg	WS	Soil			0.27 0.25				Cub	112		Critical value is mean for three cvv. cv. King grass
	60 DAS	WS	F	<0.18						PuRi	194		
K(%)	Veg	WS	Soil			2.95 2.41				Cub	111		Critical value is mean for three cvv. cv. King grass
	60 DAS	WS	F	<1.0-1.5			>1.5			PuRi	194		
Mg(%)	60 DAS	WS	F	<0.20						PuRi	194		

Phalaris aquatica (Phalaris)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	Fl	WS	S	<1.5			2.0-3.5				Aust	130	
	Veg, 3-5 weeks regrowth	YMB	D	<2.0	2.0-2.9		3.5-5.0				Aust	196	
P(%)	49 DAS 76 DAS	WS	Sand			0.41-0.43 0.26-0.29					Aust	133	cv. Holdfast
	Fl	WS	S	<0.20			0.25-0.40				Aust	130	
	Veg, 3-5 weeks regrowth	YMB	D	<0.17	0.20-0.24		0.27-0.45				Aust	196	
	49 DAS 76 DAS	YEB	Sand			0.28-0.32 0.23-0.26					Aust	133	cv. Holdfast
PO_4-P (mg/kg)	49 DAS 76 DAS	YEB	Sand			77-89 62-85					Aust	133	cv. Holdfast; Units in fresh weight; H_2SO_4 extract; Inorganic P rises with N supply
K(%)	43 DAS 65 DAS	WS	Sand	<1.9 <1.5		2.06 1.64	2.5-5.5 2.6-4.2				Aust	131	cv. Sirosa
	Fl	WS	S				1.5-3.5				Aust	130	
	Veg, 3-5 weeks regrowth	YMB	D	<1.4	1.7-2.0		2.0-3.7				Aust	196	
	43 DAS 65 DAS	YEB	Sand	<1.9 <1.1		2.09 1.75	2.6-6.1 2.7-4.6				Aust	131	cv. Sirosa
S(%)	51 DAS 77 DAS	WS	Sand	<0.23 <0.18	0.28 0.21	0.31 0.23-0.24	0.35-0.38 0.27-0.41				Aust	134	cv. Sirosa
	Fl	WS	S				0.20-0.40				Aust	130	
	Veg, 3-5 weeks regrowth	YMB	D	<0.20	0.20-0.22		0.25-0.50				Aust	196	
	51 DAS 77 DAS	YEB	Sand	<0.31 <0.23	0.25	0.36 0.28-0.29	0.41-0.46 0.33-0.54				Aust	134	cv. Sirosa
SO_4-S (mg/kg)	51 DAS 77 DAS 77 DAS	WS or YEB	Sand	<400 <170 100	180	542-686 210-216 337-344	850-1600 430-2180 900-1750				Aust	134	cv. Sirosa cv. Sirosa; High N supply cv. Sirosa; Low N supply
SO_4-S/S x100	51 DAS 77 DAS 77 DAS	WS or YEB	Sand			19.6-24.3 7.8-9.8 13.0-14.4					Aust	134	cv. Sirosa cv. Sirosa; High N supply cv. Sirosa; Low N supply
S(N/S)	51-77 DAS	WS	Sand			15					Aust	134	cv. Sirosa; Ratio > critical indicates deficiency

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Ca(%)	Fl	WS	S				0.25-0.50			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D				0.14-0.40			Aust	196		
Mg(%)	Fl	WS	S				0.20-0.35			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D		0.16		0.22-0.35			Aust	196		
Cu(mg/kg)	Fl	WS	S				4.0-10.0			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D	<2			4-12			Aust	196		
Zn(mg/kg)	Fl	WS	S				15-50			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D		11-14		15-80			Aust	196		
Mn(mg/kg)	25 DAE	WS	SC						>2200 >730-750	Aust	49		cv. Australian cvv. CPI 19275, CPI 19305
	Fl	WS	S				60-250			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D				30-300	490		Aust	196		
B(mg/kg)	Fl	WS	S				5.0-15.0			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D				8-15			Aust	196		
Mo(mg/kg)	Fl	WS	S				0.3-0.4			Aust	130		
	Veg, 3-5 weeks regrowth	YMB	D				0.15-1.6			Aust	196		
Na(%)	Veg, 3-5 weeks regrowth	YMB	D					0.7-0.8	1.0-1.3	Aust	196		
Cl(%)	Veg, 3-5 weeks regrowth	YMB	D					2.5-2.8		Aust	196		

Phleum pratense (Timothy Grass)

N(%)	1st Fl	WS above 5 cm	Lit				2.50-4.00			Ger	22		
P(%)	1st Fl	WS above 5 cm	Lit				0.30-0.50			Ger	22		
K(%)	1st Fl	WS above 5 cm	Lit				2.00-3.50			Ger	22		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Phleum pratense (Timothy Grass) (ctd)													
Ca(%)	1st Fl	WS above 5 cm	Lit				0.60-1.20			Ger	22		
Mg(%)	1st Fl	WS above 5 cm	Lit				0.15-0.50			Ger	22		
Cu(mg/kg)	1st Fl	WS above 5 cm	Lit				5-12			Ger	22		
Zn(mg/kg)	1st Fl	WS above 5 cm	Lit				20-50			Ger	22		
Mn(mg/kg)	1st Fl	WS above 5 cm	Lit				30-100			Ger	22		
Mo(mg/kg)	1st Fl	WS above 5 cm	Lit				0.15-0.50			Ger	22		
B(mg/kg)	Heads fully emerged	WS	F	<4					95	Can	69		cv. Climax; Toxicity symptoms but no decrease in yield
	1st Fl	WS above 5 cm	Lit				6-12			Ger	22		
Poa pratensis (Kentucky Bluegrass or Smooth-Stalked Meadow Grass)													
N(%)	28-42 DAC	WS	Lit	<2.1		2.4-2.8	2.6-3.2	>3.5		USA	82		
	1st Fl	WS above 5 cm	Lit				2.60-3.20			Ger	22		
P(%)	28-42 DAC	WS	Lit	<0.18		0.24-0.30	0.28-0.36	>0.40		USA	82		
	1st Fl	WS above 5 cm	Lit				0.30-0.50			Ger	22		
K(%)	28-42 DAC	WS	Lit	<1.5		1.6-2.0	2.0-2.4	>3.0		USA	82		
	1st Fl	WS above 5 cm	Lit				2.20-3.00			Ger	22		
S(%)	28-42 DAC	WS	Lit				0.16-0.24			USA	82		
Ca(%)	1st Fl	WS above 5 cm	Lit				0.60-1.20			Ger	22		
Mg(%)	28-42 DAC	WS	Lit				0.40-0.48	>5.0		USA	82		
	1st Fl	WS above 5 cm	Lit				0.15-0.50			Ger	22		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Cu(mg/kg)	1st Fl	WS above 5 cm	Lit				6-12			Ger	22		
Zn(mg/kg)	1st Fl	WS above 5 cm	Lit				20-50			Ger	22		
Mn(mg/kg)	1st Fl	WS above 5 cm	Lit				35-100			Ger	22		
Mo(mg/kg)	1st Fl	WS above 5 cm	Lit				0.15-0.50			Ger	22		
B(mg/kg)	1st Fl	WS above 5 cm	Lit				6-12			Ger	22		

Puccinellia ciliata (Saltmarsh Grass)

Na(mol/m^3)	Veg	WS	Sand						>240	Aust	103		Units in plant water; Critical for 50% reduction in shoot weight
Cl(mol/m^3)	Veg	WS	Sand						>175	Aust	103		Units in plant water; Critical for 50% reduction in shoot weight

Pueraria phaseoloides (Puero)

P(%)	60 DAE	WS	Soil			0.30				Cub	47		

Setaria sphacelata (Setaria or South African Pigeon Grass)

P(%)	57 DAE	WS	Soil	0.18	0.18-0.23	0.21	0.23-0.35			Aust	10		cv. Nandi
K(%)	32 DAE	WS	Soil	<1.5 <2.0 <1.2	1.5-2.0 2.0-3.5 1.2-2.0	1.8 3.1 1.6	2.0-4.0 3.5-5.0 2.0-4.0	>4.0 >5.0 >4.0		Aust	174		cv. Nandi cv. Kazungula cv. Narok
S(%)	28 DAE	WS	Soil	<0.07		0.07-0.12	>0.12			Aust	180		cv. Nandi
Mn(mg/kg)	51 DAE	WS	Sand							Aust	177		cv. Narok; No toxicity symptoms at concn of 3000 mg/kg

Sorghum almum (Columbus Grass)

P(%)	57 DAE	WS	Soil	<0.18	0.18-0.22	0.2	0.22-0.32			Aust	10		cv. Crooble
Mn(mg/kg)	51 DAE	WS	Sand						>1000	Aust	177		cv. Crooble

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Sorghum bicolor x _S. sudanense_ (Sorghum-sudangrass)													
N(%)	28-35 days after clipping	WS	Lit	<1.6		1.4-1.6	1.8-2.2	>2.5			USA	82	
P(%)	25 DAS	WS	Soil	<0.11		0.13	0.16-0.22				USA	72	cv. Dekalb SX-17
	28 DAS	WS	Soil	<0.30		0.4	0.48-0.52				USA	117	cv. HW 6986
	28-35 days after clipping	WS	Lit	<0.14		0.14-0.18	0.20-0.30	>0.35			USA	82	
	56 DAS	WS	Soil	<0.14		0.16	0.18-0.20				USA	117	
K(%)	28-35 days after clipping	WS	Lit	<1.0		1.5-1.8	1.9-2.8	>2.5			USA	82	
S(%)	28-35 days after clipping	WS	Lit	<0.10		0.10-0.12	0.14-0.18	>0.25			USA	82	
Sorghum halepense (Johnsongrass)													
N(%)	In boot	WS	D	<1.2		1.3-1.5	1.6-1.8	>2.2			USA	82	
P(%)	In boot	WS	D	<0.14		0.16-0.20	0.20-0.25	>0.30			USA	82	
K(%)	In boot	WS	D	1		1.2-1.5	1.6-1.8	>2.4			USA	82	
Stylosanthes capitata (Capica Stylo)													
N(%)	56 DAE	Leaves	F			1.9-2.9				Colo	38		10 ecotypes; Values for 80% maximum growth
P(%)	56 DAE	WS	F			0.11-0.18				Colo	38		10 ecotypes; Values for 80% maximum growth
K(%)	56 DAE	WS	F			1.0-1.3				Colo	38		10 ecotypes; Values for 80% maximum growth
Ca(%)	56 DAE	WS	F			0.7-1.3				Colo	38		10 ecotypes; Values for 80% maximum growth
Mg(%)	56 DAE	WS	F			0.21-0.29				Colo	38		10 ecotypes; Values for 80% maximum growth
Stylosanthes guianensis (Stylo)													
N(%)	Late Summer to Autumn; 4 cuts	WS	F			1.6-2.2				Aust	23		

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P (%)	1st Fl	WS Top 25 cm	F	<0.14	0.14-0.19	0.12 0.16	>0.19			Aust	34		cv. Schofield
	U	Tips	S			0.16				Aust	188		cv. Schofield
K(%)	35 DAC (91 DAS)	WS	Soil			0.8				USA	33		3 cultivars
	U	WS	S			1.0				Aust	188		cv. Schofield
S(%)	57 DAE	WS	Soil			0.21				Aust	65		cv. Endeavour
	5 harvests at 6 week intervals	WS	Soil			0.21-0.24				S I	195		cv. Endeavour
Ca(%)	56 DAE	WS	F			0.65-1.05				Colo	38		Range of ecotypes
	91 DAE	WS	SC			1.5				Aust	7		
Mg(%)	U	WS	F			0.27-0.33				Colo	37		
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants

Stylosanthes hamata (Caribbean Stylo)

N(%)	U	Apical tissue	Soil			2.3-2.9				Thai	1		cv. Verano
P(%)	35 DAS	WS	Soil			0.39				Aust	97		cv. Verano
	70 DAE	WS	Soil			0.18				Aust	19		cv. Verano
	98 DAE					0.06							
	70 DAE	A+YOL				0.21							
	98 DAE					0.10							
	84 DAE	Tips	Soil			0.13				Aust	198		cv. Verano
PO_4-P (mg/kg)	13 DAT	WS	SC			496-620				Aust	181		cv. Verano; Value on fresh weight basis
K(%)	56 DAS	WS	Soil			2.03				Nig	189		cv. Verano
S(%)	57 DAE	WS	Soil			0.10				Aust	65		cv. Verano
	Fl	WS	F			0.12				Aust	136		cv. Verano
	42 DAE	Tips	Soil			0.14				Aust	135		cv. Verano

Stylosanthes humilis (Townsville Stylo)

P(%)	Pre-Fl	WS	Soil	<0.14	0.14-0.18	0.17	0.17-0.30			Aust	8		
	Pre-Fl	WS	Soil			0.17				Aust	116		cv. Paterson
	Late Fl	WS	F	<0.14			>0.17			Aust	165		

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Toxic	Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)				
Stylosanthes humilis (Townsville Stylo) (ctd)													
P(%) (ctd)	Pre-Fl	A+YMB	Soil			0.26				Aust	116		cv. Paterson
K(%)	49 DAE	WS	Soil	0.35-0.55						Aust	62		
	Pre-Fl	WS	Soil	<0.4	0.4-0.6	0.6	0.6-1.2	>1.2		Aust	9		
	Late Fl	WS	F	<0.4			>0.7			Aust	165		
S(%)	57 DAE	WS	Soil			0.11				Aust	65		cv. Paterson
	Pre-Fl	WS	Soil	<0.11	0.11-0.18	0.14	0.18-0.30			Aust	4		cv. Paterson
	Fl	WS	F			0.10-0.12				Aust	80		
Ca(%)	51 DAE	WS	SC			1.60-2.40				Aust	6		
Mg(%)	51 DAE	WS	SC			0.29-0.41				Aust	9		
Zn(mg/kg)	Pre-Fl	WS	Soil			34				Aust	12		Piper-Steenbjerg effect in very deficient plants
Mn(mg/kg)	51 DAE	WS	SC						>1140	Aust	6		
Stylosanthes macrocephala (Macrocephala Stylo)													
P(%)	56 DAE	WS	F			0.1				Colo	38		
K(%)	56 DAE	WS	F			0.9				Colo	37		
Ca(%)	56 DAE	WS	F			0.60-0.85				Colo	38		
Mg(%)	U	WS	F			0.16-0.20				USA	58		
Stylosanthes scabra (Shrubby Stylo)													
P(%)	35 DAS	WS	Soil			0.30				Aust	97		cv. Seca
S(%)	57 DAE	WS	Soil			0.17				Aust	65		cv. Seca
Stylosanthes viscosa (Sticky Stylo)													
S(%)	57 DAE	WS	Soil			0.18				Aust	65		cv. CPI 39404

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Thinopyrum ponticum (_Elytrigia pontica_) (Tall Wheat Grass)													
Na(mol/m^3)	Veg	WS	Sand						>215	Aust	103		cv. Largo; Units in plant water; Critical for 50% reduction in shoot weight
Cl(mol/m^3)	Veg	WS	Sand						>150	Aust	103		cv. Largo; Units in plant water; Critical for 50% reduction in shoot weight
Thyridolepis mitchelliana (Mulga or Mitchell Grass)													
P(%)	26 DAS	WS	Soil			0.39				Aust	13		
Trifolium alexandrinum (Berseem Clover)													
S(%)	30-50 DAE	WS	Soil			0.21				Ind	20		
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
Trifolium ambiguum (Caucasian Clover)													
P(%)	Late Autumn	WS	F			0.31				NZ	50		
	Late Spring-early Summer	WS	F			0.26				NZ	50		
Trifolium balansae (_T. michelianum_) (Balansa Clover)													
P(%)	Veg, Pre-Fl Early Fl	WS	F, Sand			0.30-0.38 0.23				Aust	133		cv. Paradana; Critical for diagnosis and prediction of seasonal yield
	Full Fl	WS	F			0.16-0.22				Aust	133		cv. Paradana
	Veg to early Fl	YOL	F, Sand			0.45-0.50				Aust	133		cv. Paradana; Critical for diagnosis and prediction of seasonal yield
	Full Fl	YOL	F			0.26				Aust	133		cv. Paradana
PO_4-P (mg/kg)	Veg	YOL	F, Sand			150				Aust	133		cv. Paradana; Units in fresh weight; H_2SO_4 extract
K(%)	44 DAS	WS	Sand	<2.4	3.4	3.6	5.2-6.3			Aust	131		cv. Paradana
	Veg, Late Autumn-Winter	WS	F	<1.9		2.5	3.6-4.6			Aust	132		cv. Paradana

Trifolium balansae (*T. michelianum*) (Balansa Clover) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	69 DAS, Bud	WS	Sand			1.76					Aust	131	cv. Paradana
	Bud-Full Fl, Early Spring	WS	F	<1.06		1.36-1.73	2.0-4.3				Aust	132	cv. Paradana
	Bud-Full Fl, Spring					1.14-1.29							
	Full Fl -Seed, Late Spring			0.5		0.68-0.72	0.8-2.2						
	44 DAS	YOL	Sand			3.2					Aust	131	cv. Paradana
	Veg, Late Autumn-Winter	YOL	F	<2.70		3.1-4.0	3.4-4.6				Aust	132	cv. Paradana
	Veg- Bud, Late Winter-early Spring					1.74-2.45							
	69 DAS, Bud	YOL	Sand			1.96					Aust	131	cv. Paradana
	Bud-Full Fl, Spring	YOL	F	0.8		1.14-1.50	2.0-3.1				Aust	132	cv. Paradana
	Full Fl- Seed, Late Spring			0.5		0.7	0.8-1.9						
	44 DAS	PYOL	Sand			4.82					Aust	131	cv. Paradana
	Veg, Late Autumn	PYOL	F	<4.9		5.8	5.9-8.6				Aust	132	cv. Paradana
	Veg-Bud, Winter-early Spring			2.1		2.18-3.45	3.6-4.8						
	69 DAS, Bud	PYOL	Sand			2.78					Aust	131	cv. Paradana
	Bud-Full Fl, Spring	PYOL	F	0.9		1.40-1.68	2.2-4.2				Aust	132	cv. Paradana
K(mg/L)	Veg-Bud, Late Autumn-early Spring	PYOL	F			600-1200					Aust	132	cv. Paradana; Spot test of sap
	Fl, Spring					460-690							
	Full Fl-Seed,Late Spring					380							

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
S(%)	Veg-Start Fl (43-59 DAS)	WS	Sand	<0.16		0.18-0.19	0.22-0.51			Aust	134		cv. Paradana
	Veg-Start Fl (43-59 DAS)			<0.22		0.22-0.24	0.27-0.43						
SO_4-S (mg/kg)	Veg, 43 DAS	WS	Sand	<119		304	1150-2336			Aust	134		cv. Paradana; Piper-Steenbjerg effect at extreme deficiency
	Start Fl, 59 DAS	WS	Sand	<93		114	375-1940			Aust	134		cv. Paradana
	Veg, 43 DAS	YOL	Sand	95		205	870-1500			Aust	134		cv. Paradana; Piper-Steenbjerg effect at extreme deficiency
	Start Fl, 59 DAS	YOL	Sand	<108		136	397-1071			Aust	134		cv. Paradana
SO_4-S/S x100	Veg	WS	Sand			11.9-14.9				Aust	134		cv. Paradana
	Veg	YOL	Sand			6.1-6.4				Aust	134		cv. Paradana
S(N/S)	Veg	WS	Sand			24				Aust	134		cv. Paradana; Ratio > critical indicates deficiency
Mn(mg/kg)	35 DAS	WS	Sand				60-498	1128	1330-5931	Aust	54		cv. Paradana
		YOL					73-500	1037	1230-4926				
Na(%)	Veg	WS	SC						0.9	Aust	152		cv. Paradana; 50% reduction with 4.0%
Cl(%)	Veg	WS	SC						1.7	Aust	152		cv. Paradana; 50% reduction with 5.3%

Trifolium dubium (Suckling Clover)

P(%)	46 DAS	WS	Soil			0.42				Aust	158		

Trifolium fragiferum (Strawberry Clover)

K(%)	Pre-Fl	WS	Soil	<0.8	0.8-1.2	1.0	1.2-2.0	>2.0		Aust	9		cv. Palestine
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4.0-5.0		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
	Pre-Fl	WS	F			3.0-4.0				Aust	96		cv. Palestine
	Pre-Fl, Spring	YOL				3.0-3.5							
	Seed	Seed	F			5.0-6.0				Aust	96		cv. Palestine; Critical value depends on season
Mn(mg/kg)	62 DAE	WS	SC						>510	Aust	6		cv. Palestine

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Trifolium glomeratum (Cluster Clover)													
P(%)	Fl	WS	Soil			0.27					Aust	93	
S(%)	Fl	WS	Soil			0.27					Aust	93	
S(N/S)	Fl	WS	Soil			20					Aust	93	Ratio > critical indicates deficiency
Trifolium hirtum (Rose Clover)													
P(%)	Var	WS	Lit	<0.14		0.14-0.18	0.19-0.25				USA	82	
K(%)	Var	WS	Lit	<0.87		0.87-0.95	1.2-1.8				USA	82	
Trifolium hybridum (Alsike Clover)													
P(%)	Late Autumn	WS	F			0.23					NZ	50	
	Late Spring-early Summer	WS	F			0.27					NZ	50	
Trifolium pratense (Red Clover)													
N(%)	1st Fl	WS above 5 cm	Lit				2.50-4.00				Ger	22	
P(%)	6-12 weeks after sowing	WS	Soil			0.27					USA	200	cv. Kenland
	Late Autumn	WS	F			0.22					NZ	50	cv. Grasslands Pawera
	Late Spring-Early Summer					0.28							
	1st Fl	WS above 5 cm	Lit				0.30-0.60				Ger	22	
K(%)	1st Fl	WS above 5 cm	Lit				1.80-3.00				Ger	22	
SO_4-S (mg/kg)	Symptoms showing	WS	Soil, F			600					Jap	86	cv. Kenland; Critical for 60% maximum yield
Ca(%)	1st Fl	WS above 5 cm	Lit				1.0-2.0				Ger	22	

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Mg(%)	1st Fl	WS above 5 cm	Lit				0.25-0.60			Ger	22		
Cu(mg/kg)	1st Fl	WS above 5 cm	Lit				7-15			Ger	22		
Zn(mg/kg)	1st Fl	WS above 5 cm	Lit				25-70			Ger	22		
Mn(mg/kg)	1st Fl	WS above 5 cm	Lit				35-100			Ger	22		
Mo(mg/kg)	Fl(10%)	WS	Soil	0.03			0.27			Can	70		cv. Lakeland
	1st Fl	WS above 5 cm	Lit				0.30-1.50			Ger	22		
B(mg/kg)	Veg to 6 months	WS	Soil	15			18			NZ	166		
	Full veg. growth	WS	Soil						>250	NZ	169		cv. Grasslands Turoa; Critical for yield; Symptoms appeared at >150 mg B /kg
	1st Fl	WS above 5 cm	Lit				25-60			Ger	22		
Cl(mg/kg)	96 DAE	YOL	SC						>200	UK	197		cv. Hungaropoly

Trifolium repens (White Clover)

N(%)	28-35 DAC	WS	F	<2.8		3.2-3.6	3.8-4.2	>5.0		USA	104		
	1st Fl	WS above 5 cm	Lit				2.80-4.00			Ger	22		
	Veg	LB+P	F	<4.4	4.4-4.7		4.8-5.5	>5.5		NZ	42		
	Pre-Start Fl	LB+P	D		3.0-3.2		3.3-5.5			Aust	196		
P(%)	7-21 DAS	WS	Soil			0.32				NZ	60		
	40 DAT	WS	Soil			0.44-0.46 0.66				Aust	66		cvv. Algerian, Grasslands Huia, Ladino cv. Haifa
	66 DAE	WS	Soil			0.30-0.31 0.32 0.26-0.28				NZ	98		cvv. Huia, Whatawhata cv. Tahora cvv. Pitau, Kopu
	Late Autumn	WS	F			0.31				NZ	50		
	Late Spring to early Summer	WS	F			0.34				NZ	50		
	3 cuts over 2 seasons	WS	Soil			0.20				UK	138		cv. Grasslands Huia; critical for 100% yield

Trifolium repens (White Clover) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	Pre-Fl	WS	Soil	<0.21	0.21-0.25	0.23	>0.25				Aust	3	cv. Irrigation
	1st Fl	WS above 5 cm	Lit				0.30-0.50				Ger	22	
	Veg	LB+P	F	<0.30	0.30-0.34		0.35-0.40	>0.40			NZ	42	
	Pre-Start Fl	LB+P	D	<0.20	0.22-0.23		0.25-0.50	0.6-0.7	>0.7		Aust	196	
	Mat	LB	F			0.30					Aust	140	
K(%)	Veg; 21-27 DAC	WS	Sand				>4.8 >1.4				Aust	118	cv. Victorian; Value obtained without Na cv. Victorian; Value obtained with Na
	Var	WS	F			1.5					Aust	186	cv. Ladino
	3 cuts over 2 seasons	WS	Soil			1.0-1.5					UK	138	cv. Grasslands Huia; Critical for 100% yield
	Pre-Fl	WS	Soil	<0.8	0.8-1.1	1.0	1.1-2.0	>2.0			Aust	9	cv. Irrigation
	Pre-Fl	WS	Soil	<1.0	1.0-1.2	1.1	>1.2				Aust	3	cv. Irrigation
	1st Fl	WS above 5 cm	Lit				1.70-2.50				Ger	22	
	Veg	LB+P	F	<1.7	1.7-1.9		2.0-2.4	>2.4			NZ	42	
	Pre-Start Fl	LB+P	D	<0.8	0.8-1.0		1.1-2.5				Aust	196	
K(mg/L)	U	PYOL	F	<1500			>1500				Aust	185	Spot test; concn in sap
S(%)	Veg	WS	F			0.26					NZ	100	
	Pre-Fl	WS	Soil	<0.15	0.15-0.20	0.18	0.20-0.30				Aust	4	cv. NZ Certified
	Closing of canopy to harvest	WS	F			0.11-0.14					NZ	40	cv. Grasslands Huia; All plants possibly deficient
	Veg	LB+P	F	<0.25	0.25-0.26		0.27-0.32	>0.32			NZ	42	
	Pre-Start Fl	LB+P	D	<0.22	0.22-0.23		0.25-0.40				Aust	196	
SO_4-S (mg/kg)	Symptoms showing	WS	Soil, S			230					Jap	86	cv. Ladino; Critical for 60% maximum yield
S(N/S)	U	WS	F			17-19					NZ	99	Ratio > critical indicates S deficiency
Ca(%)	3 cuts over 2 seasons	WS	Soil			2.0					UK	138	cv. Grasslands Huia; Critical for 100% yield
	Pre-Fl	WS	Soil	<0.9	0.9-1.1	1.0	>1.1				Aust	3	cv. Irrigation

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	1st Fl	WS above 5 cm	Lit				1.0-2.0			Ger	22		
	Veg	LB+P	F	<0.3	0.3		0.4-0.5	>0.5		NZ	42		
	Pre-Start Fl	LB+P	D	<0.8			0.8-2.5			Aust	196		
Mg(%)	2.5-3 years	WS	F			0.18-0.25				NZ	191		Critical value depends on K status
	1st Fl	WS above 5 cm	Lit				0.25-0.60			Ger	22		
	Veg	LB+P	F	<0.15	0.15-0.17		0.18-0.22	>0.22		NZ	42		
	Pre-Start Fl	LB+P	D	<0.12	0.12-0.14		0.15-0.50	0.7		Aust	196		
Cu(mg/kg)	Pre-Fl	WS	Soil	<4	4-5		>5			Aust	11		Piper-Steenbjerg effect in very deficient plants
	1st Fl	WS above 5 cm	Lit				6-15			Ger	22		
	Veg	LB+P	F	<5	5		6-7	>7		NZ	42		
	Pre-Start Fl	LB+P	D	<3.0	3-4		5-30			Aust	196		
Zn(mglkg)	1st Fl	WS above 5 cm	Lit				30-80			Ger	22		
	Veg	LB+P	F	<12	12-15		16-19	>19		NZ	42		
	Pre-Start Fl	LB+P	D	<12	12-14		15-50	>50		Aust	196		
	Veg	LB	F			15				NZ	101		
Mn(mg/kg)	40-61 DAS	WS	Sand						570-780	NZ	183		cv. Grasslands Pitau; 570 at pH 5.5, 780 at pH 6.5
	62 DAE	WS	SC						<650	Aust	6		cv. NZ Certified
	1st Fl	WS above 5 cm	Lit				35-100			Ger	22		
	Veg	LB+P	F	<20	20-24		25-30	>30		NZ	42		
	Pre-Start Fl	LB+P	D	<20	20-24		25-300	400-600	>800	Aust	196		
	Pre-Fl	LB	Soil					<600		Aust	141		cv. Ladino
Fe(mg/kg)	Veg	LB+P	F	<45	45-49		50-65	>65		NZ	42		Be careful of Fe contamination from soil or grinding
B(mg/kg)	Veg	WS	Soil	13			16			NZ	166		cv. Grasslands Huia
	1st Fl	WS above 5 cm	Lit				25-60			Ger	22		
	Veg	LB+P	F	<20	20-24		25-30	>30		NZ	42		
	Pre-Start Fl	LB+P	D	<20	20-24		25-100			Aust	196		

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Trifolium repens (White Clover) (ctd)													
Mo(mg/kg)	1st Fl	WS above 5 cm	Lit				0.40-1.00			Ger	22		
	Veg	LB+P	F	<0.10	0.10-0.14		0.15-0.20	>0.20		NZ	42		
	Pre-Start Fl	LB+P	D	<0.4	0.4		0.5-10	>10		Aust	196		Deficiency concn associated with low nitrogen
Na(%)	6-8 cuts during Summer-Autumn	WS	F						>0.3	Aust	154		Mean of 5 cvv.; 50% reduction with 1.2%
	4 cuts at 20 day intervals	WS	SC						1.4-1.8	Aust	153		Mean of 4 cvv.; 50% reduction with 4.2-5.1%
	Pre-Start Fl	LB+P	D					0.5-0.7	0.8-2.4	Aust	196		
Cl(%)	6-8 cuts during Summer-Autumn	WS	F						>1.6	Aust	154		Mean of 5 cvv.; 50% reduction with 2.6%
	Veg	WS	SC						1.2-1.7	Aust	153		Mean of 4 cvv.; 50% reduction with 3.8-4.9%
	Pre-Start Fl	LB+P	D					1.7-1.9	2.2-6.8	Aust	196		
Trifolium resupinatum (Persian or Shaftal Clover)													
K(%)	41 DAS	WS	Sand	<3.3		3.65	5.2-6.3			Aust	131		cv. Maral
	66 DAS	WS	Sand	<2.3		3.54	3.9-5.8			Aust	131		cv. Maral
	41 DAS	YOL	Sand	<3.1		3.40	4.2-4.8			Aust	131		cv. Maral
	66 DAS	YOL	Sand	<2.3		3.08	3.3-3.9			Aust	131		cv. Maral
	41 DAS	PYOL	Sand	<4.6		5.18	6.5-7.9			Aust	131		cv. Maral
	66 DAS	PYOL	Sand	<3.1		4.58	6.5			Aust	131		cv. Maral
Mn(mg/kg)	35 DAS	WS	Sand				64-151		360-2245	Aust	54		cv. Maral
	35 DAS	YOL	Sand				59-130		250-1447	Aust	54		cv. Maral
Trifolium semipilosum (Kenya White Clover)													
S(%)	Pre-Fl	WS	Soil	<0.15	0.15-0.20	0.17	0.20-0.30			Aust	4		cv. Safari

Trifolium subterraneum (Subterranean Clover)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)	Pre-start Fl	LB+P	D		3.0-3.2		3.3-5.5				Aust	196	
	1st Fl	WS above 5 cm	Lit				2.20-3.00				Ger	22	
P(%)	28 DAE	WS	FSC						>1.0		Aust	14	cv. Mt Barker
	40 DAS	WS	F, Soil			0.58					Aust	26	Critical value, derived from regression of critical value with DAS, varies with season and conditions
	42 DAS	WS	Soil			0.32					Aust	190	cv. Seaton Park
	46 DAS	WS	Soil			0.31					Aust	158	
	60 DAS	WS	F, Soil			0.51					Aust	26	Critical value, derived from regression of critical value with DAS, varies with season and conditions
	53 DAE	WS	Soil	<0.15					>1.0		Aust	155	cv. Dwalganup
	80 DAS 100 DAS 120 DAS 140 DAS	WS	F, Soil			0.45 0.39 0.33 0.27					Aust	26	Critical value, derived from regression of critical value with DAS, varies with season and conditions
	Var, April	WS	F			0.63					Aust	27	Values meaned over several seasons
	Late Autumn	WS	F			0.31					Aust	133	cv. Karridale
	Late Autumn	WS	F			0.27					Aust	133	cv. Karridale; Critical for total yield during season
	Var, May Var, June	WS	F			0.56 0.49					Aust	27	Values meaned over several seasons
	Early Winter	WS	F			0.35					Aust	90	cv. Trikkala
	Early Winter	WS	F			0.39-0.40					Aust	90	cv. Trikkala; Critical for yield in spring
	Var, July	WS	F			0.44					Aust	27	Values meaned over several seasons
	Late Winter	WS	F			0.24					Aust	133	cv. Karridale; Critical for total yield during season
	Var, August	WS	F			0.34					Aust	27	Values meaned over several seasons
	Late Winter – Early Spring	WS	F			0.28-0.29					Aust	133	cv. Karridale
	Early Spring	WS	F			0.30-0.32					Aust	90	cv. Trikkala
	Early Spring	WS	F			0.29					Aust	133	cv. Karridale; Critical for total yield during season

Trifolium subterraneum (Subterranean Clover) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
P(%) (ctd)	Var, September	WS	F			0.32					Aust	27	Values meaned over several seasons
	Var, October	WS	F			0.25					Aust	27	Values meaned over several seasons
	Var, November	WS	F			0.19					Aust	27	Values meaned over several seasons
	Late Spring, Full Fl	WS	F			0.21-0.26					Aust	133	cv. Karridale
	Fl	WS	Soil			0.24					Aust	93	cv. Woogenellup
	1st Fl	WS above 5 cm	Lit				0.30-0.50				Ger	22	
	Late Autumn	YOL	F			0.34					Aust	133	cv. Karridale; Critical for total yield during season
	Veg – full Fl	YOL	F			0.37-0.39					Aust	133	cv. Karridale
	Early Winter – Late Spring	YOL	F			0.39-0.43					Aust	90	cv. Trikkala
	Late Winter	YOL	F			0.33					Aust	133	cv. Karridale; Critical for total yield during season
	Late Spring	YOL	F			0.40					Aust	133	cv. Karridale; Critical for total yield during season
	Early Winter – Late Spring	YOL+1	F			0.28-0.32					Aust	90	cv. Trikkala
	118 DAE 132-151 DAE	LB	Soil			0.135 0.11					USA	78	cv. Mt Barker; Critical value increased with more frequent defoliation
	Pre-Start Fl	LB+P	D	<0.20	0.22-0.23		0.25-0.50	0.6-0.7	>0.7		Aust	196	
	118 DAE 132-151 DAE	P	Soil			0.085 0.065-0.070					USA	78	cv. Mt Barker; Critical value increased with more frequent defoliation
	Mat	Seed	F, Soil			0.59-1.00					Aust	26	
PO_4-P (mg/kg)	69 DAS	YOL or YOL+1	Soil			185-196					Aust	90	cv. Trikkala; Units in fresh weight; H_2SO_4 extract
	101 DAS	YOL or YOL+1				80-96							
	132 DAS	YOL or YOL+1				96							
	Late Autumn	YOL	F			83-110					Aust	133	cv. Karridale; Units in fresh weight; H_2SO_4 extract; Critical for total yield during season
	Late Autumn, Veg	YOL	F			120					Aust	133	cv. Karridale; Units in fresh weight; H_2SO_4 extract; Critical for yield in spring

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Early Winter	YOL	F			187				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract
	Early Winter	YOL	F			210-235				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract; Critical for yield in spring
	Late Winter	YOL	F			128				Aust	133		cv. Karridale; Units in fresh weight; H_2SO_4 extract; Critical for total yield during season
	Early Spring, Pre-Fl	YOL	F			155-170				Aust	133		cv. Karridale; Units in fresh weight; H_2SO_4 extract
	Early Spring	YOL	F			124				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract
	Early Spring	YOL	F			143				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract; Critical for yield in late spring
	Early Spring	YOL	F			127				Aust	133		cv. Karridale; Units in fresh weight; H_2SO_4 extract; Critical for total yield during season
	Late Spring, Full Fl	YOL	F			179				Aust	133		cv. Karridale; Units in fresh weight; H_2SO_4 extract
	Early Winter	YOL+1	F			95				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract
	Early Winter	YOL+1	F			138				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract; Critical for yield in spring
	Early Spring	YOL+1	F			83				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract
	Early Spring	YOL+1	F			98				Aust	90		cv. Trikkala; Units in fresh weight; H_2SO_4 extract; Critical for yield in late spring
	Late Autumn-Early Winter Late Winter-Early Spring	LB	F			160 153				Aust	55		cv. Woogenellup; Units in fresh weight; H_2SO_4 extract of leaves of 'average age'
	Spring	LB	F	<130	130-150	150	150-250		>350	Aust	30		Units in fresh weight; H_2SO_4 extract of leaves of 'average age'
	Fl, seed set	LB	F			118				Aust	55		cv. Woogenellup; Units in fresh weight; H_2SO_4 extract of leaves of 'average age'
K(%)	Veg, Winter Bud-Full Fl, Spring Full Fl-PF	WS	F	1.21 0.67	2.13 1.24 0.66	2.38-2.54 1.69-2.08 0.74-0.81	2.91-3.6 2.53-3.84 0.95-3.68			Aust	132		cv. Karridale; Critical values decline steadily with date
	1st Fl	WS above 5 cm	Lit				1.40-2.20			Ger	22		

Trifolium subterraneum (Subterranean Clover) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
K(%) (ctd)	Veg, Late Autumn-early Winter	YOL	F	2.04 <1.23	2.7 1.57	3.11-3.52 1.85-2.14	3.77-3.98 2.48-3.69				Aust	132	cv. Karridale; Critical values decline steadily with date
	Veg-Full Fl, Spring PF, Late Spring			0.96		1.13	1.35-3.01						
	Veg, Autumn-Winter	PYOL	F	2.24		3.42-5.39	5.5-6.4				Aust	132	cv. Karridale; Critical values decline steadily with date
	Bud-Early Fl, Spring			<1.56	2.21	2.76-2.89	3.32-5.18						
	68 DAE 109 DAE	LB+P	F	<2.17 <1.79		2.41 1.83	>2.63 >2.35				Aust	46	cv. Woogenellup
	Pre-Start Fl	LB+P	D	<0.8	0.8-1.0		1.1-2.5				Aust	196	
	Early Fl Early PF	LB+P	F	<0.81 <0.51		0.92 0.73	1.21-1.62 0.76-1.06				Aust	46	cv. Woogenellup
	Mid-Fl	Leaves	F	<0.72		0.72-0.90	0.95-1.5				Aust	46	cv. Mt Barker
K(mg/L)	Var	P	F	<1500			>1500				Aust	185	Spot test of sap
	Veg, Autumn-Winter	PYOL	F	<1050	1125-1150	1200-1300	1450-1500				Aust	132	cv. Karridale; Spot test of sap
	Veg-Full Fl, Spring PF			263	563 400	776-914 529	988-1500 738-1400						
S(%)	36-61 DAS	WS	Sand	0.17	0.20-0.22	0.23-0.24	0.27-0.47				Aust	134	cv. Karridale
	Veg	WS	F			0.25					Aust	184	
	Veg, Winter-Early Spring	WS	F			0.19-0.22					Aust	91	cv. Trikkala
	Spring	WS	F			0.09-0.14					Aust	91	cv. Trikkala; Value drops with time
	Var	WS	F			0.16-0.20					Aust	31	cv. Mt Barker
	Fl	WS	Soil			0.17					Aust	93	cv. Woogenellup
	36 DAS 61 DAS	YOL	Sand	0.22 0.2	0.28 0.22	0.30 0.24	0.32-0.49 0.26-0.39				Aust	134	cv. Karridale
	58 DAE	YOL	Soil			0.20					Aust	64	cv. Trikkala
	58 DAE	YOL	Soil			0.21					Aust	64	cv. Seaton Park
	58 DAE	YOL	Soil			0.16					Aust	64	cv. Clare

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
	Veg, Winter-Early Spring	YOL	F			0.26-0.28				Aust	91		cv. Trikkala
	Spring			<0.22		0.24-0.26							
	Pre-Start Fl	LB+P	D		0.22-0.23		0.25-0.40			Aust	196		
	Var	Tip	F			0.20				Aust	201		
SO_4-S (mg/kg)	36-61 DAS	YOL or WS	Sand	<109	139-196	208-364	427-2136			Aust	134		cv. Karridale
SO_4-S/S x100	36 DAS	WS	Sand			9.7				Aust	134		cv. Karridale
	61 DAS					17.4							
	36 DAS	YOL				6.9							
	61 DAS					12.8							
	Var	LB	Soil			8-11				USA	79		cv. Mt Barker
S(N/S)	36-61 DAS	WS	Sand			20				Aust	134		cv. Karridale
	Fl	WS	Soil			20				Aust	93		cv. Woogenellup; Ratio > critical indicates S deficiency
	33 DAE	LB	Soil			19				Aust	187		cv. Woogenellup; Ratio > critical indicates S deficiency
	61-133 DAE					20-25							
	33 DAE	P				16							
	61-133 DAE					25-29							
Ca(%)	Pre-Start Fl	LB+P	D		<0.8		0.8-2.5			Aust	196		
	1st Fl	WS above 5 cm	Lit				1.00-2.00			Ger	22		
Mg(%)	29 DAS	WS	SC			0.11				Aust	161		Critical value unaffected by source of nitrogen
		YOL				0.09							Nitrogen supplied as nitrate
		YOL				0.20							Plants reliant on N_2-fixation
													cv. Seaton Park
	53 DAS	WS	Soil			0.15				China	114		cv. Nungarin; Symptoms persisted to 0.26%
	1st Fl	WS above 5 cm	Lit				0.25-0.70			Ger	22		
	16-37 DAE	1st Trifoliate leaf	SC			0.06-0.08				Aust	160		cv. Seaton Park; Critical for symptoms
	25-36 DAT	YOL	SC			0.11				Aust	159		cv. Seaton Park
	Pre-Start Fl	LB+P	D	<0.12	0.12-0.14		0.15-0.5	0.7		Aust	196		
Cu(mg/kg)	Winter-Spring	WS	F			3.0-4.0				Aust	95		cvv. Woogenellup, Nungarin and Trikkala; Critical for vegetative growth
	Winter-Spring	WS	F			3.5-4.5				Aust	95		cv.Woogenellup and Nungarin; Critical for seed yield

Trifolium subterraneum (Subterranean Clover) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Cu(mg/kg) (ctd)	Winter-Spring	WS	F			5.0-6.0				Aust	95		cv. Trikkala; Critical for seed yield
	26-98 DAE	YOL	Soil			3.0				Aust	146 147		cvv. Seaton Park, Clare, Trikkala
	Winter-Spring	YOL	F			3.0-4.5				Aust	95		cvv.Woogenellup and Nungarin; Critical value for vegetative growth and seed yield
	Winter-Spring	YOL	F			4.0-6.0				Aust	95		cv. Trikkala; Critical for vegetative growth
	Winter-Spring	YOL	F			4.5-7.0				Aust	95		cv. Trikkala; Critical for seed yield
	Early Fl	YOL	F	<3.0	3.5-4.5	4.0				Aust	94		cv. Woogenellup; Criteria based on seed yield
	Pre-Start Fl	LB+P	D	<3.0	3-4		5-30			Aust	196		
	1st Fl	WS above 5 cm	Lit				7			Ger	22		
Cu(drop)	Var	YFL	F	6.0-11.0	4.0-5.0		2.0-3.0			Aust	52		Ascorbate oxidase activity measured by drops of iodine
Zn(mg/kg)	21-55 DAE	YOL	Soil			12-14				Aust	144 145		cv. Seaton Park
	56 DAS	YOL	Soil			21-22				Aust	53		cv. Seaton Park
	Pre-Start Fl	LB+P	D	<12	12-14		15-50		>50	Aust	196		
	1st Fl	WS above 5 cm	Lit				25-70			Ger	22		
	Mid-Late Fl	YOL	Soil	10						Aust	32		cv. Nungarin
Mn(mg/kg)	22 DAE	WS	SC						>640	Aust	49		cv. Woogenellup
	35 DAS	WS	Sand				64-412 54-893	1059 2192	2010-3896 >2200	Aust	54		cv. Mt. Barker cv. Karridale
	77 DAE	WS	Soil						710	Aust	170		Toxicity symptoms appear at 710 mg/kg
	Fl	WS	Soil			25				Aust	192		cv. Mt Barker
	1st Fl	WS above 5 cm	Lit				30-100			Ger	22		
	35 DAS	YOL	Sand				46-246 66-551	634 1314	1220-2761 >1300	Aust	54		cv. Mt. Barker cv. Karridale
	U	YOL	RSC			20				Aust	121		cv. Seaton Park; Determined by correlation with photosynthetic O_2 evolution
	Pre-Start Fl	LB+P	D	<20	20-24		25-300	400-600	>800	Aust	196		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
B(mg/kg)	1st Fl	WS above 5 cm	Lit				25-60			Ger	22		
	Pre-Start Fl	LB+P	D	<20	20-24		25-100			Aust	196		
Mo(mg/kg)	Mid-Fl	WS	U			0.15				Aust	61		
	1st Fl	WS above 5 cm	Lit				0.50-1.00			Ger	22		
	U	YOL	U			0.05-0.10				Aust	150		
	Pre-Start Fl	LB+P	D	<0.4	0.4		0.5-10	>10		Aust	196		Deficient concn associated with low N
Co(mg/kg)	U	LB+P	F	<0.04			>0.04			Aust	128		cv. Woogenellup
Na(%)	Veg	WS	SC						1.4	Aust	152		cv. Clare; 50% reduction with 4.5%
	Pre-Start Fl	LB+P	D					0.5-0.7	0.8-2.4	Aust	196		Symptoms associated with toxic values
Cl(%)	Veg	WS	SC						0.9	Aust	152		cv. Clare; 50% reduction with 4.7%
	Pre-Start Fl	LB+P	D					1.7-1.9	2.2-6.8	Aust	196		Symptoms associated with toxic values

Urochloa mosambicensis (Sabi Grass)

P(%)	35 DAS	WS	Soil			0.20-0.24				Aust	97		cv. CPI 46876
	35 DAS	YEB	Soil			0.21-0.24				Aust	97		cv. CPI 46876
Mn(mg/kg)	51 DAE	WS	Sand						>200	Aust	177		cv. Nixon

Urochloa oligotricha (Urochloa)

P(%)	35 DAS	WS	Soil			0.26				Aust	97		cv. CPI 47122
	35 DAS	YEB	Soil			0.25				Aust	97		cv. CPI 47122

Vigna luteola (Dalrymple Vigna)

P(%)	Pre-Fl	WS	Soil	<0.22	0.22-0.27	0.25	0.27-0.35			Aust	8		
Na(%)	46 DAS	WS	Sand						>3.75	Nig	125		Critical for a 42% reduction in growth
Cl(%)	46 DAS	WS	Sand						>6.46	Nig	125		Critical for a 42% reduction in growth

Vigna vexillata (Wild Cowpea)

Na(%)	46 DAS	WS	Sand						>3.24	Nig	125		Critical for a 57% reduction in growth
Cl(%)	46DAS	WS	Sand						>5.64	Nig	125		Critical for a 57% reduction in growth

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Summarised Guidelines for Diagnosing Nutrient Deficiencies in Pasture Species

The main tabular compilation in this chapter provides a diverse array of published plant tests for diagnosing nutrient deficiencies in pasture species. These tests involve sampling a number of different plant parts at various stages of growth and analysing for nutrients or nutrient fractions.

The purpose of the tables produced below is to summarise this body of information into sets of interpretation guidelines, which for a **specified** stage of growth and plant part appear appropriate for diagnosing **most** nutrient deficiencies in important pasture plants. The ranges stated take into account published critical nutrient concentrations for plants sampled from the mid-vegetative stage of growth to before flowering. They lie within the zone of marginal deficiency as defined in Figure 4.3 (Chapter 4), wherein plants would not normally exhibit deficiency symptoms. Nutrient adequacy would be confirmed where values exceed the quoted guideline values. Generally, the authors recommend that young plant parts be sampled and analysed for detecting nutrient deficiencies in pastures.

The main table in this chapter contains more detailed information from which these interpretation guidelines have been derived, and as well, provides an appreciation of the effects of plant age, seasonal conditions and nutrient interactions on the nutrient composition of pasture species. The main table also furnishes values for critical nutrient concentrations during pasture establishment and early growth: some of these values may be considerably higher than those shown in the interpretation guideline tables below.

Annual Medics (*Medicago murex, M. polymorpha* and *M. truncatula*)		
Young tissue - The youngest open leaves collected during active growth, prior to flowering		
Whole shoots - All above ground parts collected prior to flowering		
Nutrient	**Young tissue**	**Whole shoots**
P(%)	0.30-0.40	0.26-0.35
K(%)	1.0-1.5	1.0-1.4
S(%)	0.18-0.25	0.17-0.19
Ca(%)	0.80-1.00	
Mg(%)	0.15-0.20	
Cu(mg/kg)	4.0-5.5	3.5-5.0
Zn(mg/kg)	14-25	15-20
Mn(mg/kg)	15-20	
B(mg/kg)	15-25	
Mo(mg/kg)	0.10-0.30	

White Clover (*Trifolium repens*)		
Young tissue - The youngest open leaves collected during active growth, prior to flowering		
Whole shoots - All above ground parts collected prior to flowering		
Nutrient	Young tissue	Whole shoots
N(%)	4.4-4.7	3.2-3.6
P(%)	0.30-0.34	0.25-0.30
K(%)	1.7-1.9	0.8-1.2
S(%)	0.22-0.26	0.15-0.20
Ca(%)	0.8-1.2	0.9-1.1
Mg(%)	0.15-0.17	0.18-0.25
Cu(mg/kg)	3.0-5.0	4.0-5.0
Zn(mg/kg)	12-15	

White Clover (*Trifolium repens*)		
Mn(mg/kg)	20-24	
Fe(mg/kg)	50-65	
B(mg/kg)	15-20	13-16
Mo(mg/kg)	0.10-0.14	

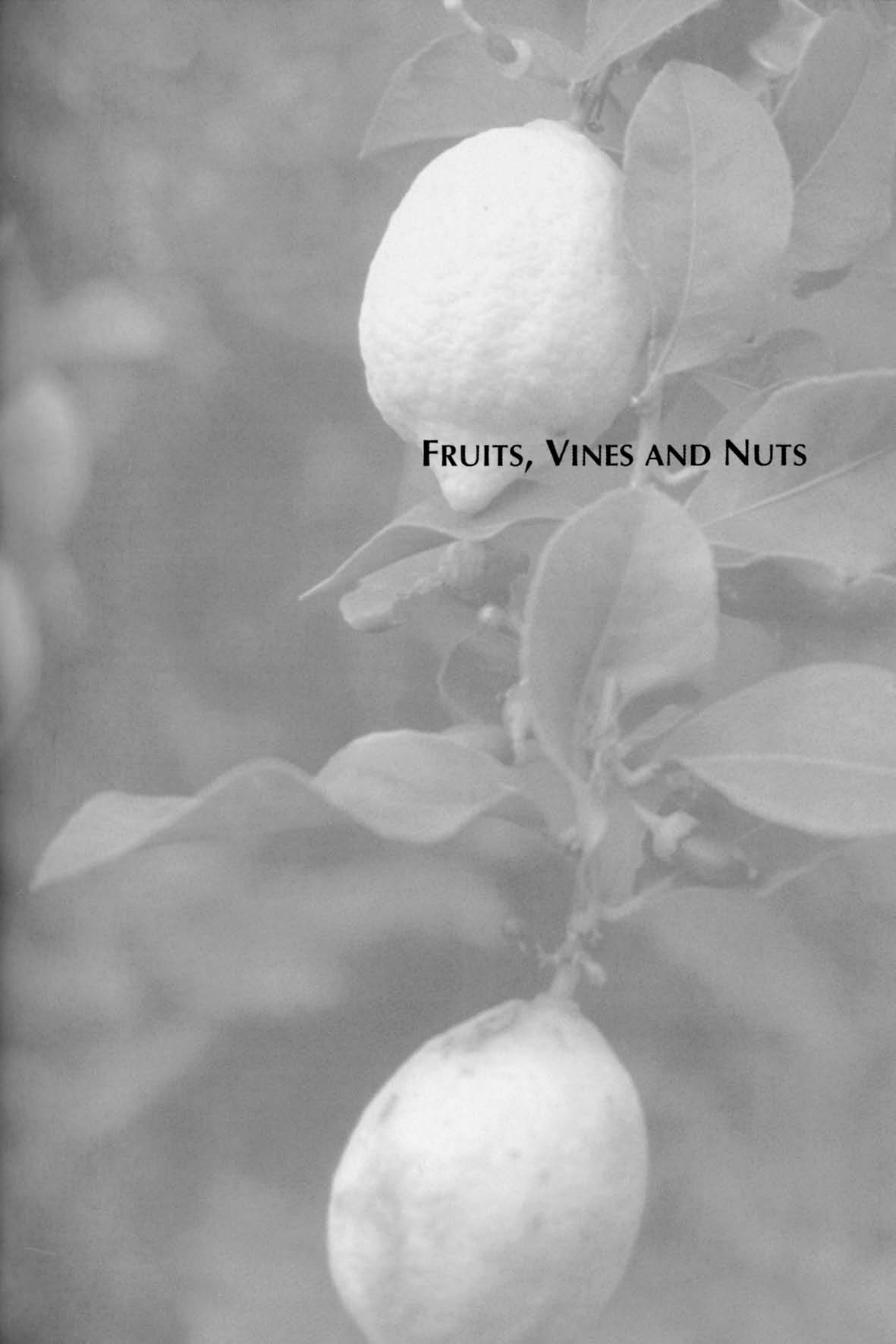
Subterranean Clover (*Trifolium Subterraneum*)		
Young tissue - The youngest open leaves collected during active growth, prior to flowering		
Whole shoots - All above ground parts collected prior to flowering		
Nutrient	**Young tissue**	**Whole shoots**
N(%)	3.0-3.2	
P(%)	0.30-0.40	0.28-0.32
K(%)	1.5-2.5	1.0-2.0
S(%)	0.18-0.30	0.19-0.25
Ca(%)	0.80-1.00	
Mg(%)	0.15-0.20	0.12-0.15
Cu(mg/kg)	4.5-5.5	3.5-4.5
Zn(mg/kg)	15-25	10-15
Mn(mg/kg)	15-20	
Fe(mg/kg)	50-75	
B(mg/kg)	15-20	
Mo(mg/kg)	0.10-0.20	0.10-0.20

Lucerne (*Medicago sativa*)		
Young tissue - Growing tips collected prior to flowering		
Whole shoots - All above ground parts collected prior to flowering		
Nutrient	**Young tissue**	**Whole shoots**
N(%)	3.5-4.4	3.0-4.0
P(%)	0.20-0.25	0.21-0.26
K(%)	1.8-2.4	1.3-1.4
S(%)	0.20-0.28	0.17-0.21
Ca(%)	0.7-1.0	0.40-0.80
Mg(%)	0.18-0.22	0.20-0.25
Cu(mg/kg)	4.0-6.0	4.0-5.0
Zn(mg/kg)	11-20	10-11
Mn(mg/kg)	20-24	20-24
Fe(mg/kg)		40-50
B(mg/kg)	15-20	20-25
Mo(mg/kg)	0.20-0.50	0.10-0.20

Phalaris (*Phalaris aquatica*)		
Young tissue - Young leaf blades collected when plants growing actively		
Whole shoots - Complete tillers collected when plant growing actively		
Nutrient	**Young tissue**	**Whole shoots**
N(%)	2.0-3.2	1.5-2.4
P(%)	0.20-0.25	0.18-0.20
K(%)	1.7-2.0	1.4-1.6
S(%)	0.21-0.25	0.21-0.23
Ca(%)	0.14-0.20	
Mg(%)	0.16-0.22	0.15-0.20
Cu(mg/kg)	2.0-4.0	
Zn(mg/kg)	12-15	
Mn(mg/kg)	20-30	
Fe(mg/kg)	40-60	
B(mg/kg)	8-15	
Mo(mg/kg)	0.10-0.15	

Perennial Rye Grass (*Lolium perenne*)		
Young tissue - Young leaf blades collected when plants growing actively		
Whole shoots - Complete tillers collected when plant growing actively		
Nutrient	**Young tissue**	**Whole shoots**
N(%)	3.0-3.5	2.0-3.2
P(%)	0.20-0.28	0.20-0.25
K(%)	1.4-1.9	1.0-1.5
S(%)	0.18-0.22	0.18-0.23
Ca(%)	0.15-0.20	0.20-0.24
Mg(%)	0.15-0.20	0.13-0.15
Cu(mg/kg)	4.0-6.0	4.0-5.0
Zn(mg/kg)	10-15	10-12
Mn(mg/kg)	15-20	12-20
Fe(mg/kg)	40-60	40-49
B(mg/kg)	3.0-5.0	4.0-6.0
Mo(mg/kg)	0.11-0.13	0.15-0.30

Stylo (*Stylosanthes* spp.)		
Young tissue - Growing tips collected prior to flowering		
Whole shoots - All above ground parts collected prior to flowering		
Nutrient	**Young tissue**	**Whole shoots**
N(%)	2.0-2.9	1.6-2.8
P(%)	0.18-0.24	0.13-0.17
K(%)	0.8-1.4	0.6-1.0
S(%)	0.18-0.22	0.14-0.17
Ca(%)		0.7-1.0
Mg(%)		0.20-0.25
Cu(mg/kg)	4.0-6.0	4.0-5.0
Zn(mg/kg)	18-24	15-20
Mn Defic.(mg/kg)		20-30
Mn Toxic. (mg/kg)		>1100
B(mg/kg)		20-30
Mo(mg/kg)	0.1-0.2	0.1-0.2



Fruits, Vines and Nuts

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7. FRUITS, VINES AND NUTS

J.B. Robinson, M.T. Treeby, and R.A. Stephenson

INTRODUCTION

For most of the temperate woody perennial crops and some of the tropical ones a good deal of literature exists on methods of using tissue analysis to monitor nutrient status and hence the success of nutrient management programs. The body of this literature for the more commonly grown crops provides such large sets of values that it is impracticable for them to be presented here as tables of primary values of tissue analyses as has been done for other crops in this manual. For this reason, summaries of the best values available at present for each crop have been drawn up with the help of colleagues in Australia and New Zealand. Where data are sketchy or where work is in progress, this has been noted in the short introduction to each crop. Where there is divergence between sources in different parts of Australia, this is noted in the 'Comments' column of the tables. As tables give a preferred sampling method and standards for each crop, they should be seen as a starting point when tissue analysis is about to be used. If widespread use of tissue analysis is contemplated in a new geographical area, some local survey work should be done to confirm that the proposed standards are useful in the new situation.

Anyone using the tables is advised to read the introductory chapters and the review by Leece (1976) which points out the hazards of interpreting tissue analysis values in the absence of good information on aspects of site and management. The user should also keep firmly in mind that for many crops more than one year's data are needed before firm interpretations can be made.

Future nutritional studies with fruit trees, vines and nuts will lead to modification of these tables in time. Users should keep in touch with their local agricultural advisory service. We have chosen to use standard ranges in the summary tables rather than use nutrient ratios, or DRIS procedures (e.g. Beverly 1987, Klein *et al.* 1991; Cerdà (*et al.* 1995; Schaller *et al.* 1995). We are not convinced that these systems offer benefits, and see potential difficulties in their use where the bases of ratios are abnormally high or low (see Righetti *et al.* 1988).

Colleagues in Australia, New Zealand and the US have helped us prepare this series of tables. They are acknowledged in the introductory paragraphs for each crop. We thank them for their ready help and prompt feedback. Special thanks are due to Dr Ken Bevington, Dr Patrick Brown, Dr Geoff Cresswell, Mr Geoff Danniells, Dr James Drinnan, Mr Alan George, Mr Brian Cull, Mr Barry Goldspink, Dr Noel Grundon, Mr Mark Herrington, Dr Rowland Holmes, Mr Colin Little, Dr Chris Menzel, Mr Graham Price, Mr Michael Rettke, Mr Garth Sanewski, Mr Colin Scott, Dr David Turner, Dr Tony Whiley and Mr Ted Winston.

If any of the following symbols appear in the Comments column, check for contamination before interpretation proceeds.

(D) = dust; (F) = fungicide; (N) = nutritional sprays.

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Almond (*Prunus amygdalus*)

Sampling

Growth stage: Mid to late Jan.

Plant part: Normal-sized leaves from non-fruiting spurs on spur bearing cultivars, or mid-shoot on current season's extension growth on young trees, or non-spur bearing cultivars. Take 4 leaves from each of 20 uniform trees of each cultivar.

How established: South Australian survey work by Robinson and Glenn (1981) based on the Californian method (e.g. Beutel *et al.* 1976). The procedure has been used commercially for some years in SA and found useful.

Nutrient	Concentration range							Comments
	Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	
N(%)	<1.8	1.8-1.9		2.0-2.5				In SA values in the marginal range are often seen when vigour is adequate and yield is satisfactory.
P(%)	<0.1			>0.1				
K(%)	<1.0	1.0-1.3		1.4-1.7				
Ca(%)				>2.0				
Mg(%)				>0.25				
Na(%)				<0.25		>0.25		Values are often high or excessive in non-irrigated orchards and those irrigated overhead.
Cl(%)				<0.3		>0.3		Values are often high or excessive in non-irrigated orchards and those irrigated overhead.
Cu(mg/kg)				>4				
Zn(mg/kg)	<15	15-24		25-30				The cultivars of almond Chellaston and White Brandis have a phytotoxic reaction to foliar applied zinc. Dormant zinc sprays can be applied safely.
Mn(mg/kg)				>20				
B(mg/kg)	<12	12-24		25-65		>85		Boron is mobile in almond (Brown and Hu 1996) so may accumulate in fruit if available in toxic quantities. Boron levels in leaves do not provide a good indication of toxicity. The following values for boron concentration in hulls at maturity are recommended in California but have not been verified elsewhere. Deficient 40-60 mg/kg; marginal 60-80 mg/kg; adequate 80-120 mg/kg; high >200 mg/kg (Brown 1996).

Apple (*Malus domestica*)

Sampling

Growth stage: Late Jan – mid-Feb.

Plant part: Entire leaf (include petiole) from a mid-shoot position on current season's extension growth. Take 4 leaves from around the periphery of each of 12-20 uniform trees of each cultivar.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
How established: Synthesis of the world literature (Leece 1976) and survey work in New South Wales (Weir and Cresswell 1993), Victoria (Baxter 1983), Western Australia (Cripps and Goldspink 1983). Where large discrepancies in criteria exist between sources, note has been made in the Comments column. See Weir, et al. (1990) for a good discussion of apple nutrition.													
N(%)		<1.6	1.6-1.9			2.0-2.4	2.5-3.0	>3.0					Values in the high range can lead to excessive vigour, poor fruit colour in red cultivars and storage problems. Optimum values vary from place to place, e.g. Vic. (Red Delicious) use 2.0-2.6%; WA (red cultivars) use 2.2-2.4%; WA (green cultivars) use 2.3-2.6%; NSW >2.4% expect storage problems.
P(%)		<0.10	0.10-0.14			0.15-0.20	0.21-0.30	>0.3					Sensitivity to low P varies from place to place. Cultivar differences occur. Marginal value for Red Delicious in Vic. begins at 0.12%. Deficiency may not be observed until <0.09% in some cases. Values up to 0.5% are quoted as satisfactory in Qld. Values >0.20% in NSW give no advantage. Recent data from WA (Cripps and Goldspink 1983) show that there is a yield advantage (with Granny Smith and Red Delicious at least) in operating in the 0.18-0.20% range and trees will die in the range 0.10-0.14%. Reasons for this difference in requirement for P are not clear.
K(%)		<0.8	0.8-1.1			1.2-1.5	1.6-2.0	>2.0					A wide range is possible without growth effects. High levels of K can have detrimental effects on fruit quality particularly if Ca is low. In NSW and Vic. no advantage is seen in levels exceeding 1.5% and those above about 2.0% may be excessive.
S(%)						0.2-0.4							Working value only - use with caution.
Ca(%)		<0.7	0.7-1.0			1.1-2.0	2.1-2.5	>2.5					Major effect of Ca is on fruit quality, and fruit analysis is needed to assess deficiency with any certainty. Fruit analysis standards for Australia have been suggested (Little and Holmes in press). Values <0.8% in leaves are considered deficient in Victoria. Green cultivars in WA are considered deficient if <0.4%. Where foliar sprays of Ca have been used high values can be expected so excess may not be meaningful.
Mg(%)		<0.15	0.15-0.20			0.21-0.25	0.26-0.45	>0.45					In WA deficiency occurs below 0.23% and high values are expected. Fruit analysis may be helpful. No toxicity symptom has been observed with leaf values >1.0%.
Na(%)						<0.02	0.02-0.5	>0.5					Na and Cl are not sensitive tests in some cases as other stresses seem to be involved in expression of salinity damage.
Cl(%)						<0.3	0.3-1.0	>1.0					In some situations values of 0.3% may indicate salinity problems. Where calcium chloride foliar sprays have been used excessive values are to be expected.
Cu(mg/kg)		<4	4-6			6-20	21-100						Trees with values as low as 4 mg/kg may not show deficiency. (F)
Zn(mg/kg)		<10	10-20			20-50	>50						Not always a sensitive test; look for symptoms, which may not occur until values as low as 5 mg/kg are reached. There are large numbers of highly productive orchards with marginal Zn concentrations in NSW. (F, N)
Mn(mg/kg)		<20	20-50			50-100	100-200	>200					High values are associated with a disorder known as 'bark measles', particularly in Red Delicious, and are usually related to acid soils. Toxicity can occur at values as low as 100 ppm in WA. (F, N)

Apple (*Malus domestica*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Fe(mg/kg)		<60	60-99					>500					(D)
B(mg/kg)		<15	15-20			21-40	40-200						In some situations deficiency may occur at higher values, e.g. WA < 24 mg/kg. The upper value of the high range is uncertain and may be as low as 80 mg/kg. Leaves are not reliable indicators of boron toxicity as boron is mobile in apple. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for boron redistribution and classic boron toxicity symptoms may occur.

Apricot (*Prunus armeniaca*)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: Jan or Feb. When values are to be compared with previous years, keep the sampling time for each variety constant in relation to its harvest period (M. Rettke - pers. comm.)													
Plant part: Mid-shoot leaves from current season's extension growth. Collect 4 leaves from each of 25 trees of one cultivar well spread through the planting.													
How established: Synthesis of the world literature verified in New South Wales and Victoria by Leece and van den Ende (1975) and in South Australia by a survey by Robinson and Nicholas (1983).													
N(%)		<1.7	1.7-2.3			2.4-3.0	3.1-4.0	>4.0					Orchards in the Riverland of SA are often in the marginal zone for N yet show adequate vigour.
P(%)		<0.09	0.09-0.13			0.14-0.25	0.26-0.40	>0.40					
K(%)		<1.0	1.0-1.9			2.0-3.5	3.6-4.0	>4.0					Trees on apricot seedling rootstock can be expected to show K concentrations in the excessive range. No detrimental effects have been noted in SA. Trees on plum rootstock grown on a similar site will show adequate values.
Ca(%)		<1.0	1.0-1.9			2.0-4.0	4.1-4.5	>4.5					
Mg(%)		<0.20	0.20-0.29			0.30-0.89	0.90-1.10	>1.10					
Na(%)						<0.02	0.02-0.50	>0.50					
Cl(%)						<0.3	0.3-1.0	>1.0					
Cu(mg/kg)		<3	3-4			5-16	17-30	>30					(F)
Zn(mg/kg)		<15	15-19			20-60	61-80	>80					Apricots show a severe phytotoxic reaction to foliar applications of certain forms of zinc, particularly zinc sulfate. Dormant season zinc applications are safe. (F)
Mn(mg/kg)		<20	20-39			40-160	161-400	>400					(F,N)
Fe(mg/kg)		<60	60-99			100-250	251-500	>500					(D)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
B(mg/kg)		<15	15-19			20-60	61-80	>80					Leaves are not reliable indicators of boron toxicity as boron is mobile in apricot. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for boron redistribution and classic boron toxicity symptoms may occur. (N)

Avocado (*Persea americana*)

Sampling

Growth stage: Summer flush (mid-April - mid-May in Queensland and northern New South Wales).							
Plant part: Recently matured fully expanded leaves (4-5 months old) from non-fruiting terminals. Take 6-8 leaves from each of 10 trees of one cultivar distributed throughout a planting.							
How established: Synthesis of local experience (e.g. Banks 1992) and literature values (Goodall *et al.* 1965; Embleton and Jones 1966; Lahav and Kadman 1980).							
N(%)	<1.6		1.6-2.0	>2.0		cv. Fuerte	
N(%)	<2.2		2.2-2.6	>2.6		cv. Hass	
P(%)	<0.05	0.05-0.08	0.08-0.25	0.26-0.3	>0.3%		
K(%)	<0.35	0.35-0.74	0.75-2.0	2.1-3.0	>3.0		
S(%)	<0.05	0.05-0.19	0.2-0.6				
Ca(%)	<0.5	0.5-0.9	1.0-3.0	3.1-4.0	>4.0		
Mg(%)	<0.15	0.15-0.24	0.25-0.80	0.81-1.0	>1.0		
Na(%)			<0.25				
Cl(%)			<0.25				
Cu(mg/kg)	<3	3-4	5-15	16-25	>25	(F)	
Zn(mg/kg)	<12	12-29	30-50	51-300	>300	(F,N)	
Mn(mg/kg)	<15	15-29	30-500	501-1000	>1000	(F,N)	
Fe(mg/kg)	<40	40-49	50-200			(D)	
B(mg/kg)		10-39	40-100		>100		
Mo(mg/kg)	<0.01	0.01-0.05	0.05-1.0				

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Banana (*Musa* spp.)

Sampling

Growth stage: During periods of active growth from medium-sized suckers with broad leaves. Weather conditions may influence the appropriate time of year.													
Plant part: Strips of leaf blade 15-20 cm wide from each side of the midrib of the 3rd youngest leaf.													
How established: Data from the literature modified by field and pot work in Alstonville, New South Wales by Turner (see Lahav and Turner 1983) and fieldwork at Carnarvon (Turner *et al.* 1989). Regional data were supplied by Weir (1983), Walduck (1983) and Incitec Ltd. (1994). The critical values presented are the tentative values of Lahav and Turner (1983). See also Lahav and Turner (1985).													
N(%)		<2.6	2.6-2.7	2.6		2.8-4.0							In North Qld and more tropical areas use 3.0-3.5% for the adequate range. Ripening may be enhanced with high soil applications of N (Srikul and Turner 1995).
P(%)		<0.13	0.13-0.19	0.2		0.2-0.25	>0.25						Very little evidence for a P response at any level.
K(%)		<2.5	2.5-3.0	3		3.1-4.0	>4.0						In North Qld and more tropical areas use 3.3-4.0% for the adequate range.
N/K						1:1.0-1:1.1							This ratio is associated with good bunch size and plant strength.
S(%)		<0.1	0.1-0.2	0.23		0.23-0.27	>0.27						
Ca(%)		<0.5	0.5-0.7	0.5		0.8-1.2	>1.25						In North Qld use 0.6-0.9% for the adequate range.
Mg(%)		<0.20	0.2-0.29	0.3		0.3-0.46	>0.46						Deficiency based on field observation.
Na(%)				0.005		0.01-0.10							
Cl(%)				0.6		0.8-0.9							
Cu(mg/kg)			3-6	9		7-20							(F)
Zn(mg/kg)		<14	14-20	18		21-35	>35						(F,N)
Mn(mg/kg)		<10		25		100-2200	4000-6000						(F,N) Strongly influenced by soil pH. On alkaline soils low values can be expected. At high concentrations fruit greenlife is reduced and ripening promoted (Turner and Barkus 1982).
Fe(mg/kg)				80		70-200							(D)
Al(mg/kg)						50-240							
B(mg/kg)		<10	10-19	11		20-80	81-300	>300					It is suspected that field deficiency occurs up to 30 mg/kg in South Qld; in North Qld adequate B is 15-50 mg/kg.
Mo(mg/kg)				1.5-3.2		>3.2							

Blackcurrant (*Ribes nigrum*)

Sampling

Growth stage: When fruit is ripening.
Plant part: Leaves from mid-third of current season's extension growth. Collect 2 leaves from each of 50 bushes well spread through a planting of one cultivar.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
How established: Based on UK work of Bould (1969) and found useful in Tasmania by Temple-Smith (1983). The source of the trace element figures (Incitec Ltd 1994) is not clear. The boron data are from Shorrocks (undated).													
N(%)		<2.6				2.9-3.0	>3.0						
P(%)		<0.25				0.26-0.3	>0.30						
K(%)		<1.0				1.5-2.0	>2.0						
Ca(%)		<1.0				2							
Mg(%)		<0.l				0.15-0.6	>0.6						
Cu(mg/kg)						5.0-10			(F)				
Zn(mg/kg)						20-40			(F,N)				
Mn(mg/kg)						30-100			(F,N)				
Fe(mg/kg)						50-100			(D)				
B(mg/kg)		<10	10-19			20-40							

Blueberry, High Bush (*Vaccinium corymbosum*)

Sampling

Growth stage: To correspond with US practice the sample should be taken in early Jan.						
Plant part: Youngest full-sized leaf from fruiting shoots (4th-6th nodes from the shoot tip). Take 5 leaves from each of 10 plants to represent a planting. Rinsing the leaves in distilled water is recommended.						
How established: Standards are directly taken from Doughty *et al.* (1981) and modified according to the data of Eck (1983). There is no known verification work in Australia.						
N(%)	<1.7	1.8-2.1	2.2-2.5	>2.5	Leaf levels above 2.10% can reduce yield.	
P(%)	<0.10	0.12-0.40	0.41-0.80	>0.80		
K(%)	<0.30	0.40-0.65	0.66-0.95	>0.95		
S(%)	<0.10	0.125-0.20				
Ca(%)	<0.13	0.4-0.8	0.9-1.0	>1.0		
Mg(%)	<0.08	0.12-0.25	0.26-0.45	>0.45		
Cu(mg/kg)	<5	5-20	21-100	>100	(F)	
Zn(mg/kg)	<8	8-30	31-80	>80	(F, N)	
Mn(mg/kg)	<23	50-350	351-450	>450	(F, N)	
Fe(mg/kg)	<60	60-200	201-400	>400	(D)	
B(mg/kg)	<20	30-70	71-200	>200		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			

Cashew (*Anacardium occidentale L.*)

Sampling

Growth stage: During the non-flowering vegetative flush.													
Plant part: Most recently matured hardened leaf on an actively growing shoot.													
How established: Synthesis of data published by Marchal (1987), Richards (1992) and Gopikumar and Aravindakshan (1986).													
N(%)			<1.38			2.40-2.58							
P(%)			<0.14			0.16-0.20							
K(%)			<0.26			1.10-1.29							
S(%)			<0.08			0.11-0.14							
Ca(%)			<0.11			0.24-0.75							
Mg(%)			<0.11			0.22-0.31							
Na(%)													
Cl(%)													
Cu(mg/kg)			<7			>7							
Zn(mg/kg)			<12			>20							Leaf Zn below 20 mg/kg said to be often associated with 'little leaf'. In Qld levels are usually below 15 mg/kg.
Mn(mg/kg)			<26			91-204							
Fe(mg/kg)			<92			148-165							
B(mg/kg)			<39			56-67							

Cherry (*Prunus avium*)

Sampling

Growth stage: Jan or Feb													
Plant part: Mid-shoot leaves from the middle of current season's extension growth. Collect 4 leaves per tree from 25 trees of one cultivar spread through the planting.													
How established: Field verification in New South Wales of literature values by Leece (1975b). Limited survey work in South Australia suggest that the values are useful. Work in New Zealand (Minard 1979) suggested that the zinc standard for deficiency should be lowered. See Righetti *et al.* (1988a, b) for a discussion of DRIS in relation to cherry nutrition.													
N(%)			<1.7	1.7-2.1		2.2-2.6	2.7-3.4	>3.4					
P(%)			<0.09	0.09-0.13		0.14-0.25	0.26-0.40	>0.40					
K(%)			<1.0	1.0-1.5		1.6-3.0	3.1-4.0	>4.0					
Ca(%)			<0.8	0.8-1.3		1.4-2.4	2.5-3.5	>3.5					

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Mg (%)		<0.20	0.20-0.29			0.30-0.80	0.81-1.10	>1.10					
Na(%)						<0.02	0.02-0.50	>0.50					
Cl(%)						<0.3	0.3-1.0	>1.0					
Cu(mg/kg)		<3	3-4			5-16	17-30	>30	(F)				
Zn(mg/kg)		<15	15-19			20-50	51-70	>70	A better deficiency standard may be <12 mg/kg. Monitor trees visually for deficiency symptoms. (F,N)				
Mn(mg/kg)		<20	20-39			40-160	161-400	>400	(F, N)				
Fe(mg/kg)		<60	60-99			100-250	251-500	>500	(D)				
B(mg/kg)		<15	15-19			20-60	61-80	>80	'Pitting' or 'cat's face' condition in Ron's seedlings associated with <25 mg/kg B in leaves and <10 mg/kg in fruit (Cresswell 1996). Leaves are not reliable indicators of boron toxicity as boron is mobile in cherry. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for boron redistribution and classic boron toxicity symptoms may occur.				

Chestnut (*Castanea sativa*)

Sampling

Growth stage: Jan - Feb.													
Plant parts: First fully expanded leaf on current season's wood.													
How established: Tentative standards for NSW developed by Weir and Cresswell (1993) based on local experience. Deficiency values are presented by Clark (1987) who quoted Japanese work.													
N(%)						2.4-2.9							
P(%)						0.14-0.30							
K(%)		0.4	0.5-0.6			0.8-1.6							
Ca(%)						0.6-1.4							
Mg(%)						0.25-0.70							
Na(%)						0-0.1							
Cl(%)						0-0.3	0.6	1.0-4.7					
Cu(mg/kg)						4-20							
Zn(mg/kg)						17-100							
Mn(mg/kg)						50-700	1200-3300						

Citrus (*Citrus* spp.)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: Sample when leaves are 5-7 months old.													
Plant part: Healthy mature leaves from the middle of non-fruiting spring extension growth. Take leaves at shoulder height. Avoid terminals which have made a subsequent growth flush. (This is more common in sub-tropical areas than inland districts.)													
How established: Based on the methods and standards of Embleton and co-workers in California (e.g. Embleton *et al.* 1978). Local survey work and data collected in commercial leaf analysis programs have led to slight modifications of the standards for different areas of Australia. Fact sheets and extension material for various districts are available and give details of local experience in most States (e.g. for South Australia, Robinson 1980; for Queensland, Owen-Turner 1995; for NSW, Weir and Cresswell 1993). Note that fruit size and rind, juice and flesh characteristics respond to variation in N,P and K concentration within the adequate and high ranges. Check original paper by Embleton *et al.* (1978). Note also that orange, lemon, grapefruit and mandarin may have slightly different requirements (Lee and Mayer 1993; Weir and Cresswell 1993) and that rootstock genotype exerts a strong influence (Taylor and Dimsey 1993).													
N(%)		<2.2	2.2-2.3		2.4-2.6								Consider vigour. In Riverland of SA values considered marginal in Qld. and NSW may be satisfactory. For grapefruit use 2.0-2.2% for adequate N and for lemons 2.2-2.6%.
P(%)		<0.09	0.09-0.11		0.12-0.16	0.17-0.25	>0.25						
K(%)		<0.4	0.4-0.69		0.7-1.5	1.6-2.3	>2.3						Trees on rough lemon rootstock in SA perform well at marginal K concentrations. In Qld. use 0.9-1.2% K for adequate.
S(%)		<0.14	0.14-0.20		0.21-0.4	0.41-0.5	>0.5						
Ca(%)		<1.6	1.6-2.9		3.0-6.0		>7.0						A wide range is permissible, but Ca in the excessive range suggests that the leaves were sampled incorrectly. Note that leaf Ca is not a suitable indicator of the likelihood of Ca-related rind disorders occurring (R. Storey and M. Treeby pers. comm).
Mg(%)		<0.16	0.16-0.25		0.26-0.6	0.7-1.2	>1.2						
Na(%)					<0.16	0.17-0.25	>0.25						High values suggest soil sodicity problem.
Cl(%)					<0.3	0.4-0.7	>0.70						High leaf levels in trees on Cl-accumulating rootstocks, such as trifoliate orange, do not necessarily cause problems.
Cu(mg/kg)		<3	3-5		6-10	11-15	>15						(F)
Zn(mg/kg)		<16	16-24		25-80	81-300	>300						(F,N)
Mn(mg/kg)		<16	16-24		25-80	81-300	>300						(F,N)
Fe(mg/kg)		<36	36-60		61-120	121-200	>200						(D,N)
B(mg/kg)		<21	21-30		31-100	101-260	>260						
Mo(mg/kg)		<0.06	0.06-0.09		0.10-3.0	3-100	>100						

Coconut (*Cocos nucifera*)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: Northern hemisphere - May, southern hemisphere - Nov.													
Plant part: Leaflets from the mid-region of the 14th leaf below the first fully opened leaf.													
How established: Synthesis of data from Manciot *et al.* (1979a, b), Jegnathan (1990) and Loganathan and Atputharajah (1986).													
N(%)						1.8-2.0							
P(%)						0.11-0.13							
K(%)						1.2-1.5							
Ca(%)		<0.1				0.3-0.54	>0.55						Loganathan & Atputharajah (1986) suggest that critical values for Ca will vary widely between sites.
Mg(%)		<0.17	0.17-0.24	0.24		0.25-0.30							
Cl(%)						0.30-0.40							

Coffee (*Coffee arabica*)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: In Papua New Guinea, Feb-Apr or Sept-Oct; collect sample before 11am. In Zimbabwe, Aug-Sept. In Brazil, mid-autumn. In all countries, samples are collected before fertilizer is applied. In Australia just before the rapid vegetative growth stage, (Sept-Dec) or again after harvesting (May-July).													
Plant part: 3rd or 4th pair of leaves from the tip of actively growing and bearing branches. (Do not count the terminal pair of leaves <50 mm long). Australian samples should be taken either from bearing or non-bearing branches, but not a mixture. Avoid leaves with insect damage. Take 4 pairs of leaves from at least 15 trees, midway between ground level and the topmost branches. Keep samples cool and wash in dilute acetic acid (28 ml in 5 L water) with a wetting agent (0.25 ml in 5 L) for 10 mins; drain and rinse in distilled water.													
How established: Synthesis by Winston (1996) of information from Queensland trials (Drinnan and Winston 1995; Winston *et al.* 1992; Winston and Young 1986a, b (unpublished data)); PNG (Southern 1966); Zimbabwe (Clowes and Hill 1981); and Brazil (Malavolta, 1976).													
N(%)		<2.2	2.2-2.4			2.5-3.0	>3.0						N fertilizer rates should increase as production increases.
P(%)		<0.1	0.1-0.14			0.15-0.2	>0.2						
K(%)		<1.5	1.5-2.0			2.1-2.6	>2.6						
SO_4-S(%)						0.02-0.1							
Ca(%)		<0.4	0.4-0.7			0.75-1.5	>1.5						
Mg(%)		<0.1	0.1-0.24			0.25-0.4	>0.4						
Cu(mg/kg)		<10	10-15			16-20	>20						(F)
Zn(mg/kg)		<10	10-14			15-30	>30						
Mn(mg/kg)		<25	25-49			50-100	101-700	>700					(F)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Coffee (*Coffee arabica*) (ctd)

Fe(mg/kg)		<40	40-69			70-200	>200		(D)				
B(mg/kg)		<25	25-39			40-100	101-200	>200					

Custard Apple (*Annona* spp.)

Sampling

Growth stage: Late Feb and early Mar.	
Plant part: Youngest mature leaf (3rd or 4th back from the growing point of non-fruiting shoots) in late Feb or early Mar after the second major growth flush. Collect 40 leaves to represent a uniform planting.	
How established: Based on tentative figures proposed for advisory work in Queensland by Sanewski (1988), George (1980), George and Haydon unpublished data (1996). See also work on sampling position by Dhandar and Barghava (1993).	
N(%)	2.4-3.0
P(%)	0.15-0.21
K(%)	1.0-1.5
Ca(%)	1.0-1.6
Mg(%)	0.26-0.50
Na(%)	<0.02
Cl(%)	<0.3
Cu(mg/kg)	10-22 (F)
Zn(mg/kg)	20-30 (F,N)
Mn(mg/kg)	52-125 (F,N)
Fe(mg/kg)	42-64
B(mg/kg)	48-80 (N)

Fig (*Ficus carica*)

Sampling

Growth stage: Mid-summer
Plant part: (Basal) 1st full-sized basal leaf from moderately vigorous shoots. (YFEL) Youngest fully expanded leaves on non-fruiting branches from the perimeter of trees at about 2.5 m height. Collect 50 leaves to represent a planting of one cultivar.
How established: The data for basal leaves were directly taken from Californian work of Proebsting and Tate (1952), Proebsting and Warner (1954) and Beutel *et al.* (1976). The data have been useful in problem solving in SA. Weir and Cresswell (1993) present a slightly different table based on problem solving work in NSW. The values for youngest fully expanded leaves represent part of the data on high yielding orchards of Calimyrna fig in California by Brown (1994) who also presents values for other sampling times, which would be useful in diagnostic work.

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N(%) (Basal)		<1.7	1.7-1.9			2.0-2.5	>2.5						
N(%) (YFEL)						2.1 ±0.3							
NO_3-N(%) (Basal)		<0.4							Below this level trees will respond to nitrogen.				
P(%) (Basal)						0.1-0.3							
P(%) (YFEL)						0.12 ±0.01							
K(%) (Basal)		<0.7	0.7-1.0			>1.0			Weir and Cresswell (1993) suggest an adequate range of 1.2-2.5%.				
K(%) (YFEL)						1.0 ±0.3							
Ca(%) (Basal)						>3.0							
Ca(%) (YFEL)						3.0 ±0.3							
Mg(%) (Basal)						>0.75							
Mg(%) (YFEL)						0.7 ±0.1							
Cu(mg/kg) (Basal)						>4							
Cu(mg/kg) (YFEL)						6 ±1							
Zn(mg/kg) (Basal)			<15			>15							
Zn(mg/kg) (YFEL)						12 ±2							
Mn(mg/kg) (Basal)						>20							
Mn(mg/kg) (YFEL)						90 ±25							
Fe(mg/kg) (YFEL)						110 ±12							
B(mg/kg) (Basal)								>300					
B(mg/kg) (YFEL)						100 ±45							

Grapevine (*Vitis vinifera*)

Sampling

Growth stage: When the majority of vines are flowering.		
Plant part: Petiole (leaf stalk) of a basal leaf opposite a bunch cluster. Take one petiole from each of 100 vines throughout a planting.		
How established: Californian standards of Cook (1966) and Christensen *et al.* (1978) modified following survey work in SA (Robinson and McCarthy, 1985) and field trials in Victoria and WA (Treeby and Nagarajah - unpublished data; Goldspink - unpublished data). Further work is in progress in Victoria to relate petiole standards to vine vigour (Treeby and Nagarajah 1996). Weir and Cresswell (1993) present leaf blade standards for both flowering and veraison sampling times which may also be useful.		
N(%)	0.8-1.10	Use 0.9-1.25% N for vines on Ramsey rootstock. In WA use 1.7- 2.2% N for Redglobe.

Grapevine (*Vitis vinifera*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
NO_3-N(mg/kg)		<340	340-499			500-1200	>1200						See reference list - Californian possibly toxic range (>2000 mg/kg) not supported by field observation in SA, Vic and WA. In WA use 2000-4000mg/kg as adequate for Redglobe. Data should be interpreted carefully in conjunction with %N, with more credence being placed on the latter. In many cases vigour or leaf colour may provide a more appropriate index of N status.
P(%)		<0.2	0.2-0.24			0.25-0.50	>0.50						Responsive vines in SA had values >0.1%, hence a critical value of 0.2% was suggested. For vines on Ramsey in Sunraysia use 0.30-0.55 as adequate. Note that cv. Pinot noir often has values lower than 0.2%.
K(%)		<1.0	1.0-1.7			1.8-3.0							For vines on Ramsey rootstock in Sunraysia use <3% and 3-4.5% for deficient and adequate levels. When deficiency is suspected, sample again 6-8 weeks later; select the blade of the most recently matured leaf. A value of <0.5% in petiole or 0.8% in blade plus petiole confirms deficiency. WA experience (Goldspink 1996) suggests that when %N is at the higher end of adequate, adequate range for K is >1.3%. There are large differences in petiole K concentrations between varieties.
Ca(%)						1.2-2.5							
Mg(%)		<0.3	0.3-0.39			>0.4							Values are often much higher than 0.4% with no observable toxic effects.
Na(%)								>0.5					
Cl(%)								>1.0-1.5					Based on survey work in SA and validated in field trials in NSW (Prior *et al.* 1992).[1] High petiole Cl of vines on Ramsey rootstock is indicative of water logging (Stevens and Harvey 1995). In the absence of other stresses vines appear to tolerate higher levels.
Fe(mg/kg)						>30							(D) In commercial services petioles are not normally washed so contamination from dust will usually lead to higher values. Leaf symptoms are a more useful diagnostic aid.
Cu(mg/kg)		<3	3-5			6-11							(F) Values >15 ppm are indicative of surface contamination with Cu sprays.
Zn(mg/kg)		<15	16-25			>26							(F, N) Deficient and marginal as used in commercial tissue analysis services.
Mn(mg/kg)		<20	20-29			30-60		>500					(F, N)
B(mg/kg)		<25	26-34			35-70	71-100	>100					If a value in the toxic range is obtained, follow up with a blade analysis: value above 150 mg/kg is indicative of B toxicity.

Guava (*Psidium guajava*)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: Nov - Dec.													
Plant part: 3rd pair of fully developed leaves from tip of fruiting terminal shoot (essentially mid-shoot leaves). Collect 20 leaves of one cultivar from trees throughout a planting. Leaves should be washed twice in distilled water.													
How established: Standards based on Du Plessis *et al.* (1973), Tassar *et al.* (1989), Marchal (1987), data found useful in Queensland (Cull 1983) and Incitec (1994). Some references from elsewhere include Garg and Khanduja (1976), Kumar and Pandey (1979), Khanduja and Garg (1980) and Shikhamany *et al.* (1986).													
N(%)				<1.4		1.4-1.6	>1.6						Excessive N often associated with irregular cropping (Marchal 1987).
P(%)						0.14-0.16							
K(%)						1.3-1.8							
Ca(%)						0.9-1.5							
Mg(%)						0.25-0.4							
Cu(mg/kg)						10-16							
Zn(mg/kg)						28-32							
Mn(mg/kg)						202-398							
Fe(mg/kg)						144-162							

Hazel-nut or Filbert (*Corylus avellana*)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: Feb or Mar													
Plant part: Collect sufficient leaves from mid-shoot leaves of current season's growth on one cultivar to represent the planting.													
How established: Standards based on US and Canadian literature (Painter 1963; Baron and Stebbins 1978; Chaplin and Dixon 1979; Kowalenko 1980; Kowalenko and Maas 1982). They have been found useful in limited work in Victoria (Peverill 1983). Weir and Cresswell (1993) provide a table based on their experience in NSW which in most cases fits within the limits suggested here. Righetti *et al.* (1988a, b) examine DRIS in relation to hazel-nut nutrition.													
N(%)				<2.0	2.0-2.1		2.2-2.4	2.5-3.0	>3.0				Weir and Cresswell (1993) suggest a slightly wider adequate range of 2.2-2.8%.
P(%)				<0.1	0.1-0.13		0.14-0.6		>0.65				
K(%)				<0.5	0.5-0.8		0.9-3.0	3.1-4.0	>4.0				
Ca(%)				<0.5	0.5-0.6		0.7-2.5	2.6-3.0	>3.0				
Mg(%)				<0.18	0.18-0.24		0.25-1.0	1.1-2.0	>2.0				
Na(%)							<0.1						Weir and Cresswell (1993)
Cl(%)							<0.5		>0.9				Weir and Cresswell (1993)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Hazel-nut or Filbert (*Corylus avellana*) (ctd)

Cu(mg/kg)				<1	1-2		3-50	51-100	>100	(F)			
Zn(mg/kg)				<10	10-15		16-80	80-300	>300	(F)			
Mn(mg/kg)				<20	20-25		26-800	800-1500	>1500	(F)			
Fe(mg/kg)				<40	40-50		51-400	400-500	>500	(D)			
B(mg/kg)				<25	25-30		31-75	76-100	>100				

Kiwi Fruit (*Actinidia chinensis*)

Sampling

Growth stage: Late Feb.													
Plant part: Take 1st leaf above the fruit towards the growing tip and collect a minimum of 10 leaves.													
How established: Weir and Cresswell (1993) from published New Zealand data and surveys, and field diagnosis in NSW (Cresswell 1989). An extensive reference list is available in Cresswell (1989).													
N(%)				<1.5	1.5-2.1		2.2-3.0	3.1-5.5	>5.5				Buwalda *et al.* (1990) suggest a value of 2.5% in YFEL on fruiting shoots 20 weeks after bud burst. Prasad *et al.* (1987) consider 90ppm NO_3-N in petiole sap desirable in December (NZ) with little or no nitrate at harvest. Greater than 180 ppm NO_3-N is required for maximum shoot growth.
P(%)				<0.13	0.13-0.17		0.18-0.25	>0.25					
K(%)				<0.7	0.8-1.7		1.8-3.0						For YFEL on non-fruiting shoots 6 weeks after bud burst. Greater than 2.5% K may be required for maximum yield (Smith *et al.* 1987).
S(%)							0.25-0.45						
Ca(%)				<0.2			2.0-4.0						
Mg(%)				<0.10	0.15-0.24		0.3-0.7	0.8-1.0					For YFEL on non-fruiting shoots 4 weeks after bud burst <0.2% is considered deficient (Clark and Smith 1987).
Na(%)							<0.05						
Cl(%)				<0.2			0.4-1.0	1.1-1.5	>1.6				A critical value of 0.2% has been established for YFEL in kiwi fruit by Smith *et al.* (1987b). Prasad *et al.* (1993) have defined excess as >1.5% in YFEL beyond the last fruit in early December (NZ).
Cu(mg/kg)				<3	3-10		10-25						
Zn(mg/kg)				<12	12-14		15-28		>1100				N, F
Mn(mg/kg)				<30	30-49		50-400	401-1500	>1500				N, F

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Fe(mg/kg)		<60				80-200							Leaf analysis is not a reliable guide.
B(mg/kg)		<20				30-60		>100					For 2nd leaf beyond fruit cluster mid season, Smith and Clark (1989) suggest a high range >80 mg/kg.
Mo(mg/kg)						0.04-0.2							

Lychee (*Litchi chinensis*)

Sampling

Growth stage: Sample leaves behind flower cluster 1-2 weeks after panicle emergence during May-July (in south east Queensland).													
Plant part: Most recently matured leaf behind the fruiting panicle or behind the flush in non-bearing trees. Avoid insect damaged trees. Collect 4 pairs of leaves from each of 20 trees. May be washed in dilute acetic acid and rinsed in distilled water.													
How established: Survey data collected from orchards in south east Queensland (Menzel *et al.* 1992). Data in Menzel *et al.* (1995) also useful.													
N(%)						1.5-1.8	1.9-2.4						
P(%)						0.14-0.22							
K(%)						0.7-1.1							
S(%)						0.10-0.16							
Ca(%)						0.6-1.0							
Mg(%)						0.3-0.5							
Na(%)						<0.05							
Cl(%)						<0.25							
Cu(mg/kg)						10-25							
Zn(mg/kg)						15-30							
Mn(mg/kg)						100-250							
Fe(mg/kg)						50-100							
B(mg/kg)						25-60							

Macadamia (*Macadamia integrifolia* and *M. tetraphylla*)

Sampling

Growth stage: Summer flush leaves should be sampled in spring when leaf nutrient levels are more stable and leaves are 6-7 months old, and before new growth from terminal buds exceeds 1cm in length (Stephenson *et al.* 1986).
Plant part: Mature leaf from 2nd or 3rd whorl of current season's growth. Collect 50-100 leaves from 10-20 trees of one cultivar spread through the planting. Leaves should be washed by lightly rubbing in deionised water and rinsing.
How established: Survey work in Queensland by Stephenson and Cull (1986) and data published by Stephenson and Gallagher (1987, 1989) and Aitken *et al.* (1992).

Macadamia (*Macadamia integrifolia* and *M. tetraphylla*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)		<1.2				1.3-1.4	>1.4						
P(%)		<0.05	0.05-0.07			0.08-0.11	0.12-0.14	>0.15					
K(%)		<0.40	0.40-0.65			0.66-0.80	>0.80						
S(%)			<0.17			0.17-0.25							
Ca(%)		<0.4	0.4-0.64			0.65-0.90	>1.0						
Mg(%)		<0.06	0.06-0.08			0.09-0.11	>0.11						
Na(%)						<0.01							
Cl(%)						<0.03							
Cu(mg/kg)		<3	3-5			5-10							
Zn(mg/kg)		<10	10-14			15-50	>50						
Mn(mg/kg)		<20	20-99			100-1000	>1500						
Fe(mg/kg)						20-200							Fe/P ratio 0.06 indicates adequate Fe, lower ratio indicative of P-induced Fe deficiency (Hue and Nakamura 1988).
B(mg/kg)		<20	20-40			50-80	80-90	>100					

Mango (*Mangifera indica*)

Sampling

Growth stage: In Florida, after flowering collect leaves equally from shoots with and without fruits. South Africa, collect in November; in Israel, collect in autumn; and in North Queensland, collect after flowering. Also in Queensland, Incitec recommend sampling immediately before flowering. Leaves sampled from non-flowering shoots generally have higher nutrient concentrations that leaves from fruiting shoots.
Plant part: There is no one accepted sampling procedure. In Florida, 60 leaves in total are collected from the 2nd or 3rd position back from the base of a bloom panicle. In South Africa, young leaves are taken from fruit bearing branches (most recent vegetative flush carrying fruit). In Israel, leaves are collected from the 6-month-old spring flush. In North Queensland, leaves are taken from non-bearing branches. Incitec recommend sampling from the latest mature flush (take 50 leaves) (Incitec 1994). A dilute acetic acid wash and distilled water rinse is suggested.
How established: The method and time of sampling varies widely. The values most commonly obtained in tissue analysis in various countries and regions are presented, but where large deviations from the common values occur, note has been made of them in the Comments column. The data were collected by Cull (1983) and Winston (1983) and modified according to the data published by Rao and Mukherjee (1988) and Catchpoole and Bally (1996). References from Florida are Young and Koo (1969, 1974). Indian work on leaf sampling procedures can be found through references quoted in Pathak and Pandey (1978) and Chadha *et al.* (1980).

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
N(%)				0.9		1.0-1.5							The Israeli method requires values >1.7%, and Smith (1992) suggests 1.2-1.4% for young trees and 1.4-1.5% for mature trees in South Africa.
P(%)				0.12		0.13-0.18							
K(%)		<0.25	0.25-0.29			0.3-1.2							The Incitec method gives an adequate range to 2.0%
S(%)						0.06-0.22							

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Ca(%)						2.0-3.5 (acid soil) 3.0-5.0 (alkaline soil)							The Incitec method gives lower values (1.0-3.0%) for all soil types. Cultivars with jelly seed disorder require the higher of the values quoted.
Mg(%)						0.2-0.4							A wide range seems permissible. Indian data suggest values up to 0.75% are not excessive (Samra *et al.* 1978).
Na(%)						<0.2		>0.4					
Cl(%)								>0.5					Excessive range with Incitec method begins at 0.2%.
Cu(mg/kg)						10-20							(D, F)
Zn(mg/kg)		<15	15-19	20		20-100							
Mn(mg/kg)						60-200							
Fe(mg/kg)						70-100							
B(mg/kg)						30-100							

Oil Palm (*Elaeis guineensis*)

Sampling

Plant part: From frond 17, about 6 leaflets (equal number from the upper and lower rank). The central 15 cm length of each sub-sampled. Twenty trees should be sampled to represent up to about 25 ha. Sample frond 3 in young plantings.		
How established: The 'tentative optimum' levels of Rosenquist (1966) who reviewed the work of Coulter (1958) and Prevot and Ollagnier (1956) have been accepted.		
N(%)	2.8-3.0	Frond 3
N(%)	2.7-2.8	Frond 17
P(%)	0.19-0.21	Frond 3
P(%)	0.18-0.19	Frond 17
K(%)	1.5-1.8	Frond 3
K(%)	1.3	Frond 17
Ca(%)	0.3-0.5	Frond 3
Ca(%)	≤0.6	Frond 17
Mg(%)	0.3-0.35	Frond 3 and Frond 17
Cu(mg/kg)	5-8	Frond 17
Zn(mg/kg)	15-20	Frond 17
Mn(mg/kg)	150-200	Frond 17

Nutrient	Concentration range						Comments
	Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic or Excessive	
Oil Palm (*Elaeis guineensis*) (ctd)							
Mo(mg/kg)				0.5-1.0			Frond 17
B(mg/kg)				10-20			Frond 17
Olive (*Olea europea*)							
Sampling							
Growth stage: Jan							
Plant part: Fully expanded basal to mid-shoot leaves. Collect 4 leaves per tree from 25 trees of one cultivar to represent the planting.							
How established: Standards based on Californian experiments and observations and found useful in South Australia for diagnostic purposes. References include Hartmann *et al.* (1966) and Beutel *et al.* (1976).							
N (%)	<1.4			1.5-2.0			
P (%)				0.1-0.3			
K (%)	<0.4	0.4-0.8		>0.8			
Ca(%)				>1.0			
Mg(%)				>0.10			
Na(%)						>0.2	
Cl(%)						>0.5	
Cu(mg/kg)				>4			(F)
Zn(mg/kg)				10-30			(N)
Mn(mg/kg)				>20			(F,N)
B(mg/kg)	<14	14-18		19-150		>185	Leaves are not reliable indicators of boron toxicity as boron is mobile in olive. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for boron redistribution and classic boron toxicity symptoms may occur.
Papaw (*Carica papaya*)							
Sampling							
Growth stage: Spring							
Plant part: Petiole of the youngest fully expanded leaf subtending the most recently opened flower.							
How established: Derived from survey work in the field by Chapman *et al.* (1980) and subsequently in a commercial advisory service in Queensland by Incitec Ltd. (1994).							

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
N (%)						1.3-2.5							
P (%)						0.2-0.4							
K(%)						3.0-6.0							
S(%)						0.3-0.8							
Ca(%)						1.0-2.5							
Mg(%)						0.5-1.5							
Na(%)						<0.20							
Cl(%)						<4.0							
Cu(mg/kg)						4-10							
Zn(mg/kg)						10-30							
Mn(mg/kg)						25-150							
Fe(mg/kg)						20-80							
B(mg/kg)						20-50							

Passionfruit (*Passiflora* spp.)

Sampling

Growth stage: May-Aug, before commencement of active vegetative growth.				
Plant part: Youngest fully expanded leaf on well-developed, actively growing laterals. Collect 120 leaves to represent a planting (6 leaves from east or northern side of vine, sampling 20 vines per block).				
How established: Survey data (Menzel *et al.* 1993). Weir and Cresswell (1993) suggest tentative values for sampling during summer which are in some cases quite different. Take care in interpretation.				
N(%)	<4.25	4.25-5.25	>5.25	
P(%)	<0.15	0.15-0.25	>0.35	Summer values may be higher
K(%)	<2.0	2.0-3.0	>3.0	
S(%)		0.2-0.4		
Ca(%)	<1.5	1.75-2.75	>3.0	Summer values may be much lower (0.5-1.5%)
Mg(%)	<0.25	0.3-0.4	>0.4	Summer values may be higher
Na(%)		<0.08	>0.2	Summer values may be higher
Cl(%)		<2.0	>2.5	The normal value in summer may be lower (<1.2%)
Cu(mg/kg)	<5	5-20	>20	
Zn(mg/kg)	<45	50-80	>80	Lower values are noted in summer (25-100mg/kg)
Mn(mg/kg)	<50	100-500	1000	Lower values are noted in summer (25-350mg/kg)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Passionfruit (*Passiflora* spp.) (ctd)

Fe(mg/kg)			<100			100-200	>200						
B(mg/kg)						40-60							Lower values are noted in summer (25-60 mg/kg)

Peach (*Prunus persica*)

Sampling

Growth stage: Jan or Feb. It is probable that earlier sampling is required in very early areas (e.g. Western Australia) but no comparative studies have been done. Early low chill peaches in NSW and Qld are sampled two weeks after harvest.													
Plant part: Leaves from the middle of current season's extension growth. Collect four leaves per tree from 25 trees of one cultivar spread through the planting.													
How established: Leece *et al.* (1971) (see also Leece 1976) reviewed the world literature and carried out validation work in New South Wales; this work was extended by Leece and Barkus (1974). Nicholas and Robinson (1977) surveyed orchards in South Australia and Cripps and Goldspink (1983) refer to work in progress in Western Australia. Tentative standards for low chill early peaches sampled two weeks after harvest are different from those accepted for the standard sampling time. Treatment with paclobutrazol has been found to change tree leaf nutrient concentrations (Huett *et al.* 1997).													
N(%)			<2.4	2.4-2.9		3.0-3.5	3.6-4.2	>4.2					Check vigour. For improved quality keep trees in SA and NSW in marginal range. In WA (south-western region) use <2.5% for deficiency. Adequate values for low chill peaches are in the range 3.0-3.6.
P(%)			<0.09	0.09-0.13		0.14-0.25	0.26-0.40	>0.40					In WA (south-western region) use <0.11% for deficiency and 0.17-0.26% for adequate range. For low chill peaches P values in the 'high' range may be needed.
K(%)			<1.0	1.0-1.9		2.0-3.0	3.1-4.0	>4.0					For low chill peaches K values around 2.4-2.6% seem to be needed.
S(%)						0.2-0.4							
Ca(%)			<1.0	1.0-1.7		1.8-2.7	2.8-3.5	>3.5					For low chill peaches Ca values in the 'low' range may be adequate.
Mg(%)			<0.20	0.20-0.29		0.30-0.80	0.81-1.10	>1.1					In WA (south-western region) use <0.3% for deficiency and 0.48-0.7% for adequate range.
Na(%)						<0.02	0.02-0.5	>0.5					Response to salinity can be modified by presence of other stresses.
Cl(%)						<0.30	0.3-1.0	>1.0					
Cu(mg/kg)			<3	3-4		5-16	17-30	>30					In WA use <4 for deficiency. (F)
Zn(mg/kg)			<15	15-19		20-50	51-70	>70					(F,N)
Mn(mg/kg)			<20	20-39		40-160	161-400	>400					In WA (south-western region) use <25 mg/kg for deficiency and 31-50 mg/kg for adequate range. Higher values are noted in early low chill peaches in Queensland. (F,N)
Fe(mg/kg)			<60	60-99		100-250	251-500	>500					Some varieties (e.g. Flordaprince) may show low values in the low range. (D)

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
B(mg/kg)		<15	15-19			20-60	61-80	>80					Leaves are not reliable indicators of boron toxicity as boron is mobile in peach. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for boron redistribution and classic boron toxicity symptoms may occur.

Pear (*Pyrus communis*)

Sampling

Growth stage: Late Jan - Mid Feb

Plant part: Entire leaf, including petiole, from a mid-shoot position on current season's extension growth. Take 4 leaves from around the periphery of each of 12-20 uniform trees of each cultivar.

How established: Synthesis of world literature, and survey work by Van den Ende and Leece (1975) and local verification work in New South Wales (e.g. Weir and Cresswell 1993), Victoria (Baxter 1983), Western Australia (Cripps and Goldspink 1983). Where large discrepancies in criteria exist between sources, note has been made in the Comments column. See Weir, et al. (1990) for a good discussion of pear nutrition. See also Clark and Kajiura (1986) for some useful information on Nashi (Asian pear).

N(%)	<1.8	1.8-2.2	2.3-2.7	2.8-3.5	>3.5	Relate N status to vigour. The adequate range is wide and varies from place to place (in Vic use 2.0-2.6%).
P(%)	<0.10	0.10-0.13	0.14-0.20	0.21-0.30	>0.30	In Vic use <0.12% for deficiency.
K(%)	<0.7	0.7-1.1	1.2-2.0	>2.0		Trees behave normally over a wide range.
S(%)	<0.1	0.1-0.16	0.17-0.26	>0.26		Working values only-use caution when interpreting.
Ca(%)	<0.8	0.8-1.4	1.5-2.2	2.2-3.7		A very wide range is possible.
Mg(%)	<0.13	0.13-0.29	0.3-0.5	0.51-0.90	>0.90	In WA use 0.3-0.5% for the adequate range and 0.51-1.0% for the high range.
Na(%)			<0.01	0.01-0.02	>0.02	Toxicity varies with soil aeration and other stresses. Values as high as 0.5% may be tolerated if water logging is not involved.
Cl(%)			<0.05	0.05-0.10	>0.10	In some situations values as low as 0.2% may indicate a salinity problem. In others values as high as 0.4% may be tolerated. As with Na water logging may be involved.
Cu(mg/kg)	<5	5-8	9-20	21-50	>50	(F)
Zn(mg/kg)	<10	10-19	20-50	>50		(F, N)
Mn(mg/kg)	<20	20-59	60-120	121-220	>220	(F, N)
Fe(mg/kg)		<60	60-200	>200		(D)
B(mg/kg)	<10	10-19	20-40	>40		Leaves are not reliable indicators of boron toxicity as boron is mobile in pear. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for boron redistribution and classic boron toxicity symptoms may occur.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Pecan (*Carya illinoensis*)

Sampling

Growth stage: Shell hardening to early kernel development (Feb in New South Wales).													
Plant part: Pairs of leaflets from midway along youngest fully expanded leaf on fruiting wood. Take 10 leaflets from each of 10 trees to represent a planting. Select from branches up to 2 m above the ground.													
How established: Compiled by Cresswell (1983) who used the method of Jones (1974) in New South Wales, see also Weir and Cresswell (1993). Other useful references include Worley (1969, 1991), Jones (1972), O'Barr (1977) and Sparks (1978).													
N(%)		<1.7	1.7-2.4			2.5-3.0	3.1-3.9	>3.9					
P(%)			<0.12			0.12-0.3	0.3-0.4	>0.4					
K(%)		<0.36	0.36-0.74			0.75-1.5	1.6-3.5	>3.5					
S(%)			<0.15			0.15-0.25	>2.5						
Ca(%)			<0.7			0.7-2.5	2.6-3.2						
Mg(%)		<0.16	0.17-0.29			0.3-0.7	0.8-0.9	>0.9					
Na(%)						<0.1	0.11-0.4						
Cl(%)						<0.5	0.51-1.0						
Cu(mg/kg)			2-4			5-50	51-350		(F)				
Zn(mg/kg)		<30	30-49			50-100	101-250		(F)				
Mn(mg/kg)		<100	100-149			150-500	501-2500	>2500	(F)				
Fe(mg/kg)			<50			50-300			(D)				
B(mg/kg)		<6	6-19			20-50	51-650	>650					

Persimmon (*Diospyros* spp.)

Sampling

Growth stage: The Australian standards are based on samples collected at anthesis. New Zealand and Japanese data are based on samples collected about two months prior to harvest.													
Plant part: Mature leaves. Samples from non-fruiting shoots.													
How established: The Australian standards are based on survey work in south-east Queensland by George *et al.* (1995) who also followed leaf nutrient levels through the growing season to help decide when to sample. Deficiency levels established in sand culture (Sato *et al.* 1955) except for Mg and Mn derived from field surveys of Fuyu orchards in New Zealand (Clark 1985). Boron values from Eaton (1944). Other standards have been developed by Sato *et al.* (1955) and Nakamura (1972) in orchard surveys in Japan and by Clark and Smith (1990) in NZ.													
N(%)		0.93				2.5-3.5					Aust		
						2.22-3.15					Japan		

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
						1.57-2.0			NZ				
P(%)		0.05				0.2-0.3			Aust				
						0.12-0.16			Japan				
						0.10-0.19			NZ				
K(%)		0.42				2.0-3.5			Aust				
						1.47-3.86			Japan				
						2.4-3.7			NZ				
S(%)						0.2-0.5			Aust				
						0.21-0.44			NZ				
Mg(%)		<0.14				0.25-0.42			Aust				
						0.22-0.77			Japan				
						0.17-0.46			NZ				
Na(%)						0.01-0.02			Aust				
						0.1-0.2			NZ				
Ca(%)		0.26				1.4-2.8			Aust				
						1.01-2.78			Japan				
						1.35-3.11			NZ				
Cu(mg/kg)						1-14			Aust				
						1-8			NZ				
Zn(mg/kg)						16-25			Aust				
						5-36			NZ				
Mn(mg/kg)		<30				350-1200			Aust (F)				
						70-1844			Japan				
						238-928			NZ				
Fe(mg/kg)						60-100			Aust				
						56-124			NZ				
B(mg/kg)		<40				30-70		>389	Aust. Nutrient solutions containing >1 mg/L B are likely to be toxic.				
						15-52			Japan				
						48-93			NZ				

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Pineapple (*Ananas comosus*)

Sampling

Growth stage: Plants should be sampled at 6, 3 and 1 month prior to flower induction. This applies to plants and ratoon suckers. Plant part: During vegetative growth, sample the most recent fully matured leaf of plants. This is known as the D leaf, and is generally the oldest leaf on the plant. The sample should not be taken soon after fertiliser application. Collect 10 leaves from throughout the area tested. Stack one leaf inside another, and cut across the bundle, retaining only the bottom 150mm of the leaves. The analyses are done only on the basal white tissue.						
How established: The major elements (N, P, K, Ca, Mg) standards shown were developed by the Pineapple Research Institute in Hawaii, and have been adapted to local conditions by Golden Circle Ltd. Work has also been conducted by Queensland Department of Primary Industries in co-operation with Incitec Ltd. Queensland. More detail on sampling can be obtained from Golden Circle Ltd. or Incitec Ltd.						
N(%)						Tissue levels are an unreliable indicator of N status.
P(%)				0.18-0.22	0.30	Level increases with age
K(%)	0.20	0.25	0.35	0.32-0.38	>0.42	Level falls at plant maturity - near flowering
Ca(%)	<0.004	0.007-0.011	0.015	0.013-0.018		Tends to drop naturally during winter
Mg(%)	<0.01	0.014-0.020	0.025	0.023-0.027	>0.04	Antagonistic to K level
Na(%)				0.004-0.015		
Cl(%)				0.2-0.8		
Cu(mg/kg)				10-50		
Zn(mg/kg)				15-70		
Mn(mg/kg)				150-400		
Fe(mg/kg)				80-150		

Pistachio (*Pistacia vera*)

Sampling

Growth stage: During a one-month period prior to harvest.		
Plant part: Single leaflets selected from the terminal or 2 opposite sub-terminal leaflets of leaves located in the middle of non-bearing branches. Select at least 6 leaflets per tree from 5 trees chosen to represent an area. A distilled water wash is suggested.		
How established: Synthesis of US information found useful in orchard monitoring and problem solving in Australia. References include Uriu and Crane (1977), Opitz (1975 and undated) and Brown (1995). Weir and Cresswell (1993) also present a table of tentative standards based on diagnostic sampling. Their suggestions for N, P, Ca, Mg are lower than those proposed for California.		
N(%)	2.3	2.5-2.9
P(%)	0.14	0.14-0.17
K(%)	1.0	1.0-2.0
Ca(%)		1.3-4.0

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
Mg(%)						0.6-1.2							
Cl(%)						0.1-0.3							
Cu(mg/kg)				4		6-10							
Zn(mg/kg)						10-15			(F)				
Mn(mg/kg)				30		30-80			(F)				
B(mg/kg)				90		120-250							Boron is important for fruit set in pistachio and it seems important to work at a relatively high leaf value.

Plum (*Prunus* spp.)

Sampling

Growth stage: Jan-Feb for d'Agen plum and Dec-Jan for Japanese plums.						
Plant part: Leaves from the middle of current season's extension growth. Collect 4 leaves per tree from 25 trees of one cultivar spread through the planting.						
How established: Survey work in 3 regions of New South Wales by Leece (1975a) to adapt overseas data to local conditions.						
N(%)	<1.7	1.7-2.3	2.4-3.0	3.1-4.0	>4.0	
P(%)	<0.09	0.09-0.13	0.14-0.25	0.26-0.4	>0.40	
K(%)	<1.0	1.0-1.5	1.6-3.0	3.1-4.0	>4.0	
Ca(%)	<1.0	1.0-1.4	1.5-3.0	3.1-4.0	>4.0	
Mg(%)	<0.20	0.20-0.29	0.3-0.8	0.81-1.10	>1.10	
Na(%)			<0.02	0.02-0.50	>0.50	
Cl(%)			<0.3	0.3-0.6	>0.6	
Cu(mg/kg)	<4	4-5	6-16	17-30	>30	(F)
Zn(mg/kg)	<15	15-19	20-50	51-70	>70	(F)
Mn(mg/kg)	<20	20-39	40-160	161-400	>400	(F)
Fe(mg/kg)	<60	60-99	100-250	251-500	>500	(D)
B(mg/kg)	<20	20-24	25-60	61-80	>80	Leaves are not reliable indicators of boron toxicity as B is mobile in plum. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for B redistribution and classic B toxicity symptoms may occur.

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments

Raspberry, Red (*Rubus idaeus*)

Sampling

Growth stage: Two to three weeks after final pick.													
Plant part: 5th-12th leaves from the terminal 150mm of the primocane.													
How established: Synthesis of North American (cv. Williamette) and British (cv. Lloyd George) data by Temple-Smith (1983). The important references are Bould (1968), Chaplin (1980), Chaplin and Martin (1980), Hughes *et al.* (1979), John *et al.* (1976a), Kowalenko (1981) and Ramig and Vandecaveye (1950). Weir and Cresswell (1993) present a table which calls for slightly lower P, K, Mg and higher Ca values.													
N(%)				2.3	2.4-4.0								
P(%)	<0.2			0.2	0.3-0.6								
K(%)	<1.0			1.5	1.5-3.0								
Ca(%)	<0.5				0.6-2.5								
Mg(%)	<0.25			0.3	0.4-1.0								
Cu(mg/kg)	<1				2-50								(F)
Zn(mg/kg)	<13				34-80								(F,N)
Mn(mg/kg)	<20				80-300		>1000						(F,N)
B(mg/kg)					25-80								Leaves are not reliable indicators of B toxicity as B is mobile in raspberry. Fruit samples collected at maturity may be more reliable (Brown 1996). Standards are not presently available. In non-fruiting or slow growing trees there may be no opportunities for B redistribution and classic B toxicity symptoms may occur. Kowalenko (1981) found inconsistent B concentrations in leaves within and between seasons and casts doubt on the use of B levels in leaves for predicting B fertilizer requirement. The fact that B is mobile may explain this observation.

Strawberry (*Fragaria* sp.)

Sampling

Growth stage: During growth.													
Plant part: Blade (Ulrich *et al.* 1980) or blade plus petiole (Vock 1991) of a young mature leaf. Select 30-40 leaves of one cultivar to represent a planting.													
How established: The critical values below are derived from Californian work summarised in Ulrich *et al.* (1980). The other values in the table are mostly drawn from Vock (1991) for Tioga. Ulrich *et al.* (1980) also report values for nutrient concentrations in petioles. Their booklet contains a comprehensive colour atlas of strawberry deficiency symptoms. John *et al.* (1976b) describe genotypic variation in leaf nutrient concentration and distribution between blade and petiole. Tissue analysis should, therefore, be interpreted cautiously. John *et al.* (1975) suggested that post harvest sampling may be most useful. Weir and Cresswell (1993) provide a set of values which calls for higher N and lower K, Ca, Mg. Further local validation work is needed.													
N(%)				2.8	2.0-2.5								Note wide variation between Ulrich's critical value and the range suggested by Vock.
NO_3-N					<800								
P(%)	<0.1	0.1-0.3		0.1	0.3-0.5								

Nutrient	Growth Stage	Plant Part	How established	Concentration range							Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic			
K(%)		<1.0	1.0-2.0	1	2.0-3.0								
S(%)				0.1	0.1-0.2								
Ca(%)		<0.3	0.3-1.5	0.3	1.5-2.0								
Mg(%)		<0.2	0.2-0.4	0.2	0.4-0.6								
Na(%)					<0.3			>0.3					
Cl(%)					0.1-0.5			>0.5					
Cu(mg/kg)		<3		3	5-10				(F)				
Zn(mg/kg)		<20		20	30-50				(F,N)				
Mn(mg/kg)		<30	30-50	30	50-350				(F, N)				
Fe(mg/kg)[1]		<50		50	50-150				(D)				
B(mg/kg)		<25		25	25-50								
Mo(mg/kg)		<0.5		0.5	>0.5								

Tamarillo (*Cyphomandra betacea*)

Sampling

Growth stage: 12-20 weeks after appearance of leaves in spring.	
Plant part: Youngest mature blades plus petioles. Approximately 30-40 leaves to represent the planting.	
How established: Synthesis of New Zealand data (Clark *et al.* (1989) summarised by Richards and Dawson (1994)).	
N(%)	3.5-4.3
P(%)	0.2-0.3
K(%)	4.0-5.0
Ca(%)	1.2-2.0
Mg(%)	0.32-0.42
S(%)	0.25-0.35
Cl(%)	0.2-0.3
Cu(mg/kg)	20-25
Zn(mg/kg)	25-32
Mn(mg/kg)	100-150
Fe(mg/kg)	100-150
B(mg/kg)	20-30

Walnut (*Juglans regia*)

Sampling

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Toxic	Country	Ref	Comments
Growth stage: Dec or Jan.													
Plant part: Terminal leaflet of basal leaves from shoots of average vigour. Collect 60-100 leaves of one cultivar to represent the plantings, avoiding atypical trees.													
How established: Synthesis of Californian data. Useful references are Serr (1960), Proebsting and Serr (1966), Serr (undated), Beutel *et al.* (1976) and Klein *et al.* (1991). Weir and Cresswell (1993) present some tentative standard values based on diagnostic work in Australia which are similar to those shown here.													
N(%)				<2.0			2.5-3.3						
P(%)				<0.09			0.1-0.3						
K(%)				<0.9			1.2-3.0						
Ca(%)							~1.2						
Mg(%)				<0.2			0.3-1.0						
Na(%)								>0.1					
Cl(%)								>0.3					
Cu(mg/kg)				1-3			4-20		(F)				
Zn(mg/kg)				<15			20-200		(F)				
Mn(mg/kg)				<20	20-30		30-350		(F)				
B(mg/kg)				<20	20-35		35-300	>300					

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VEGETABLES

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8. VEGETABLES

D.O. Huett, N.A. Maier, L.A. Sparrow and T.J. Piggott

INTRODUCTION

Vegetable crops have a high nutrient demand. Nutrient concentrations in plant parts are very sensitive to conditions which affect growth rate and nutrient supply. Plant age (sampling date) and plant part (leaf age) will also account for large differences in nutrient composition. In compiling diagnostic criteria, a range (for example of adequate concentrations) will reflect some of these variables. Thus, wherever possible, criteria in this chapter have been presented for a specific species, stage of growth and leaf age to minimise variance. For vegetable crops, diagnosis of nutrient status is often based on a specific plant part, and for many crops several sampling times are available. Plant part, therefore, has been used to group the criteria for the different times of sampling used in the tables.

Before 1986, the Australian data for vegetables (mostly unpublished from surveys) was augmented with overseas published data. Two key references were used:

- Soil and Plant Tissue Testing in California. University of California Bulletin No. 1879 (1978); and
- Evaluation of Fertility by Plant and Soil Analysis by D. Davidescu and V. Davidescu (ABACUS Press: Tunbridge Wells, U.K.) 1982.

Since 1986, considerable data have been generated from Australian studies and are now included in the revised tables. A search of the international literature up until December 31, 1995 was also undertaken to augment the Australian studies. We have given priority to information derived from experimental work rather than from general nutrition texts because of the difficulty in validating the data from the latter.

We thank Cecilia Dutkiewicz, Janice Cecil and Dianne Brown for assistance with literature searches and for preparing and coordinating the tables.

ASPARAGUS (*Asparagus officinalis*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Mid-growth	Needles from top 30 cm mature fern	F		3.61		3.79			USA	**21**	
	Apr-Jun (late spring)	Needles from top 30 cm mature fern, top 10 cm removed	F				3.5-3.6			USA	**32**	
	July-Aug - 1st fruit to seed set	Needles from top 30 cm mature fern, top 10 cm removed	F				2.6-2.7			USA	**32**	
	Sept (Autumn)	Needles from top 30 cm mature fern, top 10 cm removed	F				3.0			USA	**32**	
	Aug-Sept (Autumn)	Top 50 cm fronds		2.20-2.49			2.50-4.00	>4.0		USA	**63**	
	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		2.2		2.95-4.90	4.5		Aust	**128**	
	45-90 cm tall	Foliage of mature fronds					2.4-3.8				**5**	
			Sand	1.22-1.35			2.20-2.93			Bra	**46**	cv. Mary Washington
NO_3-N(%)	Mid-growth	10 cm tip new fern	F	0.01			0.05			USA	**71**	
P(%)	Mid-growth	Needles from top 30 cm mature fern	F		0.17		0.20-0.23			USA	**21**	
	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		0.2		0.18-0.35			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		0.22-0.24			0.25-0.50	>0.5		USA	**63**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	45-90 cm tall	Foliage of mature fronds					0.30-0.50				**5**	
	U	U	Sand	0.07-0.09			0.10-0.20			Bra	**46**	cv. Mary Washington
PO_4-P(%)	Mid-growth	10 cm tip new fern	F	0.08			0.16			USA	**71**	
K(%)	Mid-growth	10 cm tip new fern	F	1.0			3.0			USA	**71**	
	Mid-growth	Needles from top 30 cm mature fern	F		1.43		1.72			USA	**21**	
	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		1.2		1.16-2.64			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		1.20-1.49			1.50-2.80	>2.8		USA	**63**	
	45-90 cm tall	Foliage of mature fronds					1.5-2.4				**5**	
	U	U	Sand	0.39-0.75			2.95-3.11			Bra	**46**	cv. Mary Washington
S(%)	U	U	Sand	0.08-0.10			0.16-0.18			Bra	**46**	cv. Mary Washington
Ca(%)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		0.30		0.86-1.76			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		0.40-0.59			0.60-1.00	>1.0		USA	**63**	
	45-90 cm tall	Foliage of mature fronds					0.40-0.80				**5**	
	U	U	Sand	0.04-0.18			0.67-0.98			Bra	**46**	cv. Mary Washington
Mg(%)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D				0.27-0.70			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		0.22-0.24			0.25-0.30	>0.3		USA	**63**	
	45-90 cm tall	Foliage of mature fronds					0.15-0.30				**5**	
	U	U	Sand	0.05-0.15			0.76-1.35			Bra	**46**	cv. Mary Washington
Na(%)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern					0.01-0.26			Aust	**128**	

ASPARAGUS (*Asparagus officinalis*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Cl(%)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern					0.78-2.30			Aust	**128**	
Cu(mg/kg)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		5		6-11			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		3-4			5-25	>25		USA	**63**	
	45-90 cm tall	Foliage of mature fronds					6-12				**5**	
Zn(mg/kg)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		15		16-30			Aust	**128**	
	Harvest	Spears	F				52			USA	**3**	
	45-90 cm tall	Foliage of mature fronds					20-60				**5**	
	Aug-Sept (Autumn)	Top 50 cm fronds		18-19			20-100	>100		USA	**63**	
Mn(mg/kg)	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		15		72-173			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		20-24			25-200	>200		USA	**63**	
	45-90 cm tall	Foliage of mature fronds					25-100				**5**	
Fe(mg/kg)	Aug-Sept (Autumn)	Top 50 cm fronds		30-39			40-250	>250		USA	**63**	
B(mg/kg)	Mid-growth	WS	Sand	43-55					175-288	USA	**21**	
	Feb-Mar (Autumn)	Needles from top 30 cm mature fern	F,S,D		20		25-211			Aust	**128**	
	Aug-Sept (Autumn)	Top 50 cm fronds		30-39			40-100	101-250		USA	**63**	
	45-90 cm tall	Foliage of mature fronds					40-100				**5**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	U	U	Sand	12-13			82-108			Bra	**46**	cv. Mary Washington
Mo(mg/kg)	45-90 cm tall	Foliage of mature fronds					0.15-0.50				**5**	

BEAN - FRENCH, GREEN, SNAP, DWARF, BUSH (*Phaseolus vulgaris*)

N(%)	In bud	YMB + P (4th leaf from terminal)	S,D			3.5	4.0-6.0			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<5.0	5.0-5.2		5.2-5.4			Aust	**103**	
	Peak harvest	Pods	F				3.1			USA	**92**	cv. Slim Green
	Seed harvest	Seeds	F				4.5			USA	**92**	cv. Slim Green
NO_3-N(%)	Mid-growth	PYMB (4th leaf from terminal)	F	0.2			0.4			USA	**71**	
	Early Fl	PYMB (4th leaf from terminal)	F	0.1			0.2			USA	**71**	
P(%)	In bud	YMB + P (4th leaf from terminal)	S,D			0.3	0.32-0.50			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<0.25	0.25-0.40		0.40-0.60			Aust	**103**	
	Peak harvest	Leaflets	F				0.24			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				0.3			USA	**92**	cv. Slim Green
	Seed harvest	Seeds	F				0.36			USA	**92**	cv. Slim Green
PO_4-P(%)	Mid-growth	PYMB (4th leaf from terminal)	F	0.1			0.3			USA	**71**	
	Early Fl	PYMB (4th leaf from terminal)	F	0.08			0.2			USA	**71**	
K(%)	Mid-growth	PYMB (4th leaf from terminal)	F	3			5			USA	**71**	

BEAN - FRENCH, GREEN, SNAP, DWARF, BUSH (*Phaseolus vulgaris*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
K(%) (ctd)	In bud	YMB + P (4th leaf from terminal)	S,D			1.5	1.8-2.5			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<1.2	1.2-1.5		1.5-3.5			Aust	**103**	
	Early Fl	PYMB (4th leaf from terminal)	F	2			4			USA	**71**	
	Peak harvest	Leaflets	F				1.9			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				2.6			USA	**92**	cv. Slim Green
	Peak harvest	Seed	F				1.3			USA	**92**	cv. Slim Green
S(%)	Early growth	WS (dried)	Sand				0.16-0.64		1.12	USA	**21**	
	Peak harvest	Pods	F				0.17			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				0.22			USA	**92**	cv. Slim Green
Ca(%)	In bud	YMB + P (4th leaf from terminal)	S,D				0.8-3.0			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<1.2	1. 2-1.5		1.5-2.5			Aust	**103**	
	Peak harvest	WS	F				2.36			USA	**18**	
	Peak harvest	Leaflets	F				2.92			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				0.52			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				0.15			USA	**92**	cv. Slim Green
Mg(%)	In bud	YMB + P (4th leaf from terminal)	S,D			0.20	0.25-0.70			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<0.25	0.25-0.40		0.40-0.80			Aust	**103**	
	Peak harvest	Leaflets	F				0.52			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				0.24			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				0.16			USA	**92**	cv. Slim Green
Na(%)	Early Fl	YMB	F				0.04-0.33		>0.33	Aust	**2**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Peak harvest	Leaflets	F				0.04			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				0.03			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				0.03			USA	**92**	cv. Slim Green
Cl(%)	Early Fl	YMB	F				0.6-2.0		>2.0	Aust	**2**	
	Early Fl (8 days after 1st bud)	YMB	F		0.63				4.35-5.35	USA	**21**	
	Peak harvest	Leaflets	F				0.89			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				0.34			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				0.03			USA	**92**	cv. Slim Green
Cu(mg/kg)	In bud	YMB + P (4th leaf from terminal)	S,D			4	15-30			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<3	3-5		5-15			Aust	**103**	
	Peak harvest	Leaflets	F				6.1			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				4.9			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				7.5			USA	**92**	cv. Slim Green
Zn(mg/kg)	In bud	YMB + P (4th leaf from terminal)	S,D			20	30-60			Aust	**129**	
	Early Fl	YMB	F	<30			35-100			Aust	**79**	
	Peak harvest	Leaflets	F				46			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				34			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				37			USA	**92**	cv. Slim Green
Mn(mg/kg)	18 DAS	All leaves	Sand						>120	USA	**64**	cv. Wonder Crop No 2
	In bud	YMB + P (4th leaf from terminal)	S,D			25	30-300			Aust	**129**	
	Early Fl (Pods <10 cm long)	YMB	F	<25	25-50		50-400			Aust	**103**	
	Early Fl	YMB	F						>400	Aust	**2**	
	Peak harvest	Leaflets	F				96			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				27			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				16			USA	**92**	cv. Slim Green

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
BEAN - FRENCH, GREEN, SNAP, DWARF, BUSH (*Phaseolus vulgaris*) (ctd)												
Fe(mg/kg)	In bud	YMB + P (4th leaf from terminal)	S,D			60	300-450			Aust	**129**	
	Early Fl	YMB	F				100-300			Aust	**2**	
	Peak harvest	Leaflets	F				168			USA	**92**	cv. Slim Green
	Peak harvest	Pods	F				70			USA	**92**	cv. Slim Green
	Seed harvest	Seed	F				65			USA	**92**	cv. Slim Green
B(mg/kg)	In bud	YMB + P (4th leaf from terminal)	S,D				40-60			Aust	**129**	
	Pre-Fl	WS	Soil	<12			42		>125	Can	**40**	cv. Eastern Butterwax
	Early Fl	YMB	F	<6	6-10		10-50			Aust	**80**	
	Fl init.	YMB+P	F			20				Colo	**54**	
	Peak harvest	WS	Soil	<13			88		>265	Can	**40**	cv. Eastern Butterwax
	Peak harvest	WS	F				44		132	Can	**38**	
	Peak harvest	Pods	F				28		43	Can	**38**	
Mo(mg/kg)	56 DAS	WS	Soil				0.4			Can Aust	**42**	
BEETROOT (*Beta vulgaris*)												
N(%)	Early Mat	YMB+P	S,D			3.0	3.5-5.0			Aust	**129**	
	Mat	YMB+P	F				3.5-5.0			USA	**127**	
	U	YML	U				3.5-5.0			U	**5**	
P(%)	Early Mat	YMB+P	S,D			0.20	0.25-0.35			Aust	**129**	
	Mat	YMB+P	F				0.20-0.30			USA	**127**	
	Mat	Leaves	F		0.15		0.28			USA	**21**	
	U	YML	U				0.25-0.5			U	**5**	
	Mat	Roots	F		0.10		0.27			USA	**21**	
K(%)	Roots, 4-7.5 cm diam.	WS	F				3-5			Aust	**80**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	U	YML	U				2.8-5.0			U	**5**	
	Early Mat	YMB+P	S,D			2	2-4			Aust	**129**	
	Mat	YMB+P	F				2-4			USA	**127**	
S(%)	Roots, 4-7.5 cm diam.	WS	F				0.18-0.30			Aust	**80**	
Ca(%)	Roots, 4-7.5 cm diam.	WS	F				0.7-1.5			Aust	**80**	
	Early Mat	YMB+P	S,D				2.5-3.5			Aust	**129**	
	Mat	YMB+P	F				2.5-3.5			USA	**127**	
	Mat	Whole plant	F				1.24			USA	**18**	
	U	YML	U				1.5-2.5			U	**5**	
Mg(%)	Roots, 4-7.5 cm diam.	WS	F				1.5-2.5			Aust	**80**	
	Early Mat	YMB+P	S,D			0.25	0.30-0.80			Aust	**129**	
	Mat	YMB+P	F				0.30-0.80			USA	**127**	
	U	YML	U				0.3-0.8			U	**5**	
Na(%)	Roots, 4-7.5 cm diam.	WS	F				3-10			Aust	**80**	
	U	Leaves	Soil				3.42		10.3	USA	**21**	
Cl(%)	Roots, 4-7.5 cm diam.	WS	F				2-10			Aust	**80**	
Cu(mg/kg)	Roots, 4-7.5 cm diam.	WS	F				5-10			Aust	**80**	
	U	YML	U				7-15			U	**5**	
Zn(mg/kg)	Early Mat	YMB+P	S,D			15	20-40			Aust	**129**	
	Mat	YMB+P	F				15-30			USA	**127**	
	U	YML	U				20-60			U	**5**	
Mn(mg/kg)	Early Mat	YMB+P	S,D			20				Aust	**129**	
	Mat	YMB+P	F				70-200			USA	**127**	
	U	YML	U				50-150			U	**5**	
Fe(mg/kg)	Early Mat		S,D				70-200			Aust	**129**	
B(mg/kg)	Roots, 4-7.5 cm diam.	WS	F				20-40			Aust	**80**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
BEETROOT (*Beta vulgaris*) (ctd)												
B(mg/kg) (ctd)	Early Mat	YMB+P	S,D			21	60-80			Aust	**129**	
	Mat	LB	Sand	15-16			27-83			USA	**21**	
	U	YML	U				35-80			U	**5**	
Mo(mg/kg)	56 DAS	WS	Soil	0.05			0.62			USA	**21**	
	U	YML	U				0.2-1.0			U	**5**	
Co(mg/kg)	Mat	WS	F				0.19			USA	**21**	
	Mat	Root	F				0.08			USA	**21**	
BROCCOLI (*Brassica oleracea* var. *italica*)												
N(%)	Head	WL	S,D				3.2-5.5			Aust	**129**	
	Peak harvest	WL	F			4.0	4.5-4.8			Aust	**94**	
	Peak harvest	Head	F			5.0	5.6-6.1			Aust	**94**	
NO_3- N (mg/kg)	50 DAT	PYFEL	F			9300-9800	9800-15800			USA	**31**	
	70 DAT	PYFEL	F			5500-7500	8700-12000			USA	**31**	
	90 DAT	PYFEL	F			2700-3700	6700-10500			USA	**31**	
NO_3-N(%)	Budding	MRWL	F	<0.5			0.9			USA	**71**	
P(%)	Head	WL	S,D				0.3-0.7			Aust	**129**	
	Peak harvest	WL	F			0.7	0.8-0.9			Aust	**94**	
	Peak harvest	Head	F			0.90	0.95-1.00			Aust	**94**	
	Peak harvest	Head	F		0.69		0.79-1.07			USA	**21**	
PO_4-P(%)	Budding	MRWL	F	<0.2			0.4			USA	**71**	
K(%)	Budding	MRWL	F	2			4			USA	**71**	
	Head	WL	S,D				2-4			Aust	**129**	
	Peak harvest	WL	F			3.0	3.5-4.2			Aust	**94**	
	Peak harvest	Head	F			3.8	4.2-4.5			Aust	**94**	
Ca(%)	Head	WL	S,D				1.2-2.5			Aust	**129**	
	Peak harvest	WL	F			2.5	2.9-3.1			Aust	**94**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Peak harvest	Head	F			0.70	0.80-0.95			Aust	**94**	
Mg(%)	Head	WL	S,D				0.23-0.40			Aust	**129**	
	Peak harvest	WL	F			0.45	0.48-0.54			Aust	**94**	
	Peak harvest	Head	F			0.20	0.25-0.33			Aust	**94**	
Cl(%)	Peak harvest	WL	F			2.00	2.25-2.65			Aust	**94**	
	Peak harvest	Head	F				0.7-0.8			Aust	**94**	
Cu(mg/kg)	Head	WL	F				1-5			USA	**127**	
Zn(mg/kg)	Head	WL	S,D				45-95			Aust	**129**	
Mn(mg/kg)	Head	WL	S,D				25-150			Aust	**129**	
B(mg/kg)	Head	WL	S,D	<20			30-200			Aust	**129**	
	Head	WL	S,D				30-60			Aust	**97**	
	5% Heads	WL	F, Soil	2-9			10-71			Can	**38**	
Mo(mg/kg)	56 DAS	WS	Soil	0.04						Can Aust	**42**	
	Head	WL	S,D	<0.1			0.3-0.5			Aust	**97**	

BRUSSELS SPROUTS (*Brassica oleracea* var. *gemmifera*)

N(%)	Heart, 7 cm	Upper leaves	S,D				2.2-4.2			Aust	**129**	
	Sprout initiation	YML	U				2.2-4.2			U	**5**	
	Heart, 7 cm	Upper leaves	S,D				3-5			Aust	**20**	
NO_3-N(%)	Mid-growth	Midrib of YMB	F	0.5			0.9			USA	**71**	
P(%)	Sprout initiation	YML	U				0.25-0.50			U	**5**	
	Heart, 7 cm	Upper leaves	S,D				0.26-0.45			Aust	**129**	
	Heart, 7 cm	Upper leaves	S,D				0.2-0.6			Aust	**20**	
	July	YMB+P	F	0.12			0.29-0.40			USA	**21**	
PO_4-P(%)	Mid-growth	Midrib of YMB	F	0.20			0.35			USA	**71**	
K(%)	Sprout initiation	YML	U				2.4-3.4			U	**5**	
	Mid-growth	Midrib of YMB	F	3			5			USA	**71**	
	Heart, 7 cm	Upper leaves	S,D				2.4-3.4			Aust	**129**	

BRUSSELS SPROUTS (*Brassica oleracea* var. *gemmifera*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Ca(%)	Sprout initiation	YML	U				0.4-2.0			U	**5**	
	Early sprout growth	YMB	F				1.4-2.6			Can	**26**	
	Heart, 7 cm	Upper leaves	S,D				0.3-2.2			Aust	**129**	
	Heart, 7 cm	Upper leaves	S,D				0.5-1.5			Aust	**20**	
Mg(%)	Sprout initiation	YML	U				0.25-0.50			U	**5**	
	Early sprout growth	YMB	F				0.25-0.32			Can	**26**	
	Heart, 7 cm	Upper leaves	S,D				0.23-0.40			Aust	**129**	
	Heart, 7 cm	Upper leaves	S,D				0.2-0.3			Aust	**20**	
Na(%)	Heart, 7 cm	Upper leaves	S,D				0.1-0.2			Aust	**20**	
Cl(%)	Heart, 7 cm	Upper leaves	S,D				0.2-0.5			Aust	**20**	
Cu(mg/kg)	Sprout initiation	YML	U				5-12			U	**5**	
Zn(mg/kg)	Sprout initiation	YML	U				20-60			U	**5**	
	Early sprout growth	YMB	F				26-35			Can	**26**	
	Heart, 7 cm	Upper leaves	S,D				20-80			Aust	**20**	
Mn(mg/kg)	Sprout initiation	YML	U				40-100			U	**5**	
	Early sprout growth	YMB	F				88-274			Can	**26**	
	Heart, 7 cm	Upper leaves	S,D				20-120			Aust	**20**	
	July	YMB+P	F				78-148		760-2035	USA	**21**	
Fe(mg/kg)	Heart, 7 cm	Upper leaves	S,D				50-150			Aust	**20**	
Al(mg/kg)	U	YMB+P	Soil					51		USA	**21**	
B(mg/kg)	Sprout initiation	YML	U				30-80			U	**5**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	early sprouting	YMB	F				26-70	113-123		Can	**44**	cv. Jade Cross
	Heart, 7 cm	Upper leaves	F					30-40		USA	**127**	
	Heart, 7 cm	Upper leaves	S,D					10-50		Aust	**20**	
	Budding	LB	F,Soil	6-10				13-101		Can	**38**	
Mo(mg/kg)	Sprout initiation	YML	U				0.4-0.7			U	**5**	
	Budding	WS	Soil	<0.08			0.11-0.69			Can Aust	**42**	

CABBAGE (*Brassica oleracea* L. var. *capitata*)

N(%)	Mid head	YMB	F				2.3-3.4			USA	**52**	cvv. Gourmet, Copenhagen
	14 DAT	YML	Sand,F			4.38	4.50			Aust	**58**	cv. Rampo
	28 DAT	YML	Sand,F			4.35	4.63				**58**	cv. Rampo
	42 DAT	YML	Sand,F			4.14	4.66				**58**	cv. Rampo
	56 DAT	YML	Sand,F			3.1	3.4				**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F			3.50	3.96				**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F			3.10	3.92				**58**	cv. Rampo
	Peak harvest	YMHL	F			2.9	3.0-3.7			Aust	**94**	cv. Irish
	Head formation	fully developed leaves	U				3.7-4.5			U	**5**	
	Peak harvest	Head (core sample)	F				3			USA	**92**	cv. King Cole
	Peak harvest	WL	F			1.8	2.0-2.6			Aust	**94**	cv. Irish
	Head	WL	S,D	<2.50			2.5-4.0			Aust	**20**	
	Head	WL	S,D			2.5	3.0-4.6			Aust	**129**	
NO_3-N(%)	4-6 leaf	midrib-YMB	F			1.1				USA	**33**	response expected at lower values
	10-12 leaf	midrib-YMB	F			0.8				USA	**33**	response expected at lower values
	Early head	midrib-YMB	F			0.4				USA	**33**	response expected at lower values
	Folding	midrib-YMB	F			0.6				USA	**33**	response expected at lower values
	Pre-harvest	midrib-YMB	F			0.3				USA	**33**	response expected at lower values
	14 DAT	YML	Sand,F			0.84	1.02			Aust	**58**	cv. Rampo

CABBAGE (*Brassica oleracea* L. var. *capitata*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
NO_3-N(%) (ctd)	28 DAT	YML	Sand,F			1.03	1.30			Aust	**58**	cv. Rampo
	42 DAT	YML	Sand,F			0.77	1.39			Aust	**58**	cv. Rampo
	56 DAT	YML	Sand,F			0.61	0.90			Aust	**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F			0.44	0.86			Aust	**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F			0.73	1.26			Aust	**58**	cv. Rampo
	Head	MRWL	F	0.5			0.9			USA	**71**	
	Head	Heart leaf	F		<0.50		0.50-1.00			Rom	**27**	
NO_3-N (mg/kg) petiole sap	14 DAT	PYMB	Sand,F			2800	3760			Aust	**58**	cv. Rampo
	28 DAT	PYMB	Sand,F			1800	2440			Aust	**58**	cv. Rampo
	42 DAT	PYMB	Sand,F			1300	2200			Aust	**58**	cv. Rampo
	56 DAT	PYMB	Sand,F			1000	1660			Aust	**58**	cv. Rampo
	70 DAT (Head)	PYMB	Sand,F			1750	3500			Aust	**58**	cv. Rampo
	84 DAT (Mat)	PYMB	Sand,F			2700	4210			Aust	**58**	cv. Rampo
P(%)	Mid head	YMB	F				0.3-0.4			USA	**52**	cvv. Gourmet, Copenhagen
	14 DAT	YML	Sand,F				0.49			Aust	**58**	cv. Rampo
	28 DAT	YML	Sand,F				0.6			Aust	**58**	cv. Rampo
	42 DAT	YML	Sand,F				0.6			Aust	**58**	cv. Rampo
	56 DAT	YML	Sand,F				0.49			Aust	**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F				0.46			Aust	**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F				0.55			Aust	**58**	cv. Rampo
	Head	WL	S,D	<0.20			0.30-0.50			Aust	**20**	
	Head	WL	S,D			0.20	0.25-0.50			Aust	**129**	
	Peak harvest	WL	F			0.35	0.40-0.50			Aust	**94**	cv. Irish
	Peak harvest	YMHL	F			0.60	0.65-0.75			Aust	**94**	cv. Irish
	head formation	fully developed leaves	U				0.3-0.5			U	**5**	
	Peak harvest	Head (core sample)	F				0.26			USA	**92**	cv. King Cole

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
PO_4-P(%)	Head	Heart leaf			<0.18		0.18-0.40			Rom	**27**	
	Head	MRWL	F	0.25			0.35			USA	**71**	
K(%)	Mid head	YMB	F				2.6-3.1			USA	**52**	cvs. or cvv. Gourmet, Copenhagen
	14 DAT	YML	Sand,F				4.32			Aust	**58**	cv. Rampo
	28 DAT	YML	Sand,F				4.05			Aust	**58**	cv. Rampo
	42 DAT	YML	Sand,F				4.82			Aust	**58**	cv. Rampo
	56 DAT	YML	Sand,F				6.79			Aust	**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F				6.63			Aust	**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F				5.2			Aust	**58**	cv. Rampo
	Peak harvest	YMHL	F				2.50	3.10-3.60		Aust	**94**	cv. Irish
	Head	WL	S,D	<2.0				2.0-4.0		Aust	**20**	
	Head	WL	S,D				2.0	3.0-4.0		Aust	**129**	
	Peak harvest	WL	F				1.8	1.9-2.2		Aust	**94**	cv. Irish
	Head formation	fully developed leaves	U				3.0-4.0			U	**5**	
	Peak harvest	Head (core sample)	F					2.4		USA	**92**	cv. King Cole
	Head	MRWL	F	2				4		USA	**71**	
K_20-K(%)	Head	Heart leaf	F		<2.0			2.0-3.5		Rom	**27**	
S(%)	14 DAT	YML	Sand,F				1.5			Aust	**58**	cv. Rampo
	28 DAT	YML	Sand,F				1.44			Aust	**58**	cv. Rampo
	42 DAT	YML	Sand,F				1.92			Aust	**58**	cv. Rampo
	56 DAT	YML	Sand,F				1.45			Aust	**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F				1.86			Aust	**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F				1.88			Aust	**58**	cv. Rampo
	Peak harvest	Head (core sample)	F					0.66		USA	**92**	cv. King Cole
Ca(%)	Peak harvest	WS	F				0.55			USA	**18**	
	Mid head	YMB	F				1.5-1.8			USA	**52**	cvv. Gourmet, Copenhagen
	14 DAT	YML	Sand,F				1.89			Aust	**58**	cv. Rampo
	28 DAT	YML	Sand,F				1.87			Aust	**58**	cv. Rampo

CABBAGE (*Brassica oleracea* L. var. *capitata*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Ca(%) (ctd)	42 DAT	YML	Sand,F				2.69			Aust	**58**	cv. Rampo
	56 DAT	YML	Sand,F				1.98			Aust	**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F				3.22			Aust	**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F				3.64			Aust	**58**	cv. Rampo
	Peak harvest	YMHL	F			0.40	0.45-0.55			Aust	**94**	cv. Irish
	Head	WL	S,D	<0.5			2.0-3.0			Aust	**20**	
	Head	WL	S,D			1.0	1.5-3.0			Aust	**129**	
	Peak harvest	WL	F			2.0	2.5-3.2			Aust	**94**	cv. Irish
	Head formation	fully developed leaves	U				1.5-2.0			U	**5**	
	Peak harvest	Head (core sample)	F				0.7			USA	**92**	cv. King Cole
Mg(%)	Mid head	YMB	F				0.3-0.4			USA	**52**	cvv. Gourmet, Copenhagen
	14 DAT	YML	Sand,F				0.55			Aust	**58**	cv. Rampo
	28 DAT	YML	Sand,F				0.46			Aust	**58**	cv. Rampo
	42 DAT	YML	Sand,F				0.54			Aust	**58**	cv. Rampo
	56 DAT	YML	Sand,F				0.4			Aust	**58**	cv. Rampo
	70 DAT (Head)	YML	Sand,F				0.57			Aust	**58**	cv. Rampo
	84 DAT (Mat)	YML	Sand,F				0.44			Aust	**58**	cv. Rampo
	Peak harvest	YMHL	F			0.18	0.20-0.25			Aust	**94**	cv. Irish
	Head	WL	S,D	<0.1			0.2-0.6			Aust	**20**	
	Head	WL	S,D			0.15	0.20-0.60			Aust	**129**	
	Peak harvest	WL	F			0.35	0.40-0.50			Aust	**94**	cv. Irish
	Head formation	fully developed leaves	U				0.25-0.50			U	**5**	
	Peak harvest	Head (core sample)	F				0.18			USA	**92**	cv. King Cole
Na(%)	Head	WL	S,D				<1.0			Aust	**20**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
Na(%)	Peak harvest	Head (core sample)	F				0.11			USA	**92**	cv. King Cole
Cl(%)	Peak harvest	YMHL	F			0.3	0.4-0.7			Aust	**94**	cv. Irish
	Head	WL	S,D				<2.0			Aust	**20**	
	Peak harvest	WL	F				1.3-3.2			Aust	**94**	cv. Irish
	Peak harvest	Head (core sample)	F				0.29			USA	**92**	cv. King Cole
Cu(mg/kg)	55 DAT	WL	Sand						56-116	Jap	**51**	cv. Soshu
	Head	WL	S,D				5.2			Aust	**20**	
	Head	WL	S,D			5.0	5.2			Aust	**129**	
	Head formation	fully developed leaves	U				5-12			U	**5**	
	Peak harvest	Head (core sample)	F				3.3			USA	**92**	cv. King Cole
	55 DAT	Roots	Sand						3225-13000	Jap	**51**	cv. Soshu: extremely toxic
Zn(mg/kg)	55 DAT	WL	Sand						358-805	Jap	**51**	cv. Soshu
	Head	WL	S,D	<10			10-200			Aust	**20**	
	Head	WL	S,D			15	20-200			Aust	**129**	
	Head formation	fully developed leaves	U				20-60			U	**5**	
	Peak harvest	Head (core sample)	F				34			USA	**92**	cv. King Cole
	55 DAT	Roots	Sand						2075-6555	Jap	**51**	cv. Soshu
Mn(mg/kg)	Head formation	fully developed leaves	U				30-100			U	**5**	
Fe(mg/kg)	55 DAT	WL	Sand					129	143	Jap	**51**	cv. Soshu; marginal growth reduction
	Head	WL	S,D	<50			50-200			Aust	**20**	
	Head	WL	S,D			50	60-200			Aust	**129**	
	Peak harvest	Head (core sample)	F				51			USA	**92**	cv. King Cole

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
CABBAGE (*Brassica oleracea* L. var. *capitata*) (ctd)												
Fe(mg/kg) (ctd)	55 DAT	Roots	Sand					7493	26534	Jap	**51**	cv. Soshu; root necrosis
B(mg/kg)	Head	WL	S,D			20	20-60			Aust	**129**	
	Head	WL	S,D	<20			30-60			Aust	**97**	
	Head formation	fully developed leaves	U				25-80			U	**5**	
Mo(mg/kg)	Early head	WS	F	<0.26			0.68-1.49			Can	**42**	
	Head	WL	S,D	<0.l		0.2	0.3-0.5			Aust	**97**	
	Head formation	fully developed leaves	U				0.4-0.7			U	**5**	
Co(mg/kg)	55 DAT	WL	Sand						138-1250	Jap	**51**	cv. Soshu
	55 DAT	Roots							1665-3235	Jap	**51**	cv. Soshu; little growth reduction at lower level
CAPSICUM - BELL, CHERRY, CONE, CLUSTER, CHILLI, SWEET (*Capsicum annuum* var. *annuum*)												
N(%)	Mid-growth	YML	F				3.0-4.5			USA	**127**	Bell pepper
	Mid-growth	YML					3.0-4.5				**5**	Paprika or pod pepper
	Spring Bud development	YML	F				5.89-6.02			Aust	**91**	cv. Bell Tower
	Spring 1st anthesis	YML	F				6.53-6.87			Aust	**91**	cv. Bell Tower
	Spring Flowering	YML	F				6.19-6.46			Aust	**91**	cv. Bell Tower
	Spring Fruit set	YML	F				5.98-6.35			Aust	**91**	cv. Bell Tower
	1st bloom to final 1/3	YML		3.50-3.99			4.00-6.00	>6.00		USA	**63**	Bell pepper, Grossum group
	Final 1/3	YML		3.00-3.49			3.50-5.00	>5.00		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				2.9-4.6			Aust	**129**	Bell pepper
	U	L		<2.0			3.5-5.5			UK	**134**	cv. Bellboy

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
NO_3-N(%)	Early growth	PYML	F	0.5			0.7			USA	**71**	Chilli pepper
	Early growth	PYML	F	0.8			1.2			USA	**71**	Sweet pepper
	Spring Bud development	PYML	F				0.5-0.6			Aust	**91**	cv. Bell Tower
	Spring 1st anthesis	PYML	F				0.62-0.71			Aust	**91**	cv. Bell Tower
	Spring Flowering	PYML	F				0.46-0.60			Aust	**91**	cv. Bell Tower
	Spring Fruit set	PYML	F				0.16-0.28			Aust	**91**	cv. Bell Tower
	Early fruit	PYML	F	0.1			0.2			USA	**71**	Chilli
	Early fruit	PYML	F	0.3			0.5			USA	**71**	Sweet
	Prior to harvest	YFML	F	<0.10						USA	**120**	Chilli pepper cv. New Mexico
	Prior to harvest	YFML	F	0.40-0.60			1.97			USA	**120**	Chilli pepper cv. New Mexico
P(%)	Mid-growth	YML	F				0.3-0.7			USA	**127**	Bell pepper
	Mid-growth	YML					0.3-0.6				**5**	Paprika or pod pepper
	1st bloom to final 1/3	YML		0.23-0.34			0.35-1.00	>1.00		USA	**63**	Bell pepper, Grossum group
	Final 1/3	YML		0.18-0.21			0.22-0.70	>0.80		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				0.3-0.5			Aust	**129**	Bell pepper
	U	L		<0.2			0.3-0.8			UK	**134**	cv. Bellboy
PO_4-P(%)	Early growth	PYML	F	0.2			0.3			USA	**71**	Chilli pepper
	Early growth	PYML	F	0.2			0.4			USA	**71**	Sweet pepper
	Early fruit	PYML	F	0.15			0.25			USA	**71**	Chilli pepper
	Early fruit	PYML	F	0.15			0.25			USA	**71**	Sweet pepper
K(%)	Early growth	PYML	F	4			6			USA	**71**	Chilli pepper
	Early growth	PYML	F	4			6			USA	**71**	Sweet pepper
	Mid-growth	YML	F				4.0-5.4			USA	**127**	Bell pepper
	Mid-growth	YML					4.0-5.4				**5**	Paprika or pod pepper
	1st bloom to final 1/3	YML		3.60-3.99			4.00-6.00	>6.00		USA	**63**	Bell pepper, Grossum group
	Final 1/3	YML		3.00-3.49			3.50-4.50	>4.50		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				2.6-5.5			Aust	**129**	Bell pepper

CAPSICUM - BELL, CHERRY, CONE, CLUSTER, CHILLI, SWEET (*Capsicum annuum* var. *annuum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
K(%) (ctd)	Early fruit	PYML	F	3.0			5.0			USA	**71**	Chilli & sweet pepper
	U	L		<2.0			3.0-6.0			UK	**134**	cv. Bellboy
Ca(%)	Mid-growth	YML	F				0.4-0.6			USA	**127**	Bell pepper
	Mid-growth	YML					0.4-1.0				**5**	Paprika or pod pepper
	1st bloom to final 1/3	YML		0.80-0.99			1.00-2.50	>2.50		USA	**63**	Bell pepper, Grossum group
	Final 1/3	YML		1.00-1.29			1.30-2.80	>2.80		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				1.30-3.70			Aust	**129**	Bell pepper
	U	L		<1.0			1.5-3.5			UK	**134**	cv. Bellboy
Mg(%)	Mid-growth	YML					0.3-0.8				**5**	Paprika or pod pepper
	1st bloom & final 1/3	YML		0.26-0.29			0.30-1.00	>1.00		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				0.25-1.20			Aust	**129**	Bell pepper
	U	L		<0.3			0.35-0.80			UK	**134**	cv. Bellboy
Cu(mg/kg)	Mid-growth	YML	F				10-20			USA	**127**	Bell pepper
	U	L		<4			6-20			UK	**134**	cv. Bellboy
	Mid-growth	YML					8-15				**5**	Paprika or pod pepper
	1st bloom & final 1/3	YML		4-5			6-25	>25		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				10-200			Aust	**129**	Bell pepper
Zn(mg/kg)	1st bloom & final 1/3	YML		18-19			20-200	>200		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				35-260			Aust	**129**	Bell pepper
	Early fruit	YML					20-60				**5**	Paprika or pod pepper
	U	L		<25			40-100			UK	**134**	cv. Bellboy
Mn(mg/kg)	1st bloom & final 1/3	YML		40-49			50-250	>250		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				26-300			Aust	**129**	Bell pepper
	Early fruit	YML					30-100				**5**	Paprika or pod pepper
	U	L		<20			100-300			UK	**134**	cv. Bellboy

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
Fe(mg/kg)	1st bloom & final 1/3	YML		50-59			60-300	>300		USA	**63**	Bell pepper, Grossum group
	U	L		66			80-200			UK	**134**	cv. Bellboy
B(mg/kg)	Mid-growth	YML	F				40-100			USA	**127**	Bell pepper
	Mid-growth	YML					40-80				**5**	Paprika or pod pepper
	1st bloom & final 1/3	YML		23-24			25-75	>75		USA	**63**	Bell pepper, Grossum group
	Early fruit	YML	S,D				30-100			Aust	**129**	Bell pepper
	U	L		<20			30-90			UK	**134**	cv. Bellboy
Mo(mg/kg)	Mid-growth	YML					0.2-0.6				**5**	Paprika or pod pepper
Co(mg/kg)	Mat	WS	F				0.31			USA	**21**	Bell pepper
	Mat	Fruit	F				0.12			USA	**21**	Bell pepper

CARROT (*Daucus carota* L.)

N(%)	Pre-thinning	WS	F			3.5-3.7				Rom	**27**	
	Mid-growth	WS	U				2.0-3.5			U	**5**	
	Root thickening	WS	F			2.6				Rom	**27**	
	Mid-growth	YML	S,D			1.8	2.0-3.5			Aust	**129**	
	Peak harvest	YML	F			1.5	1.6-1.7			Aust	**94**	
	28 DAS	Whole plant	Sand			5.9-8.3				UK	**53**	cv. Kingston; for 90% max relative growth rate
	Peak harvest	Root	F			0.80	0.85-0.95			Aust	**94**	
NO_3-N(%)	Mid-growth	PYML	F	0.5			1.0			USA	**71**	
	Root thickening	PYML	F		0.25-0.45		0.50-0.75			Rom	**27**	
P(%)	Pre-thinning	WS	F			0.35-0.44				Rom	**27**	
	Mid-growth	WS	U				0.3-0.5			U	**5**	
	Root thickening	WS	F			0.31				Rom	**27**	
	63 DAS	YMB+P	F			0.38				Aust	**81**	cv. Western Red; for 99% max yield
	Mid-growth	YML	S,D			0.18	0.20-0.35			Aust	**129**	
	Peak harvest	YML	F			0.2	0.3-0.4			Aust	**94**	

CARROT (*Daucus carota* L.) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
P(%) (ctd)	28 DAS	Whole plant	Sand			0.72-0.91				UK	**53**	cv. Kingston; for 90% max relative growth rate
	Peak harvest	Root	F			0.30	0.35-0.45			Aust	**94**	
	Peak harvest	Root	F		0.14		0.33-0.65			USA	**21**	
PO_4-P(%)	Mid-growth	PYML	F	0.2			0.4			USA	**71**	
	Root thickening	PYML	F		0.10-0.15		0.20-0.25			Rom	**27**	
	Pre-harvest	YML	F	<0.15			0.26-0.30			Rom	**27**	
	Pre-harvest	Root	F	<0.14			0.33-0.65			Rom	**27**	
K(%)	Pre-harvest	WS	F			3.5-3.7				Rom	**27**	
	Mid-growth	WS	U				2.7-4.0			U	**5**	
	Root thickening	WS	F				2.9-3.3			Rom	**27**	
	Mid-growth	PYML	F	4			6			USA	**71**	
	Mid-growth	YML	S,D			2.0	2.5-4.5			Aust	**129**	
	Peak harvest	YML	F			1.0	1.3-1.5			Aust	**94**	
	28 DAS	Whole plant	Sand			0.9-2.2				UK	**5**	cv. Kingston; for 90% max relative growth rate
	Peak harvest	Root	F			1.3	1.4-1.9			Aust	**94**	
K_20%	Root thickening	PYML	F	<2.0			4.0-5.0			Rom	**27**	
S(%)	Roots, 1-3 cm diam.	WS	F				0.2-0.4			Aust	**80**	
	Peak harvest	WS	Peat				0.32-0.63			Can	**41**	
	28 DAS	Whole plant	Sand			0.12-0.18				UK	**53**	cv. Kingston; for 90% max relative growth rate
Ca(%)	Mid-growth	WS	U				1.2-2.0			U	**5**	
	Mid-growth	YML	S,D				1.4-3.0			Aust	**129**	
	Peak harvest	YML	F				1.8-2.0			Aust	**94**	
	28 DAS	Whole plant	Sand			2				UK	**53**	cv. Kingston; for 90% max relative growth rate
	Peak harvest	Whole plant	F				0.93			USA	**18**	
	Peak harvest	Root	F				0.30-0.35			Aust	**94**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
Mg(%)	Roots, 1-3 cm diam.	WS	F				0.4-0.6			Aust	**80**	
	Mid-growth	YML	S,D			0.15	0.30-0.55			Aust	**129**	
	Peak harvest	YML	F				0.35-0.40			Aust	**94**	
	28 DAS	Whole plant	Sand			0.06-0.08				UK	**53**	cv. Kingston; for 90% max relative growth rate
	Peak harvest	Root	F				0.12-0.15			Aust	**94**	
Na(%)	90 DAS	WS	Sand				0.66-4.50			USA	**21**	
Cl(%)	Roots, 1-3 cm diam.	WS	F				2-3			Aust	**80**	
	Peak harvest	YML	F				3.0-3.6			Aust	**94**	
	Peak harvest	Root	F				1.0-1.2			Aust	**94**	
Cu(mg/kg)	Mid-growth	YML	S,D			4	5-7			Aust	**129**	
	Mid-growth	YML	F	<5			10-25	>30		Aust	**96**	
	15 cm high	Mature leaf	F				4			Can	**68**	cv. Spartan Fancy
	28 DAS	Whole plant	Sand			<30				UK	**53**	cv. Kingston; for 90% max relative growth rate
Zn(mg/kg)	Mid-growth	WS	U				30-80			U	**5**	
	Peak harvest	WS	Peat				184-490			Can	**41**	
	Mid-growth	YML	S,D			18	20-50			Aust	**129**	
	15 cm high	Mature leaf	F				44			Can	**68**	cv. Spartan Fancy
	28 DAS	Whole plant	Sand			<30				UK	**53**	cv. Kingston; for 90% max relative growth rate
Mn(mg/kg)	Mid-growth	WS	U				50-100			U	**53**	
	Roots, 1-3 cm diam.	WS	F				40-100			Aust	**80**	
	Peak harvest	WS	Peat						>332	Can	**41**	
	Mid-growth	YML	S,D				190-350			Aust	**129**	
	28 DAS	Whole plant	Sand			<50				UK	**53**	cv. Kingston; for 90% max relative growth rate
Fe(mg/kg)	Peak harvest	WS	Peat	39-82						Can	**41**	
	Mid-growth	YML	S,D				120-350			Aust	**129**	
	28 DAS	Whole plant	Sand			466-818				UK	**53**	cv. Kingston; for 90% max relative growth rate
B(mg/kg)	Mid-growth	WS	U				30-80			U	**5**	
	Roots, 1-3 cm diam.	WS	F				20-40			Aust	**80**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
CARROT (*Daucus carota* L.) (ctd)												
B(mg/kg) (ctd)	Mid-growth	YML	S,D			20	29-35			Aust	**129**	
	Harvest	LB	F	<16			32-103		175-307	Can	**38**	
	15 cm high	Mature leaf	F				29			Can	**68**	cv. Spartan Fancy
	28 DAS	Whole plant	Sand			<30				UK	**53**	cv. Kingston; for 90% max relative growth rate
Mo(mg/kg)	Mid-growth	WS	U				0.5-1.5			U	**5**	
	Mat	WS	Soil				0.04			Can	**45**	cv. Sativa D.C.
	15 cm high	Mature leaf	F				0.15			Can	**45**	cv. Spartan Fancy
	15 cm high	Mature leaf	F				0.17			Can	**68**	cv. Spartan Fancy
	28 DAS	Whole plant	Sand			<3.6				UK	**53**	cv. Kingston; for 90% max relative growth rate
Co(mg/kg)	Pre-harvest	WS	F				0.11			USA	**21**	
	Harvest	Root	F				0.03			USA	**21**	
CAULIFLOWER (*Brassica oleracea* var. *botrytis*)												
N(%)	Buttoning	YMB	S,D				5.0-7.0			Aust	**20**	
	Curd onset	Middle fully developed leaves	U				3.0-4.5			U	**5**	
	Peak harvest	WL	F			2.0	2.5-3.5			Aust	**94**	
	Peak harvest	Curd	F			3.0	3.2-4.0			Aust	**94**	
	U	Leaf	F	2.7						Ind	**1**	cv. Snowball 16
	U	Curd	F	2.8						Ind	**1**	cv. Snowball 16
NO_3-N(%)	Buttoning	MRWL	F	<0.5			0.9			USA	**71**	
P(%)	Buttoning	YMB+P	F			0.46				Aust	**82**	cv. Arfak; for 95% max yield
	Buttoning	YMB+P	F			0.47				Aust	**82**	cv. Arfak; for 99% max yield
	Peak harvest	LB	S,D		0.3					Aust	**48**	
	Buttoning	WL	S,D				0.5-0.7			Aust	**129**	
	Peak harvest	WL	F			0.40	0.45-0.50			Aust	**94**	
	Peak harvest	WL	F			0.70	0.75-0.80			Aust	**94**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
P(%)	Curd onset	Middle fully developed leaves	U				0.4-0.7			U	**5**	
PO_4-P(%)	Buttoning	MRWL	F	0.25			0.35			USA	**71**	
K(%)	Buttoning	YMB	S,D				1.5-2.8			Aust	**20**	
	Buttoning	MRWL	F	2			4			USA	**71**	
	Peak harvest	LB	S,D		<2.5					Aust	**48**	
	Buttoning	WL	S,D				3.0-3.7			Aust	**129**	
	Peak harvest	WL	F			2.6	2.8-3.5			Aust	**94**	
	Peak harvest	Curd	F			4.0	4.2-4.5			Aust	**94**	
	Curd onset	Middle fully developed leaves	U				3.0-4.2			U	**5**	
S(%)	Peak harvest	LB	S,D				1.0-1.5			Aust	**48**	
Ca(%)	Peak harvest	WS	F				1.63			USA	**18**	
	Buttoning	YMB	S,D				1.0-2.0			Aust	**20**	
	Head (pre-buttoning)	WL	S,D				2.0-3.5			Aust	**129**	
	Buttoning	WL	S,D				0.7-0.8			Aust	**129**	
	Peak harvest	WL	F			2.0	2.3-2.7			Aust	**94**	
	Curd onset	Middle fully developed leaves	U				1.0-1.5			U	**5**	
	Peak harvest	Curd	F			0.30	0.35-0.40			Aust	**94**	
Mg(%)	Buttoning	YMB	S,D				0.15-0.30			Aust	**20**	
	Peak harvest	LB	S,D		<0.25					Aust	**48**	
	Buttoning	WL	S,D				0.24-0.26			Aust	**129**	
	Peak harvest	WL	F			0.35	0.40-0.45			Aust	**94**	
	Curd onset	Middle fully developed leaves	U				0.25-0.50			U	**5**	
	Peak harvest	Curd	F			0.20	0.24-0.30			Aust	**94**	
Cu(mg/kg)	Curd onset	Middle fully developed leaves	U				5-12			U	**5**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
CAULIFLOWER (*Brassica oleracea* var. *botrytis*) (ctd)												
Zn(mg/kg)	Curd onset	Middle fully developed leaves	U				30-70			U	**5**	
	U	Leaf	F	33			49			Ind	**1**	cv. Snowball 16
	U	Curd	F	35			50			Ind	**1**	cv. Snowball 16
Mn(mg/kg)	Curd onset	Middle fully developed leaves	U				30-100			U	**5**	
B(mg/kg)	5% heads formed	YMB	F	8-9			15-40			Can	**43**	cv. Snowball Y
	50% curds formed	YMB+P	F	11					37	Ind	**65**	cv. Pusa Snowball 1
	Curd onset	Middle fully developed leaves	U				30-80			U	**5**	
	Mat	Leaf	F	10					47-60	Ind	**66**	cv. Pusa Snowball 1
Mo(mg/kg)	Curd appearance	WS	Soil				0.07			Can	**45**	cv. Primosnow
	50 DAS	WS	F	0.1			2.0-5.0			NZ	**114**	No intermediate treatments
	Curd onset	Middle fully developed leaves	U				0.5-1.0			U	**5**	
CELERY (*Apium graveolens* var. *dulce*)												
N(%)	Pre-harvest	Trimmed WS	S,D				1.5-2.5			Aust	**20**	
	Peak harvest	Trimmed WS	F			1.5	1.8-2.4			Aust	**94**	
	30 DAS	YMB+P	Soil				4.8-5.8			NZ	**84**	
	Transplanting	YMB+P	Soil				4.4-6.2			NZ	**84**	
	Mid-growth	YMB+P	S,D				3.0-6.0			Aust	**20**	
	Mid-growth	YMB+P	F				2.5-3.5			USA	**127**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
N(%)	Mid-growth	Middle fully developed leaves	U				2.8-4.0			U	**5**	
	Pre-harvest	YMB+P	F				4.0-5.0			NZ	**84**	
NO_3-N(%)	Mid-growth	PYMB	F	0.5			0.9			USA	**71**	
	Pre-harvest	PYMB	F	0.4			0.6			USA	**71**	
P(%)	105 DAS	WS	Soil				0.25			USA	**13**	
	Pre-harvest	Trimmed WS	S,D				0.5-0.7			Aust	**20**	
	Peak harvest	Trimmed WS	F			0.50	0.55-0.70			Aust	**94**	
	30 DAS	YMB+P	Soil				0.6-1.0			NZ	**84**	
	Transplanting	YMB+P	Soil				0.3-0.6			NZ	**84**	
	Mid-growth	YMB+P	S,D				0.7-0.9			Aust	**20**	
	Mid-growth	YMB+P	F				0.3-0.5			USA	**127**	
	Pre-harvest	YMB+P	F				0.3-0.4			NZ	**84**	
	Mid-growth	P	F	0.23-0.26			0.29			USA	**21**	
	Peak harvest	P	F		0.43		0.64-0.90			USA	**21**	
	Harvest	P-outer leaves	F			0.55				USA	**111**	98% max yield
	Mid-growth	Middle fully developed leaves	U				0.20-0.35			U	**5**	
PO_4-P(%)	Mid-growth	PYMB		0.2			0.4			USA	**71**	
	Pre-harvest	PYMB		0.2			0.4			USA	**71**	
K(%)	Pre-harvest	Trimmed WS	S,D				3.5-5.3			Aust	**20**	
	Peak harvest	Trimmed WS	F			2.9	3.0-3.5			Aust	**94**	
	30 DAS	YMB+P	Soil				5.2-7.0			NZ	**84**	
	Transplanting	YMB+P	Soil				3.6-5.0			NZ	**84**	
	Mid-growth	YMB+P	S,D				3.8-8.0			Aust	**20**	
	Mid-growth	YMB+P	F				4.0-7.0			USA	**127**	
	Pre-harvest	YMB+P	F				1.7-4.0			NZ	**84**	
	Mid-growth	PYMB	F				4.0-7.0			USA	**71**	
	Pre-harvest	PYMB	F				3.0-5.0			USA	**71**	
	Harvest	P-outer leaves	F			7.7				USA	**111**	98% max yield

CELERY (*Apium graveolens* var. *dulce*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
K(%) (ctd)	Mid-growth	Middle fully developed leaves	U				2.4-3.8			U	**5**	
Ca(%)	Peak harvest	WS	F				1.61			USA	**18**	
	Pre-harvest	Trimmed WS	S,D				1.0-1.8			Aust	**20**	
	Peak harvest	Trimmed WS	F			1.50	1.55-1.70			Aust	**94**	
	30 DAS	YMB+P	Soil				1.6-2.0			NZ	**84**	
	Transplanting	YMB+P	Soil				1.6-2.0			NZ	**84**	
	Mid-growth	YMB+P	S,D				0.8-2.5			Aust	**20**	
	Pre-harvest	YMB+P	F				2.8-3.6			NZ	**84**	
	Mid-growth	Middle fully developed leaves	U				2.0-3.0			U	**5**	
Mg(%)	Peak harvest	WS	F		0.11-0.25		0.34-0.43			USA	**21**	
	Pre-harvest	Trimmed WS	S,D				0.20-0.28			Aust	**20**	
	Peak harvest	Trimmed WS	F			0.3	0.35-0.45			Aust	**94**	
	30 DAS	YMB+P	Soil				0.2-0.4			NZ	**84**	
	Transplanting	YMB+P	Soil				0.2-0.4			NZ	**84**	
	Mid-growth	YMB+P	S,D				0.25-0.50			Aust	**20**	
	Mid-growth	YMB+P	F				0.20-0.50			USA	**127**	
	Mid-growth	Middle fully developed leaves	U				0.25-0.50			U	**5**	
	Pre-harvest	YMB+P	F				0.3-0.4			NZ	**84**	
Na(%)	Pre-harvest	Trimmed WS	S,D				0.2			Aust	**20**	
	30 DAS	YMB+P	Soil				0.9-1.3			NZ	**84**	
	Transplanting	YMB+P	Soil				0.5-1.0			NZ	**84**	
	Mid-growth	YMB+P	S,D				0.2			Aust	**20**	
	Pre-harvest	YMB+P	F				0.4-0.8			NZ	**84**	
Cl(%)	Pre-harvest	Trimmed WS	S,D				2.0-4.0			Aust	**20**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Peak harvest	Trimmed WS	F				7.4-8.8			Aust	**94**	
	Mid-growth	YMB+P	S,D				2-3		>4	Aust	**20**	
Cu(mg/kg)	Pre-harvest	Trimmed WS	S,D				100-250			Aust	**20**	Contamination may be involved
	Mid-growth	YMB+P	S,D		<5		10-40			Aust	**20**	
	Mid-growth	Middle fully developed leaves	U				8-12			U	**5**	
Zn(mg/kg)	Pre-harvest	Trimmed WS	S,D				30-70			Aust	**20**	
	Mid-growth	YMB+P	S,D		<20		40-100			Aust	**20**	
	Mid-growth	P	F				30-100			USA	**3**	
	Mid-growth	Middle fully developed leaves	U				35-70			U	**5**	
Mn(mg/kg)	Pre-harvest	Trimmed WS	S,D				15-50			Aust	**20**	
	30 DAS	YMB+P	Soil				60-200			NZ	**84**	
	Transplanting	YMB+P	Soil				120-350			NZ	**84**	
	Mid-growth	YMB+P	S,D		<15		20-50			Aust	**20**	
	Pre-harvest	YMB+P	F				70-110			NZ	**84**	
	Mid-growth	Middle fully developed leaves	U				60-120			U	**5**	
Fe(mg/kg)	Pre-harvest	Trimmed WS	S,D				30-70			Aust	**20**	
	Mid-growth	YMB+P	S,D				80-200			Aust	**20**	
B(mg/kg)	Pre-harvest	Trimmed WS	S,D				40-60			Aust	**20**	
	Mid-growth	YMB+P	S,D		<25		30-60			Aust	**20**	
	Mid-growth	Middle fully developed leaves	U				40-60			U	**5**	
	Pre-harvest	Leaflets	F	20			68-432	720		Can	**38**	
	Peak harvest	P	F	16			28-75			Can	**38**	
Mo(mg/kg)	Mid-growth	Middle fully developed leaves	U				0.3-1.0			U	**5**	

CUCUMBER (*Cucumis sativus*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Mid-Fl	WS	F			3.5-4.4				Rom	**27**	
	Fl bud to small fruit	5th B from tip		3.80-4.49			4.50-6.00	>6.00		USA	**63**	Field type
	1st fully dev. fruit	5th B from tip		3.50-4.29			4.30-6.00	>6.00		USA	**63**	European type
	Small fruit to harvest	5th B from tip		3.50-3.99			4.00-5.50	>5.50		USA	**63**	Field type
	Fruit set	YML	F			2.2-2.8				Rom	**27**	
	3-8 leaves	PYML	F				0.4-0.7			Rom	**27**	
	Early Fl	PYML	Sand			0.2				UAR	**29**	
	Fruit set	PYML	F				0.58-0.63			Rom	**27**	
	Fruit set (6th leaf)	PYML	F	0.5			0.9			USA	**71**	Pickling cultivar
	Fl to fruit dev	Middle ML					2.8-5.0				**5**	
	U	ML					2.5-5.0			USA	**4**	
	U	Younger L	Sand	<3			5-7				**132**	
	U	Older L	Sand	<2.0			2.5-3.5				**132**	
	4th leaf	Sap of WS	F			4.6-4.9				Rom	**27**	
	Mid-Fl	Sap of PYML	F				0.58-0.63			Rom	**27**	
	Mature fruit	Fruit	F			2.4-3.7				Rom	**27**	Fruit centre sampled
NO_3-N(%)	U	ML, mid stem		0.1			0.1-1.6		1.8	Neth	**106**	
P(%)	7-10 DAS	WS	F		0.17-0.33		0.45-0.70			USA	**21**	
	Mid-Fl	WS	F			0.44				Rom	**27**	
	Fl bud to small fruit	5th B from tip		0.28-0.34			0.34-1.25	>1.25		USA	**63**	
	1st fully dev. fruit	5th B from tip		0.25-0.29			0.30-1.00	>1.0		USA	**63**	
	Small fruit to harvest	5th B from tip		0.22-0.24			0.25-1.00	>1.00		USA	**63**	
	Mid-Fl	PYML	F				0.04-0.05			Rom	**27**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Fruit set (6th leaf)	PYML	F	0.15			0.25			USA	**71**	Pickling cultivar
	Fruit set	YML	F			0.22				Rom	**27**	
	Fl to fruit dev	Middle ML					0.5-0.9				**5**	
	U	ML					0.2-0.6			USA	**4**	
	U	Younger L	Sand	<0.3			0.8-1.5				**132**	
	U	Older L	Sand	<0.2			0.6-1.3				**132**	
		ML, mid stem		0.13			0.35-0.74	>1.00		Neth	**106**	
	4th leaf	Sap of WS	F			>0.44				Rom	**27**	
	3-8 leaves	Sap of PYML	F				0.014-0.030			Rom	**27**	
	Fruiting	Sap of PYML	F				0.03			Rom	**27**	
K(%)	7-10 DAS	WS	F		1.60-1.80		3.30-4.20			USA	**21**	
	4th leaf	WS	F			3.15-3.32				Rom	**27**	
	Mid-Fl	WS	F			2.41-2.66				Rom	**27**	Pickling cultivar
	Fl bud to small fruit	5th B from tip		3.20-3.89			3.90-5.00	>5.00		USA	**63**	
	1st fully dev. fruit	5th B from tip		2.00-3.09			3.10-5.50	>5.50		USA	**63**	
	Small fruit to harvest	5th B from tip		2.80-3.29			3.50-4.50	>4.50		USA	**63**	
	Fl to fruit dev	Middle ML					4-7				**5**	
	Fruit set (6th leaf)	PYML	F	3			5			USA	**71**	
	U	ML					2.0-6.0			USA	**4**	
	U	L	Sand	0.8-1.5							**132**	
	U	ML, mid stem		0.5	2.1		2.5-5.4			Neth	**106**	
K_2O-K(%)	3-8 leaves	Sap of PYML	F				0.60-0.65			Rom	**27**	
	Mid-Fl	Sap of PYML	F				0.65-0.70			Rom	**27**	
	Fruiting	Sap of PYML	F				0.55-0.60			Rom	**27**	
S(%)	Fl bud to small fruit	5th B from tip		0.25-0.39			0.40-0.70	>0.70		USA	**63**	European type
	1st fully dev. fruit	5th B from tip		<0.4			0.4-0.7	>0.7		USA	**63**	Field type

CUCUMBER (*Cucumis sativus*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
S(%) (ctd)	Small fruit to harvest	5th B from tip		0.25-0.29			0.30-1.00	>1.00		USA	**63**	
	U	ML					0.3-0.5			USA	**4**	
	U	ML, mid stem		0.06			0.60-0.70			Neth	**106**	
Ca(%)	Fl bud to small fruit	5th B from tip		0.90-1.39			1.40-3.50	>3.50		USA	**63**	
	1st fully dev. fruit	5th B from tip		1.50-2.49			2.50-4.00	>4.00		USA	**63**	
	Small fruit to harvest	5th B from tip		1.00-1.49			1.50-4.00	>4.00		USA	**63**	
	Fl to fruit dev	Middle ML					0.7-1.1				**5**	
	U	ML					1.0-2.0			USA	**4**	Field type
	Harvest	YML	F				3.71			USA	**18**	
	U	ML, mid stem		2.3	2.3-4.3		5.7-11.4			Neth	**106**	
	U	Younger L	Sand	<0.7							**132**	European type
	U	Older L	Sand	<2.0							**132**	
Mg(%)	Fl bud to small fruit	5th B from tip		0.22-0.29			0.30-1.00	>1.00		USA	**63**	
	1st fully dev. fruit	5th B from tip		0.25-0.34			0.35-1.00	>1.00		USA	**63**	Field type
	Small fruit to harvest	5th B from tip		0.25-0.29			0.30-1.20	>1.20		USA	**63**	Field type
	Fl to fruit dev	Middle ML					0.3-0.6				**5**	Field type
	U	ML					0.3-0.6			USA	**4**	Field type
	U	ML, mid stem		0.22			0.60-1.30			Neth	**106**	Field type
	U	Younger L	Sand	<0.35			0.50-0.90				**132**	
	3-7 leaves	Sap of PYML	F				0.012-0.017			Rom	**27**	
	Mid-Fl	Sap of PYML	F				0.024-0.028			Rom	**27**	
	Fruiting	Sap of PYML	F				0.028-0.032			Rom	**27**	European type
Cl(%)	U	ML					0.5-1.0			USA	**4**	Field type
	All stages	Sap of PYML	F				0.06-0.10			Rom	**27**	Series of experiments

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
Cu(mg/kg)	Fl bud to small fruit	5th B from tip		4-6			7-20	>20		USA	**63**	Field type
	1st fully dev. fruit	5th B from tip		6-7			8-10	>20		USA	**63**	European type
	Small fruit to harvest	5th B from tip		3-7			8-20	>20		USA	**63**	
	2 weeks after 1st harvest	YML	F	<8			7-10		>10	Can	**39**	
	Fl to fruit dev	Middle ML					6-15				**5**	Field type
	U	ML					5-10			USA	**4**	
	U	ML, mid stem		2			7-10			Neth	**106**	Field type
	U	4-5th L		2	6-8		10-18				**89**	Field type
Zn(mg/kg)	Fl bud to small fruit	5th B from tip		15-24			25-100	>100		USA	**63**	
	1st fully dev. fruit	5th B from tip		18-24			25-200	>200		USA	**63**	
	Small fruit to harvest	5th B from tip		18-24			25-300	>300		USA	**63**	
	Harvest	YML	F				20-40			USA	**127**	
	Fl to fruit dev	Middle ML					30-80				**5**	
	U	ML					50-150			USA	**4**	
	U	ML, mid stem		9			90-150		900	Neth	**106**	
	U	4-5th L		20-25			40-80		150-180		**89**	
Mn(mg/kg)	Fl bud to small fruit	5th B from tip		20-49			50-300	301-500		USA	**63**	Field type
	1st fully dev. fruit	5th B from tip		25-49			50-300	301-500		USA	**63**	Field type
	Small fruit to harvest	5th B from tip		25-49			50-400	401-600		USA	**63**	Field type
	Fl to fruit dev	Middle ML					30-50				**5**	European type
	U	ML					100-200			USA	**4**	European type
	U	Younger L	Sand				30-60		>500		**132**	
	U	Older L	Sand				100-250		>800		**132**	
	U	ML, mid stem		12			100-300		>682	Neth	**106**	

CUCUMBER (*Cucumis sativus*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	U	4-5th L					40-100				**89**	
Fe(mg/kg)	Fl bud to small fruit	5th B from tip		30-49			50-300	>300		USA	**63**	European type
	1st fully dev. fruit	5th B from tip		35-49			50-300	>300		USA	**63**	
	Small fruit to harvest	5th B from tip		30-49			50-300	>300		USA	**63**	Field type
	U	ML					30-150			USA	**4**	Field type
	U	ML, mid stem		63			120-420			Neth	**106**	Field type
	U	L	Sand	<50			100-300				**132**	European type
	U	4-5th L		100-120			150-250				**89**	Field type
B(mg/kg)	Fl bud to small fruit	5th B from tip		22-24			25-60	61-200		USA	**63**	Field type
	1st fully dev. fruit	5th B from tip		25-29			30-100	>100		USA	**63**	Field type
	Small fruit to harvest	5th B from tip		22-29			30-100	101-250		USA	**63**	
	Harvest	YML	F				50-80			USA	**127**	
	2 weeks after lst harvest	YML	F	<20			40-120		>300	Can	**38**	
	Fl to fruit dev	Middle ML					25-40				**5**	European type
	U	ML					80-100			USA	**4**	Field type
	U	L	Sand	25			50-140		>400		**132**	
	U	ML, mid stem		20			40-120		300-500	Neth	**106**	European type
	U	4-5th L		20-25			30-60		240-280		**89**	
Mo(mg/kg)	Fl bud to small fruit	5th B from tip		0.4-0.7			0.8-3.3	>3.3		USA	**63**	
	1st fully dev. fruit	5th B from tip		0.4-0.7			0.8-3.3	>3.3		USA	**63**	
	Small fruit to harvest	5th B from tip		0.4-0.7			0.8-3.3	>3.3		USA	**63**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	U	ML					0.5-1.0			USA	4	
	Fl to fruit dev.	Middle ML					0.5-1.0				5	
	U	ML, mid stem		<0.3			0.8-3.3			Neth	106	
	U	4-5th L		0.5-0.6			1.0-5.0				89	

GARLIC (*Allium sativum*)

N(%)	Pre-bulb	YMB		5.5						Chile	108	
	Pre-bulb	YMB		4						USA	121	
	Bulbing	YMB		3						USA	121	
	Post-bulb	YMB		2						USA	121	
	Pre-bulb	YMB (no white portion)		4.00-4.39			4.40-5.00	>5.00		USA	63	
	Bulbing	YMB (no white portion)		3.00-3.39			3.40-4.50	>4.50		USA	63	
P(%)	Pre-bulb	YMB		0.5						Chile	108	
	Pre-bulb	YMB (no white portion)		0.25-0.29			0.30-0.60	>0.60		USA	63	
	Bulbing	YMB (no white portion)		0.23-0.27			0.28-0.50	>0.50		USA	63	
K(%)	Pre-bulb	YMB (no white portion)		3.00-3.89			3.90-4.80	>4.80		USA	63	
	Pre-bulb	YMB		2						Chile	108	
	Bulbing	YMB (no white portion)		2.50-2.99			3.00-4.50	>4.50		USA	63	
Ca(%)	Pre-bulb	YMB (no white portion)		0.60-0.79			0.80-1.50	>1.50		USA	63	
	Bulbing	YMB (no white portion)		0.80-0.99			1.00-1.80	>1.80		USA	63	
Mg(%)	Pre-bulb	YMB (no white portion)		0.10-0.14			0.15-0.25	>0.25		USA	63	
	Pre-bulb	YMB		0.2						Chile	108	
	Bulbing	YMB (no white portion)		0.18-0.22			0.23-0.30	>0.30		USA	63	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
GARLIC (*Allium sativum*) (ctd)												
Zn(mg/kg)	Pre-bulb	YMB		10						Chile	**108**	
Mn(mg/kg)	Pre-bulb	YMB		25						Chile	**108**	
LETTUCE (*Lactuca sativa*)												
N(%)	8 leaf	YMB+2*	F				4.10-5.46			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2*	F				3.00-4.36			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				4.21-4.51			USA	**88**	Leaf lettuce (e.g. Grand Rapids)
	7 DAT	YML	Sand,F			5.03				Aust	**60**	cv. Montello - crisphead
	14 DAT	YML	Sand,F			5.3	5.4			Aust	**60**	cv. Montello - crisphead
	21 DAT	YML	Sand,F			4.9	5.2			Aust	**60**	cv. Montello - crisphead
	35 DAT	YML	Sand,F			4.25	4.50			Aust	**60**	cv. Montello - crisphead
	49 DAT (Head)	YML	Sand,F			4.05	4.30			Aust	**60**	cv. Montello - crisphead
	56 DAT (Mat)	YML	Sand,F			4.0	4.3			Aust	**60**	cv. Montello - crisphead
	Mat	YML	Sand,F				4.01			Aust	**56**	cv. Fame - crisphead
	Mat	YML	Sand,F				3.44-3.57			Aust	**56**	cv. Coolguard - crisphead
	Head	WL	S,D			2.8	3.3-4.0			Aust	**129**	
	Head	WL	F				4.0-4.5			NZ	**85**	cv. Triumph
	Harvest	WL	F			3.0	3.1-3.5			Aust	**94**	cv. Great Lakes
	Harvest	YMHL	F			3.3	3.5-4.0			Aust	**94**	cv. Great Lakes
NO_3-N(%)	Harvest	WS	Sand			0.3				USA		
	Head	MRWL	F	0.4			0.8			USA	**71**	
	Harvest	MRWL	F	0.3			0.6			USA	**71**	
	Head	Upper part heart leaf	F		<0.20		0.20-0.40			Hun	**27**	
NO_3-N (mg/kg) petiole sap	7 DAT	PYML	Sand,F			500	1100			Aust	**60**	cv. Montello - crisphead
	14 DAT	PYML	Sand,F			300	700			Aust	**60**	cv. Montello - crisphead
	21 DAT	PYML	Sand,F			500	1000			Aust	**60**	cv. Montello - crisphead
	35 DAT	PYML	Sand,F			800	1400			Aust	**60**	cv. Montello - crisphead

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	49 DAT (Head)	PYML	Sand,F			950	1600			Aust	**60**	Head development week 6
	56 DAT (Mat)	YML	Sand,F			900	1500			Aust	**60**	cv. Montello - crisphead
P(%)	8 leaf	YMB+2*	F	0.20-0.38		0.38	0.44-0.58			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2*	F				0.34-0.44			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				0.38-0.46			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Mat	YML	Sand,F				0.43			Aust	**56**	cv. Fame - crisphead
	Mat	YML	Sand,F				0.7			Aust	**56**	cv. Coolguard - crisphead
	Harvest	YMHL	F			0.80	0.85-0.95			Aust	**94**	cv. Great Lakes
	28 DAS	Leaf	Peat-Ver				0.55-0.76			USA Can	**8**	
	Head	WL	S,D			0.3	0.4-0.6			Aust	**129**	
	Head	WL	F				0.4-0.6			NZ	**85**	cv. Triumph
	Harvest	WL	F			0.50	0.55-0.65			Aust	**94**	cv. Great Lakes
PO_4-P(%)	Head	MRWL	F	0.2			0.4			USA	**71**	
	Mid-Head	Leaf	F		<0.2		0.2-0.4			Hun	**27**	
	Harvest	MRWL	F	0.15			0.25			USA	**71**	
K(%)	8 leaf	YMB+2*	F	2.1-4.7		4.7	5.6-9.2			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2	Sand,F	5.47			10.00-10.30			Aust	**56**	cv. Coolguard - crisphead
	Mat (70DAS)	YMB	F				3.83-4.46			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	14 DAT	YML	Sand,F				7.1			Aust	**60**	cv. Montello-crisphead
	21 DAT	YML	Sand,F				7.4			Aust	**60**	cv. Montello-crisphead
	35 DAT	YML	Sand,F				8.4			Aust	**60**	cv. Montello-crisphead
	49 DAT (Head)	YML	Sand,F				10.4			Aust	**60**	cv. Montello-crisphead
	56 DAT (Mat)	YML	Sand,F				10.6			Aust	**60**	cv. Montello-crisphead
	Harvest	YMHL	F			4.0	5.5-6.0			Aust	**94**	cv. Great Lakes
	Harvest	WL	F			5.0	7.0-8.0			Aust	**94**	cv. Great Lakes
	Head	WL	S,D				5.0-8.0			Aust	**129**	
	Head	WL	F				4.5-5.5			NZ	**85**	cv. Triumph
	28 DAS	Leaf	Peat-Ver				8.2-10.5			USA Can	**8**	
	Head	MRWL	F	2			4			USA	**71**	
	Harvest	MRWL	F	1.5			2.5			USA	**71**	

LETTUCE (*Lactuca sativa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
K_2O-K(%)	Mid-Head	YMHL	F		<0.30		0.43-0.70			Hun	**27**	
S(%)	Harvest	WS	Soil				0.30-0.32			Neth	**116**	
Ca(%)	Head	WS	F			0.43				USA	**18**	
	8 leaf	YMB+2*	F				1.61-1.97			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2*	F				1.49-3.05			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				0.76-0.87			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Head	YMHL	F			0.50	0.55-0.75			Aust	**94**	cv. Great Lakes
	Mat	YML	Sand,F				1.49-1.78			Aust	**56**	cv. Coolguard - crisphead
	Head	WL	S,D				1.4-2.0			Aust	**129**	
	Head	WL	F			1.3	1.4-1.5			Aust	**94**	cv. Great Lakes
	28 DAS	Leaf	Peat-Ver				1.41-1.70			USA Can	**8**	
Mg(%)	8 leaf	YMB+2*	F				0.29-0.57			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2*	F				0.36-0.48			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				0.52-0.57			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Mat	YML	Sand,F				0.35-0.40			Aust	**56**	cv. Coolguard - crisphead
	Harvest	YMHL	F			0.30	0.32-0.60			Aust	**94**	cv. Great Lakes
	Head	WL	S,D				0.3-0.7			Aust	**129**	
	Head	WL	F				0.14-0.27			NZ	**85**	cv. Triumph
	Harvest	WL	F			0.50	0.55-0.60			Aust	**94**	cv. Great Lakes
	28 DAS	Leaf	Peat-Ver				0.31-0.39			USA Can	**8**	
Na(%)	Head	WL	F				0.02-0.20			NZ	**85**	cv. Triumph
	Head	WL	D				<0.5-1.0			Aust	**102**	
	28 DAS	Leaf	Peat-Ver				0.16-0.40			USA Can	**8**	
Cl(%)	Harvest	YMHL	F				2.90-2.95			Aust	**94**	cv. Great Lakes
	Head	WL	D				<2-3			Aust	**102**	
	Harvest	WL	F				5.3-5.7			Aust	**94**	cv. Great Lakes
Cu(mg/kg)	Mat (35 DAT)	WS	Sand				0.37		1.43	Korea	**135**	Leaf lettuce (e.g. Grand Rapids)
	8 leaf	YMB+2*	F				10-18			USA	**112**	*Oldest sound leaf, range of crisphead cultivars

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Mat	YMB+2*	F				4-12			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				8-11			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Mat	YML	Sand,F				13			Aust	**56**	cv. Fame - crisphead
	Head	WL	S,D			5	10-80			Aust	**129**	
	Head	WL	D		<10		10-35			Aust	**102**	
	Head	WL	Soil,F	<5			10-25			Aust	**95**	
	Head	WL	F				7-10			NZ	**85**	cv. Triumph
	28 DAS	Leaf	Peat-Ver			7-14				USA Can	**8**	
	5th leaf	Leaf	Sand						>21	UK	**28**	cv. Webbs Wonderful
Zn(mg/kg)	Head	WS	Soil						96-665	USA	**14**	
	Mat (35 DAS)	WS	Sand				1-17		1.92	Korea	**135**	Leaf lettuce (e.g. Grand Rapids)
	8 leaf	YMB+2*	F				45-81			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2*	F				24-70			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				49-67			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Head	WL	S,D			20	25-150			Aust	**129**	
	Head	WL	D		<30		30-100			Aust	**102**	
	Head	WL	F				26-34			NZ	**85**	cv. Triumph
	28 DAS	Leaf	Peat-Ver				39-71			USA Can	**8**	
Mn(mg/kg)	27 DAS	WS	Sand	14						USA	**125**	
	Harvest	WS	Soil						356-580	Neth	**117**	
	27 DAS	YMHL	Sand				63-130		333-1150	USA	**125**	
	Mat (70 DAS)	YMB	F				44-81			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Mat	YML	Sand,F				46-57			Aust	**56**	cv. Coolguard - crisphead
	27 DAS	WL	Sand				307-704		1845-5430	USA	**125**	
	Head	WL	S,D				30-200			Aust	**129**	
	Head	WL	F				30-90			NZ	**85**	cv. Triumph
	Head	WL	D				50-300			Aust	**102**	
	28 DAS	Leaf	Peat-Ver				14-136			USA Can	**8**	
Fe(mg/kg)	Mat (70 DAS)	YMB	F				109-120			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Mat	YML	Sand,F				189			Aust	**56**	cv. Fame - crisphead

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
LETTUCE (*Lactuca sativa*) (ctd)												
Fe(mg/kg) (ctd)	Mat	YML	Sand,F				172			Aust	**56**	cv. Coolguard - crisphead
	28 DAS	Leaf	Peat-Ver				130-192			NZ	**85**	cv. Triumph
	Head	WL	D				50-500			Aust	**102**	
Al(mg/kg)	Mat (70 DAS)	YMB	F				48-62			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Head	WL	D				<100			Aust	**102**	
	28 DAS	Leaf	Peat-Ver				28-221			USA Can	**8**	
B(mg/kg)	8 leaf	YMB+2*	F				5-37			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat	YMB+2*	F				11-31			USA	**112**	*Oldest sound leaf, range of crisphead cultivars
	Mat (70 DAS)	YMB	F				16-17			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
	Head	WL	S,D			20	25-55			Aust	**129**	
	Head	WL	F				30-50			NZ	**85**	cv. Triumph
	28 DAS	Leaf	Peat-Ver				16-30			USA Can	**8**	
Mo(mg/kg)	Head	WL	Soil	0.06			0.08-0.14			Can	**42**	
	Head	WL	F				0.08			USA	**119**	
	28 DAS	Leaf	Peat-Ver				1.2-2.7			USA Can	**8**	
Co(mg/kg)	Harvest	WS	F				6.25			USA	**21**	
Pb	Mat (35 DAS)	WS	Sand				0		0.76	Korea	**135**	Leaf lettuce (e.g. Grand Rapids)
	Mat (70 DAS)	YMB	F				7-8			USA	**49**	Leaf lettuce (e.g. Grand Rapids)
Cd	Mat (35 DAS)	WS	Sand				0.02		0.14	Korea	**135**	Leaf lettuce (e.g. Grand Rapids)
ONION (*Allium cepa*)												
N(%)	2 leaves	WS	F				4.57			USA	**136**	
	4 leaves	WS	F				3.63			USA	**136**	cv. Southport White Globe green bunching onions
	6 leaves	WS	F				2.6			USA	**136**	
	1/3 to 1/2 grown	WS (no white)		4.50-4.99			5.00-6.00	>6.00		USA	**63**	
	1/2 grown - Mat	WS (no white)		4.00-4.59			4.50-5.50	>5.50		USA	**63**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
N(%)	Mid-growth	YMB	S,D				2.5-3.5			Aust	**129**	
	Mid-growth	YMB					2.0-3.0				**5**	
	Peak harvest	YMB	F			1.3	1.50-1.75			Aust	**94**	cv. Pukekohe
	2 cm bulb	Bulb	F			2.75				Rom	**27**	
	Peak harvest	Bulb	F			1.00	1.20-1.35			Aust	**94**	cv. Pukekohe
NO_3N(%)	Bulbing	YMB	F		<0.2		0.2-0.4			Rom	**27**	
P(%)	2 leaves	WS	F				0.44			USA	**136**	
	4 leaves	WS	F				0.31			USA	**136**	
	6 leaves	WS	F				0.34			USA	**136**	
	1/3 to 1/2 grown	WS (no white)		0.25-0.34			0.35-0.50	>0.50		USA	**63**	
	1/2 grown - Mat	WS (no white)		0.25-0.29			0.30-0.45	>0.45		USA	**63**	
	Mid-growth	YMB	S,D				0.25-0.40			Aust	**129**	
	Mid-growth	YMB					0.25-0.40				**5**	
	Peak harvest	YMB	F			0.20	0.30-0.45			Aust	**94**	cv. Pukekohe
	2 cm bulb	Bulb	F			0.3-0.4				Rom	**27**	
	Peak harvest	Bulb	F			0.30	0.35-0.40			Aust	**94**	cv. Pukekohe
PO_4-P(%)	Bulbing	YMB	F		<0.2		0.2-0.4			Rom	**27**	
K(%)	2 leaves	WS	F				4.18			USA	**136**	
	4 leaves	WS	F				3.48			USA	**136**	cv. Southport White Globe green bunching onions
	6 leaves	WS	F				3.68			USA	**136**	
	1/3 to 1/2 grown	WS (no white)		3.50-3.99			4.00-5.50	>5.50		USA	**63**	
	1/2 grown - Mat	WS (no white)		3.00-3.49			3.50-5.00	>5.00		USA	**63**	
	Mid-growth	YMB	S,D				2.5-5.0			Aust	**129**	
	Mid-growth	YMB					2.5-3.5				**5**	
	Peak harvest	YMB	F			1.3	1.6-2.2			Aust	**94**	cv. Pukekohe
	13 weeks	MB	Sand	0.8			4.1			UK	**113**	
	2 cm bulb	Bulb	F				2.50-2.75			Rom	**27**	
	Peak harvest	Bulb	F			1.50	1.70-1.85			Aust	**94**	cv. Pukekohe

ONION (*Allium cepa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
K_2O-K(%)	Bulbing	YMB	F			2.0	3.5-4-0			Rom	**27**	
S(%)	1/3 to 1/2 grown	WS (no white)		0.30-0.49			0.50-1.00	>1.00		USA	**63**	
	1/2 grown - Mat	WS (no white)		0.30-0.49			0.50-1.00	>1.00		USA	**63**	
Ca(%)	2 leaves	WS	F				1.6			USA	**136**	
	4 leaves	WS	F				1.28			USA	**136**	cv. Southport White Globe green bunching onions
	6 leaves	WS	F				1.28			USA	**136**	
	1/3 to 1/2 grown	WS (no white)		0.80-0.99			1.00-2.00	>2.00		USA	**63**	
	1/2 grown - Mat	WS (no white)		1.00-1.49			1.50-2.20	>2.20		USA	**63**	
	Mid-growth	YMB					0.6-1.5				**5**	
	Mid-growth	YMB	S,D				1.5-3.5			Aust	**129**	
	Peak harvest	YMB	F				2.2-2.9			Aust	**94**	cv. Pukekohe
	13 weeks	MB	Sand	0.18			0.52			UK	**113**	
	Peak harvest	Bulb	F				0.4-0.5			Aust	**94**	cv. Pukekohe
	Peak harvest	Whole plant	F				0.88			USA	**18**	
Mg(%)	2 leaves	WS	F				0.47			USA	**136**	
	4 leaves	WS	F				0.35			USA	**136**	cv. Southport White Globe green bunching onions
	6 leaves	WS	F				0.29			USA	**136**	
	1/3 to 1/2 grown	WS (no white)		0.22-0.24			0.25-0.40	>0.40		USA	**63**	
	1/2 grown - Mat	WS (no white)		0.22-0.24			0.25-0.40	>0.40		USA	**63**	
	17 weeks	WS	Sand	0.34			0.37			UK	**113**	cv. Pukekohe
	Mid-growth	YMB	S,D				0.30-0.50			Aust	**129**	
	Mid-growth	YMB					0.25-0.50				**5**	
	Peak harvest	YMB	F				0.6-0.8			Aust	**94**	cv. Pukekohe
	Peak harvest	Bulb	F				0.15-0.20			Aust	**94**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
Na(%)	2 leaves	WS	F				0.41			USA	**136**	
	4 leaves	WS	F				0.34			USA	**136**	cv. Southport White Globe green bunching onions
	6 leaves	WS	F				0.29			USA	**136**	
Cl(%)	Peak harvest	YMB	F				4-5			Aust	**94**	cv. Pukekohe
	Peak harvest	Bulb	F				0.32-0.42			Aust	**94**	cv. Pukekohe
	Storage	Bulb	Salt plots				0.25		0.53-1.53	USA	**21**	Salt applied to field plots
Cu(mg/kg)	1/3 grown to Mat	WS (no white)		<15			15-35	>35		USA	**63**	
	Mid-growth	YMB	S,D				6-20			Aust	**129**	
	Mid-growth	YMB	S,D	<5			10-25			Aust	**98**	
	Mid-growth	YMB					7-15				**5**	
	Peak harvest	Leaves	F		<4		5-10			Rom	**27**	
Zn(mg/kg)	1/3 grown to Mat	WS (no white)		20-24			25-100	>100		USA	**63**	
	Mid-growth	YMB	S,D				20-55			Aust	**129**	
	Mid-growth	YMB	F				10-15			USA	**127**	
	Mid-growth	YMB	F				30-100			USA	**3**	
	Mid-growth	YMB					20-70				**5**	
Mn(mg/kg)	1/3 grown to Mat	WS (no white)		30-49			50-250	>250		USA	**63**	
	Mid-growth	YMB					40-100				**5**	
	Bulbing	YMB	F		<40		55-65			Rom	**27**	
Fe(mg/kg)	1/3 grown to Mat	WS (no white)		50-59			60-300	>300		USA	**63**	
B(mg/kg)	1/3 -1/2 grown	WS (no white)		18-22			22-60	>60		USA	**63**	
	1/2 grown - Mat	WS (no white)		20-24			25-75	>75		USA	**63**	
	Mid-growth	YMB	S,D				30-45			Aust	**129**	
	Mid-growth	YMB					30-50				**5**	
	Bulbing	YMB	F		<20		25-45			Rom	**27**	
Mo(mg/kg)	Mid-growth	YMB					0.15-0.30				**5**	

PEA (*Pisum sativum*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Late Fl	WS	F				3.1-3.6			USA	**127**	
	Mid-growth	LYMCL	S,D				2.7-3.5			Aust	**129**	
	Early Fl	Leaflets	F				4.8			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				2			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				4.8			USA	**92**	cv. Freezer 60
P(%)	Late Fl	WS	F				0.30-0.35			USA	**127**	
	Mid-growth	LYMCL	S,D				0.25-0.35			Aust	**129**	
	Early Fl	Leaflets	F				0.33			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				0.2			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				0.35			USA	**92**	cv. Freezer 60
	Early PF	Pods	F		0.23		0.57-0.78			USA	**21**	
K(%)	Late Fl	WS	F				2-3			Aust	**80**	
	Mid-growth	LYMCL	S,D				1.5-3.0			Aust	**129**	
	Pre-Fl	Leaflets	F			1.3				USA	**21**	
	Early Fl	Leaflets	F				2.4			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				1.2			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				1.2			USA	**92**	cv. Freezer 60
S(%)	Early PF	WS	F				0.2-0.4			Aust	**80**	
	Seed harvest	Seed	F				0.23			USA	**92**	cv. Freezer 60
Ca(%)	82 DAS	WS	Soil		1.69		2.74-4.39			USA	**21**	
	Early PF	WS	F				1.2-1.5			USA	**127**	
	Mid-growth	LYMCL	S,D				1.5-2.5			Aust	**129**	
	Early Fl	Leaflets	F				1.15			USA	**92**	cv. Freezer 60
	Early PF	Foliage	F				1.61			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				0.85			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				2.79			USA	**18**	
	Seed harvest	Seed	F				0.1			USA	**92**	cv. Freezer 60
Mg(%)	Early PF	WS	F				0.27-0.35			USA	**127**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Mid-growth	LYMCL	S,D				0.25-0.40			Aust	**129**	
	Early Fl	Leaflets	F				0.24			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				0.19			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				0.13			USA	**92**	cv. Freezer 60
Na(%)	Early PF	WS	F				<0.8			Aust	**80**	
	Early Fl	Leaflets	F				0.04			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				0.14			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				0.02			USA	**92**	cv. Freezer 60
Cl(%)	Early PF	WS	F				<2.0			Aust	**80**	
	Early Fl	Leaflets	F				0.63			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				0.3			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				0.1			USA	**92**	cv. Freezer 60
Cu(mg/kg)	Early PF	WS	F				5-10			Aust	**80**	
	Early Fl	Leaflets	F				7.4			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				4			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				8.3			USA	**92**	cv. Freezer 60
Zn(mg/kg)	Bud stage	WS	F				34-36		236-665	USA	**14**	
	Early PF	WS	F				>25			Aust	**80**	
	Early Fl	Leaflets	F				53			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				24			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				61			USA	**92**	cv. Freezer 60
Mn(mg/kg)	Early PF	WS	F				35-100			Aust	**80**	
	Early Fl	Leaflets	F				45			USA	**92**	cv. Freezer 60
	Early PF	Pods	F				14			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F				14			USA	**92**	cv. Freezer 60
	Seed harvest	Seed	F	12-15			16-26			USA	**21**	
B(mg/kg)	Early PF	WS	F				20-60			USA	**127**	
	Mid-growth	LYMCL	S,D				30-60			Aust	**129**	

POTATO (*Solanum tuberosum*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
N(%)	28 DAT	WS	Sand				5.6-5.9			USA	**17**	cv. Norland
	35 DAT	WS	Sand				6.0-6.4			USA	**16**	cv. Norland
	10-20 mm Tuber	YML	F			5.0-6.5				Aust	**74**	many cultivars
	10-20 mm Tuber	YML	F			5.3-6.6				USA	**107**	cv. Russet Burbank
	Start Fl	YML	F	<4.2	4.2-4.9		5.0-6.5	>6.5		Aust	**130**	
	Early Fl	YML	S,D			5.0	5.5-6.5			Aust	**129**	
	42 DAE	YML	F,S				4-5			USA	**125**	
	42 DAE	YML	F			4				S Afr	**69**	
	Late Fl	YML	F	<3.5	3.5-4.4		4.5-5.5	5.6-6.0	>6.0	Aust	**130**	
	Late Fl	YML	F,S,D			4.5				Aust	**129**	
	60 mm Tuber	YML	F				5.3-6.6			USA	**107**	cv. Russet Burbank
	Tuber bulking	YML		<2.5	2.5-3.5		>3.5			USA	**131**	
	100 mm Tuber	YML	F				4.0-5.6			Aust	**74**	cvv. Kennebec, Pontiac & R. Burbank
	49 DAP	PYML	F				3.7			Aust	**61**	cv. Sebago
	10% Fl	PYML	F				5.6-6.9			Can	**72**	
	57 DAP	PYML	F				3.4			Aust	**61**	cv. Sebago
	69 DAP	PYML	F				3.1			Aust	**61**	cv. Sebago
	Tubers half grown	PYML	F,S				2-3			USA	**71**	
	84 DAP	PYML	F				2.5			Aust	**61**	cv. Sebago
	104 DAP	PYML	F				1.7			Aust	**61**	cv. Sebago
	118 DAP	PYML	F				1.4			Aust	**74**	cvv. Coliban & Kennebec
	14 DAE	YFOL	Sand			5.0				Aust	**74**	cv. Atlantic
	28 DAE	YFOL	Sand			5.5				USA	**107**	cv. Russet Burbank
	42 DAE	YFOL	Sand			5.0				USA	**107**	cv. Russet Burbank
	56 DAE	YFOL	Sand, F			4.5				Aust	**61**	cv. Sebago
	70 DAE	YFOL	Sand, F			4.4				Aust	**61**	cv. Sebago

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	84 DAE	YFOL	Sand, F			3.2				Aust	**61**	cv. Sebago
	14 DAE	YFEL	Sand			4.6				Aust	**74**	cv. Crystal
	28 DAE	YFEL	Sand			5.1				USA	**107**	cv. Russet Burbank
	42 DAE	YFEL	Sand			4.7				USA	**107**	cv. Russet Burbank
	56 DAE	YFEL	Sand, F			4.6				Aust	**61**	cv. Sebago
	70 DAE	YFEL	Sand, F			3.9				Aust	**61**	cv. Sebago
	84 DAE	YFEL	Sand, F			3.2				Aust	**61**	cv. Sebago
	5-10 mm Tuber	PYFEL	F				2.9-4.2			Aust	**61**	cv. Sebago
	Early FI	MSL	F,S,D	<2.0	2.0-3.5		3.5-5.5			Aust	**93**	
NO_3-N(%)	<2 mm Tubers	PYML	F			2.7-3.0				Aust	**133**	cv. Kennebec
	Tuber initiation	PYML	F,S	<0.6				>0.9		USA	**71**	
	Early tuber set	PYML	F	<0.6	0.6-1.7		1.8-2.2	>2.2		USA	**124**	cvv. Russet Burbank, Sebago
	10mm Tuber	PYML	F			2.42-2.74				Aust	**133**	cvv. Atlantic & Kennebec
	31 DAE	PYML	Sand			0.2				USA	**123**	2nd leaf from terminal
	25 mm Tuber	PYML	F			1.88-2.31				Aust	**133**	cvv. Atlantic & Kennebec
	50-52 DAP	PYML	F				1.7-2.2			USA	**100**	cv. Russet Burbank
	42 DAE	PYML	F,S	<0.8				>1.2		USA	**71**	Plants 30 cm tall
	43 DAP	PYML	F				2.2			USA	**100**	cv. Russet Burbank
	45 DAE	PYML	F			0.91-0.96				Can	**37**	
	58-61 DAP	PYML	F			1.6				USA	**99**	cv. Shepody
	61-62 DAP	PYML	F				1.4-2.0			USA	**100**	cv. Russet Burbank
	Tubers half grown	PYML	F,S	<0.3				>0.5		USA	**71**	
	Mid season	PYML	F	<0.5	0.5-1.1		1.2-1.5	>1.5		USA	**124**	cvv. Russet Burbank, Sebago
	Late season	PYML	F	<0.4	0.4-0.5		0.6-0.8	>0.8		USA	**124**	cv. Russet Burbank
	14 DAE	PYFOL	Sand, F			1.6-2.1				Aust	**61**	cv. Sebago
	28 DAE	PYFOL	Sand, F			1.5				Aust	**61**	cv. Sebago
	42 DAE	PYFOL	Sand, F			1.2				Aust	**61**	cv. Sebago
	56 DAE	PYFOL	Sand			1.4				Aust	**50**	cv. Sebago
	70 DAE	PYFOL	Sand			0.7				Aust	**50**	cv. Sebago
	28 DAE	PYFEL	Sand, F			2.2				Aust	**61**	cv. Sebago

POTATO (*Solanum tuberosum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
NO_3-N(%) (ctd)	42 DAE	PYFEL	Sand, F			1.9				Aust	**61**	cv. Sebago
	35 mm Tuber	PYFEL	F			1.5-2.0				Aust	**133**	cv. Kennebec
	50 mm Tuber	PYFEL	F			1.0-1.6				Aust	**133**	cv. Kennebec
	56 DAE	PYFEL	Sand			1.7				Aust	**50**	cv. Sebago
	70 DAE	PYFEL	Sand			1.0				Aust	**50**	cv. Sebago
P(%)	28 DAT	WS	Sand				0.72-0.81			USA	**17**	cv. Norland
	35 DAT	WS	Sand				0.79-0.88			USA	**16**	cv. Norland
	Early Fl	WS	F				0.48-0.62			USA	**70**	cv. Atlantic
	Early Fl	YMB	F	<0.35			>0.47			Can	**72**	cv. Russet Burbank
	10-20 mm Tuber	YML	F				0.35-0.59			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D			0.30	0.35-0.55			Aust	**129**	
	Early Fl	YML	F			0.36-0.53				USA	**70**	cv. Atlantic
	Early Fl	YML	F	<0.23	0.23-0.29		0.30-0.55	>0.60		Aust	**130**	
	42 DAE	YML	F,S				0.2-0.4			USA	**127**	
	42 DAE	YML	F			0.25				S Afr	**69**	
	Late Fl	YML	F,S,D			0.25				Aust	**129**	
	Late Fl	YML	F	<0.20	0.20-0.24		0.25-0.45	>0.50		Aust	**130**	
	Tubers half grown	YML	F,S				0.2-0.4			USA	**127**	Tubers 5-7.5 cm
	Tubers half grown	YML	F,S				0.1-0.3			USA	**122**	
	60 mm Tuber	YML	F				0.37-0.45			Aust	**74**	cvv. Kennebec, Russet Burbank, Pontiac
	74 DAP	YML	F				0.32-0.33			USA	**107**	cv. Russet Burbank
	100 mm Tuber	YML	F				0.26			Aust	**74**	cvv. Kennebec, Russet Burbank, Pontiac
	Tuber bulking	YML		<0.15	0.15-0.25		>0.25			USA	**131**	cv. Russet Burbank
	Early Fl	MSL	F,S	<0.20	0.20-0.30		0.30-0.45			Aust	**93**	
	Tuber initiation	PYML	F			0.38-0.45				USA	**104**	
	40-45 DAE	PYML	F			0.29-0.35				Aust	**67**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Tuber bulking	PYML		<0.17	0.17-0.22		>0.22			USA	**131**	cv. Russet Burbank
	Tubers mature	PYML	F			0.14-0.17				USA	**104**	
	5-10 mm Tuber	PYFEL	F			0.41-0.53				Aust	**76**	cvv. Coliban & Kennebec
	5-10 mm Tuber	PYFEL	F				0.48-0.73			Aust	**74**	cvv. Coliban & Kennebec
	10 mm Tuber	PYFEL	F			0.60-0.87				Aust	**50**	cv. Delaware
PO_4-P(%)	Tuber initiation	PYML	F,S	<0.8				>1.6		USA	**71**	
	27 DAE	PYML	Sand			1.0				USA	**123**	
	42 DAE	PYML	F,S	<1.2				>2.0		USA	**71**	
	50 DAP	PYML	F				0.55-0.63			USA	**109**	cv. Russet Burbank
	Tubers half grown	PYML	F,S	<0.5				>1.0		USA	**71**	
	Tuber bulking	PYML		<0.07	0.07-0.1		>0.1			USA	**131**	cv. Russet Burbank
	90 DAP	PYML	F				0.22-0.36			USA	**109**	cv. Russet Burbank
K(%)	28 DAT	WS	Sand				5.43-5.45			USA	**17**	cv. Norland
	35 DAT	WS	Sand				4.67-6.05			USA	**16**	cv. Norland
	Early Fl	WS	F				3.4-3.9			USA	**70**	cv. Atlantic
	Early Fl	YMB	F	<3			>4			Can	**73**	cv. Russet Burbank
	10-20 mm Tuber	YML	F				4.7-6.8			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D			4.0	4.5-6.5			Aust	**129**	
	Early Fl	YML	F				7.0-8.2			USA	**70**	cv. Atlantic
	Early Fl	YML	F	<3.3	3.3-3.9		4.0-6.5	6.5-7.0	>7.0	Aust	**130**	
	42 DAE	YML	F,S				3.5-5.0			USA	**127**	
	42 DAE	YML	F			3				SAfr	**69**	
	Late Fl	YML	F,S,D			3.5				Aust	**129**	
	Late Fl	YML	F	<3.0	3.0-3.4		3.5-5.5	5.6-6.5	>6.5	Aust	**130**	
	Tubers half grown	YML	F,S				4-8			USA	**127**	
	10-15 mm Tuber	PYML	F			12-13						cv. Kennebec
	10-15 mm Tuber	PYML	F			11-12						cv. Russet Burbank

POTATO (*Solanum tuberosum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
K(%) (ctd)	60 mm Tuber	YML	F				3.60-4.92			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	74 DAP	YML	F				4.10-4.24			USA	**107**	cv. Russet Burbank
	100 mm Tuber	YML	F				3.08-4.88			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML		<2.25	2.25-3.50		>3.50			USA	**131**	cv. Russet Burbank
	Tuber initiation	PYML	F,S	<7			>9			USA	**127**	
	5-10 mm Tuber	PYML	F			11-12				Aust	**75**	cv. Kennebec
	5-10 mm Tuber	PYML	F				11.1-17.6			Aust	**74**	cvv. Coliban, Kennebec
	42 DAE	PYML	F,S	<9			>11			USA	**71**	
	Tubers half grown	PYML	F,S	<4			>6			USA	**71**	
	Tubers half grown	PYML	F,S				5-9			USA	**127**	
	Tuber bulking	PYML		<7	7-8		>8			USA	**131**	cv. Russet Burbank
	Early Fl	MSL	F,S,D	<3.0	3.0-4.0		4.5-6.5			Aust	**93**	Before tuber initiation K level not well defined
	Harvest	Tuber	F			1.94-2.19				Aust	**75**	cv. Coliban
S(%)	28 DAT	WS	Sand				0.33-0.43			USA	**17**	cv. Norland
	35 DAT	WS	Sand				0.41-0.46			USA	**16**	cv. Norland
	10-20 mm Tuber	YML	F				0.27-0.50			Aust	**74**	many cultivars
	Early - Late Fl	YML	F				0.3-0.5			Aust	**130**	
	Tuber bulking	YML		<0.12	0.12-0.20		>0.20			USA	**131**	cv. Russet Burbank
	5-10 mm Tuber	PYML	F		0.16-0.17		0.22-0.54			Aust	**74**	cvv. Coliban, Exton, Kennebec
	Tuber bulking	PYML		<0.15	0.15-0.20		>0.20			USA	**131**	cv. Russet Burabnk
	Early Fl	MSL	F,S,D	<0.2	0.2-0.3		0.3-0.5			Aust	**93**	
Ca(%)	10-20 mm Tuber	YML	F				0.58-1.67			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D			0.8	1.0-2.0			Aust	**96**	
	Early Fl	YML	F				0.39-0.59			USA	**70**	cv. Atlantic
	Early Fl	YML	F	<0.6	0.6-0.8		0.8-2.0	>2.0		Aust	**130**	
	42 DAE	YML	F,S				0.6-0.9			USA	**127**	
	Late Fl	YML	F,S,D			1.0				Aust	**129**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Late Fl	YML	F	<0.7	0.7-0.9		1.0-2.5	>2.5		Aust	**130**	
	60 mm Tuber	YML	F				0.66-1.35			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	74 DAP	YML	F				0.92-0.93			USA	**107**	cv. Russet Burbank
	100 mm Tuber	YML	F				1.00-1.13			Aust	**74**	cv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML		<0.3	0.3-0.6		>0.6			USA	**131**	
	5-10 mm Tuber	PYML	F				0.44-1.50			Aust	**74**	cvv. Coliban, Kennebec
	10-15 mm Tuber	PYML	F				0.5-1.5			Aust	**22**	
	31 DAE	PYML	Sand			0.15				USA	**123**	
	Tubers half grown	PYML	F,S				1.5-2.5			USA	**127**	
	Tuber bulking	PYML		<0.4	0.4-0.6		>0.6			USA	**131**	cv. Russet Burbank
	Early Fl	MSL	F,S,D	<0.7	0.7-1.2		1.2-2.5			Aust	**93**	
Mg(%)	28 DAT	WS	Sand				0.43-0.71			USA	**17**	cv. Norland
	35 DAT	WS	Sand				0.53-0.65			USA	**16**	cv. Norland
	Early Fl	WS	F				0.92-1.22			USA	**70**	cv. Atlantic
	10-15 mm Tuber	YML	F		0.35-0.40		0.40-0.80			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D		0.25	0.30	0.30-0.50			Aust	**129**	
	Early Fl	YML	F				0.74-1.08			USA	**70**	cv. Atlantic
	Early Fl	YML	F	<0.22	0.22-0.24		0.25-0.50	>0.50		Aust	**130**	
	42 DAE	YML	F,S				0.8-1.1			USA	**71**	
	Late Fl	YML	F,S,D			0.25				Aust	**129**	
	Late Fl	YML	F	<0.20	0.20-0.24		0.25-0.50	>0.50		Aust	**130**	
	Tubers half grown	YML	F,S				0.5-0.8			USA	**71**	
	60 mm Tuber	YML	F				0.47-0.68			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	74 DAP	YML	F				0.78-0.79			USA	**107**	cv. Russet Burbank
	100 mm Tuber	YML	F				0.57-0.74			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML		<0.15	0.15-0.25		>0.25			USA	**131**	cv. Russet Burbank
	5-10 mm Tuber	PYML	F				0.26-0.82			Aust	**74**	cvv. Coliban, Exton, Kennebec
	10-15 mm Tuber	PYML	F				0.3-0.4			Aust	**22**	
	Tubers half grown	PYML	F,S				0.5-1.5			USA	**71**	

POTATO (*Solanum tuberosum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Mg(%) (ctd)	Tuber bulking	PYML		<0.15	0.15-0.30		>0.30			USA	**131**	cv. Russet Burbank
	Early Fl	MSL	F,S,D	<0.35	0.35-0.50		0.50-1.00			Aust	**93**	
Na(%)	10-20 mm Tuber	YML	F				0.03-0.08	0.17-0.26		Aust	**74**	many cultivars
	Early Fl	YML	F				0-0.4	>0.4		Aust	**130**	
	Late Fl	YML	F				0-0.5	>0.5		Aust	**130**	
	60 mm Tuber	YML	F				0.04-0.10			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	100 mm Tuber	YML	F				0.06-0.40			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Early Fl	MSL	F,S,D	<0.05			0.05-0.50			Aust	**93**	
Cl(%)	28 DAT	WS	Sand				0.26-0.50			USA	**17**	cv. Norland
	35 DAT	WS	Sand				0.26-0.69			USA	**16**	cv. Norland
	10-20 mm Tuber	YML	F				0.73-2.35	1.73-3.04		Aust	**74**	many cultivars
	Early Fl	YML	F				0-3.0	3.0-3.5	>3.5	Aust	**130**	
	Late Fl	YML	F				0-3.5	3.6-4.0	>4.0	Aust	**130**	
	Tubers half grown	YML	F				1.8		>5.0	USA	**7**	
	60 mm Tuber	YML	F				1.51-2.43	3.56		Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	100 mm Tuber	YML	F				1.62-2.58	3.76		Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	5-10 mm Tuber	PYML	F				1.0-3.5	3.5-5.5	>5.5	Aust	**74**	cvv. Coliban, Exton, Kennebec
	Early Fl	MSL	F,S,D	<0.5			0.5-4.0		>4.0	Aust	**93**	
Cu(mg/kg)	Early Fl	WS	F				5-10			USA	**70**	cv. Atlantic
	75 DAE	WS	F	<8			11-20		>20	Can	**40**	
	10 mm Tuber	YML	F				5-20			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D				6-20			Aust	**129**	
	Early Fl	YML	F				4			USA	**70**	cv. Atlantic
	Early - Late Fl	YML	F	<3	3-5		5-20	30-100		Aust	**130**	
	60 mm Tuber	YML	F				5-17			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	74 DAP	YML	F				45-47			USA	**107**	cv. Russet Burbank
	100 mm Tuber	YML	F				3-4	37		Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML		<2	2-5		>5			USA	**131**	cv. Russet Burbank
	Tuber bulking	PYML		<2	2-4		>4			USA	**131**	cv. Russet Burbank
	5-20 mm Tuber	PYFEL					4-5			Aust	**110**	cv. Russet Burbank
	Early Fl	MSL	F,S,D	<3	3.5		5-10			Aust	**93**	
Zn(mg/kg)	Early Fl	WS	F		34-43					USA	**70**	cv. Atlantic
	10 mm Tuber	YML	F			24-48				Aust	**74**	many cultivars
	Early Fl	YML	F,S,D				20-60			Aust	**129**	
	Early Fl	YML	F			38-67				USA	**70**	cv. Atlantic
	Early - Late Fl	YML	F	<15	15-19		20-50			USA	**130**	
	Tubers half grown	YML	F,S				20-40			USA	**127**	
	74 DAP	YML	F			17				USA	**107**	cv. Russet Burbank
	Tuber bulking	YML		<15	15-20		>20			USA	**131**	
	Tuber bulking	PYML		<10	10-20		>20			USA	**131**	
	5-20 mm Tuber	PYFEL					54-101			Aust	**110**	cv. Russet Burbank
	Early Fl	MSL	F,S,D	<10	10-15		15-30			Aust	**93**	
Mn(mg/kg)	Early Fl	WS	F				36-70			USA	**70**	cv. Atlantic
	10-20 mm Tuber	YML	F				61-273			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D					>800		Aust	**129**	
	Early Fl	YML	F				22-37			USA	**70**	cv. Atlantic
	Early Fl	YML	F	<20	20-30		50-300	700-800	>800	Aust	**130**	
	Late Fl	YML	F,S,D					>1000		Aust	**129**	
	Late Fl	YML	F				50-300	800-1000	>1000	Aust	**130**	
	Tubers half grown	YML	F,S				30-450			USA	**127**	
	Tubers half grown	YML	F,S					>450		USA	**21**	
	60 mm Tuber	YML	F				92-144			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	74 DAP	YML	F				69-73			USA	**107**	cv. Russet Burbank

POTATO (*Solanum tuberosum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Mn(mg/kg) (ctd)	100 mm Tuber	YML	F				101-252			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML	F	<10	10-20		>20			USA	**131**	cv. Russet Burbank
	Tuber bulking	PYML	F	<20	20-30		>30			USA	**131**	cv. Russet Burbank
	10-15 mm Tuber	PYFEL	F				100-400			Aust	**22**	
	Early Fl	MSL	F,S,D	<20	20-40		40-300			Aust	**93**	
Fe(mg/kg)	Early Fl	WS	F				101-163			USA	**70**	cv. Atlantic
	10-20 mm Tuber	YML	F				96-549			Aust	**74**	many cultivars
	Early Fl	YML	F				53-104			USA	**70**	cv. Atlantic
	Early - Late Fl	YML	F				50-150			Aust	**130**	
	Tubers half grown	YML	F,S				70-150			USA	**127**	
	60 mm Tuber	YML	F				139-327			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	74 DAP	YML	F				94-96			USA	**107**	cv. Russet Burbank
	100 mm Tuber	YML	F				100-378			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML		<11	11-30		>30			USA	**131**	
B(mg/kg)	32 DAE	WS	F				12		>180	Can	**39**	
	49 DAP	WS	F	26			33-39		44-50	Aust	**101**	cv. Sebago
	71 DAP	WS	F				30-62	88-120		USA	**105**	cv. Russet Burbank
	129 DAP	WS	F				27-45	57-69		USA	**105**	cv. Russet Burbank
	10 mm Tuber	YML	F				18-37			Aust	**74**	many cultivars
	Early Fl	YML	F,S,D				30-60			Aust	**129**	
	Early - Late Fl	YML	F	<15	18-24		30-60			Aust	**131**	
	Tubers half grown	YML	F,S				30-40			USA	**127**	
	60 mm Tuber	YML	F				20.0-34.0	47.8		Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	74 DAP	YML	F				28-42			USA	**107**	cv. Russet Burbank
	75 DAE	YML	F	<15			21-50		>50	Can	**39**	
	100 mm Tuber	YML	F				16.1-19.5			Aust	**74**	cvv. Kennebec, Pontiac, Russet Burbank
	Tuber bulking	YML		<10	10-20		>20			USA	**131**	cv. Russet Burbank

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Tuber bulking	PYML		<10	10-20		>20			USA	**131**	cv. Russet Burbank
	5-20 mm Tuber	PYFEL					23-30			Aust	**110**	cv. Russet Burbank
	49 DAP	YFEL	F	19			24-26		30-31	Aust	**101**	cv. Sebago
	Early Fl	MSL	F,S,D	<10	10-20		20-50			Aust	**93**	
	71 DAP	Tuber	F				7.7-9.9	12.2		USA	**105**	cv. Russet Burbank
	129 DAP	Tuber	F				4.4-9.0			USA	**105**	cv. Russet Burbank
	Harvest	Tuber					4.7-7.7	13.8		USA	**105**	cv. Russet Burbank
Mo(mg/kg)	Early Fl	MSL	F,S,D		0.1		0.1-1.5			Aust	**93**	
Co(mg/kg)	Harvest	Tubers	S				0.4-2.0			USA	**21**	

PUMPKIN - MARROW, SQUASH (*Cucurbita pepo*)

N(%)	Mat	YMB	F			3.77			USA	**23**	cv. Lemondrop
	42 DAT	YML	Sand, F		4.9			5	Aust	**59**	cv. Blackjack
	56 DAT	YML	Sand, F		4.75			5.2	Aust	**59**	cv. Blackjack
	70 DAT (Early fruit)	YML	Sand, F		4.65			5.1	Aust	**59**	cv. Blackjack
	84 DAT	YML	Sand, F		4.75			5.1	Aust	**59**	cv. Blackjack
	98 DAT (Final harvest)	YML	Sand, F		4.4			5.1	Aust	**59**	cv. Blackjack
	Early fruiting	YML (9th node)	F		2.5	3.0-3.5			Aust	**94**	cv. Butternut Large
	Peak harvest	Fruit	F		2.0	2.2-2.3			Aust	**94**	cv. Butternut Large
NO_3-N(%)	14 DAT	YML	Sand, F		0.25			0.45	Aust	**59**	cv. Blackjack
	28 DAT	YML	Sand, F		0.35			0.6	Aust	**59**	cv. Blackjack
	42 DAT	YML	Sand, F		0.95			1.1	Aust	**59**	cv. Blackjack
	56 DAT	YML	Sand, F		0.9			1.55	Aust	**59**	cv. Blackjack
	70 DAT (Early fruit)	YML	Sand, F		0.75			1.00	Aust	**59**	cv. Blackjack
	84 DAT	YML	Sand, F		1.0			1.3	Aust	**59**	cv. Blackjack
	98 DAT (Final harvest)	YML	Sand, F		0.75			0.80	Aust	**59**	cv. Blackjack
	EF	PYMB	Sand		0.1				UAR	**29**	

PUMPKIN - MARROW, SQUASH (*Cucurbita pepo*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
NO_3-N (mg/kg) petiole sap	14 DAT	PYML	Sand, F			1650			5900	Aust	**59**	cv. Blackjack
	28 DAT	PYML	Sand, F			1500			2600	Aust	**59**	cv. Blackjack
	42 DAT	PYML	Sand, F			3500			4500	Aust	**59**	cv. Blackjack
	56 DAT	PYML	Sand, F			5800			6700	Aust	**59**	cv. Blackjack
	70 DAT (Early fruit)	PYML	Sand, F			3500			5900	Aust	**59**	cv. Blackjack
	84 DAT	PYML	Sand, F			5850			6700	Aust	**59**	cv. Blackjack
	98 DAT (Final harvest)	PYML	Sand, F			2950			6100	Aust	**59**	cv. Blackjack
P(%)	Mat	YMB	F				0.54			USA	**23**	cv. Lemondrop
	Early fruiting	YML (9th node)	F			0.5	0.6-0.7			Aust	**94**	cv. Butternut Large
	Peak harvest	Fruit	F			0.35	0.50-0.60			Aust	**94**	cv. Butternut Large
K(%)	Mat	YMB	F				5.21			USA	**23**	cv. Lemondrop
	Early fruiting	YML (9th node)	F			2.3	2.4-2.6			Aust	**94**	cv. Butternut Large
	Peak harvest	Fruit	F			2.5	2.7-3.1			Aust	**94**	cv. Butternut Large
Ca(%)	Mat	YMB	F				2.38			USA	**23**	cv. Lemondrop
	Early fruiting	YML (9th node)	F				4.8-4.9			Aust	**94**	cv. Butternut Large
	Harvest	YML	F				9.96			USA	**18**	
	Peak harvest	Fruit	F				0.15-0.20			Aust	**94**	cv. Butternut Large
Mg(%)	Mat	YMB	F				0.65			USA	**23**	cv. Lemondrop
	Early fruiting	YML (9th node)	F				0.90-1.05			Aust	**94**	cv. Butternut Large
	Peak harvest	Fruit	F				0.20-0.25			Aust	**94**	cv. Butternut Large
Cl(%)	Early fruiting	YML (9th node)	F				4.0-4.5			Aust	**94**	cv. Butternut Large
	Peak harvest	Fruit	F				0.75-0.90			Aust	**94**	cv. Butternut Large
Mo(mg/kg)	56 DAE	YML	Soil	0.2			5			USA	**21**	

ROCKMELON - MUSK, PERSIAN, HONEYDEW AND CASABA MELONS (*Cucumis melo*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
N(%)	Harvest	YMB	F				2.0-3.0			USA	**127**	
NO_3-N(%)	1st runners	PYMB (6th leaf from terminal)	F	0.8			1.2			USA	**71**	
	Eary FI	PYMB	Sand			0.3				UAR	**29**	
	Fruiting	PYMB (6th leaf from terminal)	F	0.5			0.9			USA	**71**	
	1st mature fruit	PYMB (6th leaf from terminal)	F	0.2			0.4			USA	**71**	
P(%)	7-10 DAE	WS	F		0.19-0.28		0.36-0.45			USA		
	Harvest	YMB	F				0.25-0.40			USA	**127**	
PO_4-P(%)	1st runners	PYMB (6th leaf from terminal)	F	0.2			0.4			USA	**71**	
	Fruiting	PYMB (6th leaf from terminal)	F	0.15			0.25			USA	**71**	
	1st mature fruit	PYMB (6th leaf from terminal)	F	0.1			0.2			USA	**71**	
K(%)	7-10 DAE	WS	F		1.1-1.6		2.9-3.2			USA	**21**	
	1st runners	PYMB (6th leaf from terminal)	F	4			6			USA	**71**	
	Fruiting	PYMB (6th leaf from terminal)	F	3			5			USA	**71**	
	1st mature fruit	PYMB (6th leaf from terminal)	F	2			4			USA	**71**	
	Harvest	PYMB	F				6.0-8.0			USA	**127**	
	Harvest	YMB	F				1.8-2.5			USA	**127**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
ROCKMELON - MUSK, PERSIAN, HONEYDEW AND CASABA MELONS (*Cucumis melo*) (ctd)												
Ca(%)	Harvest	PYMB	F				3.0-5.0			USA	**127**	
	Harvest	YMB	F				5.0-7.0			USA	**127**	
	Harvest	YML	F				7.27			USA	**18**	
Mg(%)	Harvest	PYMB	F				0.7-1.0			USA	**127**	
	Harvest	YMB	F				1.0-1.5			USA	**127**	
Zn(mg/kg)	Harvest	YMB	F				30-50			USA	**127**	
B(mg/kg)	Harvest	YMB	F				30-80			USA	**127**	
	Mat	Leaves	Sand				37-223		>923	USA	**21**	
SPINACH (*Spinacia oleracea*)												
N(%)	30-50 DAS	YMB+P	F				4.2-5.2			USA	**127**	
	Mat	YMB+P	F				4.0-6.0			USA	**127**	
	U	YML	U				3.8-5.0			U	**5**	
NO_3-N(%)	Mat	WS	Sand			0.4				USA	**77**	
	Mid-growth	PYMB	F	0.4			0.8			USA	**127**	
P(%)	30-50 DAS	YMB+P	F				0.48-0.58			USA	**127**	
	Mat	YMB+P	F				0.3-0.5			USA	**71**	
	U	YML	U				0.4-0.6			U	**5**	
	Mid-growth	PYMB	F	0.2			0.4			USA	**71**	
	48 DAS	Leaves	Soil		0.10		0.25-0.35			USA	**21**	
	Mat	Whole plant	F		0.27		0.72		1.17	USA	**21**	
K(%)	30-50 DAS	YMB+P	F				3.8-5.3			USA	**127**	
	Mat	YMB+P	F				3-4			USA	**127**	
	Mid-growth	PYMB	F	2			4			USA	**71**	
	U	YML	U				3.5-5.3			U	**5**	
Ca(%)	30-50 DAS	YMB+P	F				0.60-1.20			USA	**127**	
	Mat	YMB+P	F				0.60-1.00			USA	**127**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	U	YML	U				0.6-1.2			U	**5**	
	Mat	WS	Soil	0.53-0.92			0.66-1.39			USA	**21**	
	Mat	Foliage	F				0.97			USA	**18**	
Mg%	30-50 DAS	YMB+P	F				1.6-1.8			USA	**127**	
	Mat	YMB+P	F				1.6-1.8			USA	**127**	
	U	YML	U				0.35-0.8			U	**5**	
Cu(mg/kg)	30-50 DAS	YMB+P	F				45-65			USA	**127**	
	Mat	YMB+P	F				5-7			USA	**127**	
	U	YML	U				7-15			U	**5**	
Zn(mg/kg)	Cupping	WS	Soil				72-452		640-945	USA	**14**	
	30-50 DAS	YMB+P	F				50-75			USA	**127**	
	Mat	YMB+P	F				50-75			USA	**127**	
	U	YML	U				20-70			U	**5**	
Mn(mg/kg)	30-50 DAS	YMB+P	F				50-85			USA	**127**	
	Mat	YMB+P	F				30-60			USA	**127**	
	U	Stem + P	F	12			31			USA	**21**	
	U	YML	U				40-100			U	**5**	
Fe(mg/kg)	30-50 DAS	YMB+P	F				220-245			USA	**127**	
	Mat	YMB+P	F				220-245			USA	**127**	
B(mg/kg)	30-50 DAS	YMB+P	F				42-63			USA	**127**	
	Mat	YMB+P	F				40-60			USA	**127**	
	U	YML	U				40-80			U	**5**	
Mo(mg/kg)	Mat	WS	F				0.15-1.09			Can Aust	**42**	
	56 DAS	Leaves	Soil	0.1			1.6			USA	**21**	
	U	YML	U				0.3-1.0			U	**5**	
Co(mg/kg)	Mat	WS	F				0.20-0.67			USA	**21**	

SWEET CORN (*Zea mays* var. *rugosa*)

N(%)	45 DAS	4th LB	Sand	2.1			3.38			USA	**21**	
	Plant 30-50 cm	5th leaf from tip		3.50-3.99			4.00-4.50	>4.50		USA	**63**	

SWEET CORN (*Zea mays* var. *rugosa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
N(%) (ctd)	5-6 wks, 50-70 cm	5th leaf from tip		3.00-3.49			3.50-4.50	>4.50		USA	**63**	
	7-8 wks, tassel start	5th leaf from tip		2.50-2.69			2.70-3.50	>3.50		USA	**63**	
	Full tassel, silk start	5th leaf from tip		2.20-2.49			2.50-3.00	>3.00		USA	**63**	
	Silking	Ear leaf					2.7-3.5			USA	**4**	
	Silking	Ear leaf	F			3				USA	**83**	
	Silking	Ear leaf	F				2.6-3.5			USA	**127**	
	80% silking	Ear leaf	S,D			2.6	2.9-3.5			Aust	**129**	
	Post-silking	Ear leaf	F				2.8-3.5			USA	**127**	
	Prior tasselling	6th leaf from base	F	3.09			3.29-3.49			USA	**115**	
NO_3-N(%)	Tasselling	Midrib of 1st leaf above primary ear	F	0.05			0.15			USA	**71**	
P(%)	45 DAS	4th LB	Sand	0.17			0.52			USA	**21**	
	Plant 30-50 cm	5th leaf from tip		0.41-0.59			0.60-1.00	>1.00		USA	**63**	
	5-6 wks, 50-70 cm	5th leaf from tip		0.35-0.49			0.50-0.80	>0.90		USA	**63**	
	7-8 wks, tassel start	5th leaf from tip		0.30-0.39			0.40-0.70	>0.70		USA	**63**	
	Full tassel, silk start	5th leaf from tip		0.20-0.29			0.30-0.60	>0.60		USA	**63**	
	Silking	Ear leaf					0.2-0.4			USA	**4**	
	Silking	Ear leaf	F			0.25				USA	**83**	
	Silking	Ear leaf	F				0.2-0.3			USA	**127**	
	80% silking	Ear leaf	S,D			0.25	0.18-0.30			Aust	**129**	
	Post-silking	Ear leaf	F				0.18-0.30			USA	**127**	
	Tasselling	5th leaf from base	F				0.14-0.41			USA	**21**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Milk	Kernels	F		0.30		0.40-0.56			USA	**21**	
PO_4-P(%)	Tasselling	Midrib of 1st leaf above primary ear	F	0.05			0.10			USA	**71**	
K(%)	45 DAS	4th LB	Sand		2.60		3.64			USA	**21**	
	Plant 30-50 cm	5th leaf from tip		3.00-3.49			3.50-4.50	>4.50		USA	**63**	
	5-6 wks, 50-70 cm	5th leaf from tip		2.50-2.79			2.80-3.80	>3.80		USA	**63**	
	7-8 wks, tassel start	5th leaf from tip		2.00-2.49			2.50-3.50	>3.50		USA	**63**	
	Full tassel, silk start	5th leaf from tip		0.20-1.49			1.50-2.50	>2.50		USA	**63**	
	Tasselling	Midrib of 1st leaf above primary ear	F	2			4			USA	**71**	
	Silking	Ear leaf					1.7-2.5			USA	**4**	
	Silking	Ear leaf	F			1.9				USA	**83**	
	Silking	Ear leaf	F				1.8-2.5			USA	**127**	
	80% silking	Ear leaf	S,D			1.5	1.8-2.6			Aust	**129**	
	Post-silking	Ear leaf	F				1.8-2.8			USA	**127**	
S(%)	Plant 30-50 cm	5th leaf from tip		0.13-0.20			0.21-0.75	>0.75		USA	**63**	
	5-6 wks, 50-70 cm	5th leaf from tip		0.13-0.20			0.21-0.75	>0.75		USA	**63**	
	7-8 wks, tassel start	5th leaf from tip		0.13-0.20			0.21-0.75	>0.75		USA	**63**	
	Full tassel, silk start	5th leaf from tip		0.13-0.20			0.21-0.75	>0.75		USA	**63**	
	7 weeks	3rd leaf	Sand	0.10			0.89			UK	**113**	
	Silking	Ear leaf					0.1-0.3			USA	**4**	
Ca(%)	Plant 30-50 cm	5th leaf from tip		0.24-0.49			0.50-0.80	>0.80		USA	**63**	
	5-6 wks, 50-70 cm	5th leaf from tip		0.30-0.49			0.50-0.90	>0.90		USA	**63**	

SWEET CORN (*Zea mays* var. *rugosa*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Ca(%) (ctd)	7-8 wks, tassel start	5th leaf from tip		0.40-0.69			0.70-1.00	>1.00		USA	**63**	
	Full tassel, silk start	5th leaf from tip		0.50-0.69			0.60-1.10	>1.10		USA	**63**	
	Silking	Ear leaf					0.2-1.0			USA	**4**	
	Silking	Ear leaf	F			0.4				USA	**83**	
	Silking	Ear leaf	F				0.15-0.30			USA	**127**	
	80% silking	Ear leaf	S,D			0.30	0.90-1.30			Aust	**129**	
	Post-silking	Ear leaf	F				1.6-2.5			USA	**127**	
	Harvest	Foliage	F				0.7			USA	**18**	
Mg(%)	Plant 30-50 cm to full tassel & silk start	5th leaf from tip		0.15-0.19			0.20-0.50	>0.50		USA	**63**	
	Silking	Ear leaf					0.2-0.6			USA	**4**	
	Silking	Ear leaf	F			0.25				USA	**83**	
	Silking	Ear leaf	F				0.2-0.3			USA	**127**	
	80% silking	Ear leaf	S,D			0.15	0.30-0.80			Aust	**129**	
	Post-silking	Ear leaf	F				0.4-0.8			USA	**127**	
Cl(%)	Silking	Ear leaf	F		0.20-0.32		0.34-0.53			USA	**21**	
Cu(mg/kg)	Plant 30-50 cm to full tassel & silk start	5th leaf from tip		3-4			5-25	>25		USA	**63**	
	Silking	Ear leaf					6-20			USA	**4**	
	80% silking	Ear leaf	S,D			5	8-12			Aust	**129**	
	Post-silking	Ear leaf	F				8-12			USA	**127**	
Zn(mg/kg)	28 DAS	WS	Soil				41		255-713	USA	**14**	
	Plant 30-50 cm to full tassel & silk start	5th leaf from tip		15-19			20-150	>150		USA	**63**	
	80% silking	Ear leaf	S,D			20	20-40			Aust	**129**	
	Post-silking	Ear leaf	F				20-40			USA	**127**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Silking	Ear leaf					20-70			USA	**4**	
	Harvest	Leaves	F	25						USA	**3**	
Mn(mg/kg)	Plant 30-50 cm	5th leaf from tip		20-30			31-300	>300		USA	**63**	
	5-6 wks, 50-70 cm to full tassel & silk start	5th leaf from tip		20-30			31-300	300-1000		USA	**63**	
	Silking	Ear leaf					20-150			USA	**4**	
	80% silking	Ear leaf	S,D				20		50-140	Aust	**129**	
	Post-silking	Ear leaf	F						100-140	USA	**127**	
Fe(mg/kg)	Plant 30-50 cm to full tassel & silk start	5th leaf from tip		26-49			50-300	>350		USA	**63**	
	Silking	Ear leaf					21-250			USA	**4**	
	80% silking	Ear leaf	S,D			50	60-160			Aust	**129**	
	Post-silking	Ear leaf	F				60-160			USA	**127**	
	Harvest	Ear leaf	F	24-56				56-178		USA	**21**	
B(mg/kg)	Plant 25 cm high	WS	Soil				8-38		>98	Can	**40**	
	Plant 30-50 cm to full tassel & silk start	5th leaf from tip		5-7			8-25	26-60		USA	**63**	
	Silking	Ear leaf					4-25			USA	**4**	
	80% silking	Ear leaf	S,D			5	50-70			Aust	**129**	
	Post-silking	Ear leaf	F				40--70			USA	**127**	
Mo(mg/kg)	Plant 30-50 cm to full tassel & silk start	5th leaf from tip		0.3-0.8			0.9-10.0	>10		USA	**63**	
	Tasselling	Ear leaf	F	<0.1			>0.2			Can	**42**	
	Silking	Ear leaf					0.6-1.0			USA	**4**	

SWEET POTATO (*Ipomoea batatas*)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Harvest	WS	F				2.26-3.27			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB	Sand			4.2	4.3-4.5			Aust	**90**	
	44 DAT	YMB	F				3.52-4.14			USA	**126**	cvv. Centennial, Jewel
	58 DAT	YMB	F				2.65-3.24			USA	**126**	cvv. Centennial, Jewel
	Mid-growth	YML	F				3.2-4.2			USA	**127**	
	Harvest	Foliage	Sand			2.5				Jam	**118**	
	Harvest	LB	Sand	1.5			2.37-4.01			Ind	**15**	
	Harvest	4th leaf from terminal	F				2.37-4.01			SiLe	**35**	
NO_3 -N(%)	58 DAT	YMB	F				0.04-0.05			USA	**126**	cvv. Centennial, Jewel
	Mid-growth	P of 6th leaf	F	0.15			0.35			USA	**71**	
P(%)	Harvest	WS	F				0.28-0.45			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB	Sand			0.22	0.26-0.45			Aust	**90**	
	Mid-growth	YML	F				0.2-0.3			USA	**127**	
	4th leaf	LB	F		0.20		0.23			USA	**21**	
	Harvest	LB	Sand	0.01						Ind	**15**	
	Harvest	Foliage	Sand			0.12				Jam	**118**	
	Harvest	Tuber	F		0.06		0.12-0.22			USA	**21**	
PO_4-P(%)	Mid-growth	P of 6th leaf	F	0.1			0.2			USA	**71**	
K(%)	Harvest	WS	F				4.57-5.40			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB	Sand			4.0	4.7-6.0			Aust	**90**	
	Mid-growth	YML	F				2.9-4.3			USA	**127**	
	Mid-growth	P of 6th leaf	F	3			5			USA	**71**	
	Harvest	Foliage	Sand			0.75				Jam	**118**	
	Harvest	LB	Sand	0.5						Ind	**15**	
S(%)	28 DAT	YMB				0.34	0.35-0.45			Aust	**90**	
	Harvest	LB	Sand	0.08						Ind	**15**	
	Harvest	Foliage	Sand			0.08				Jam	**118**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
Ca(%)	Harvest	WS	F				0.73-0.74			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB	Sand			0.76	0.90-1.20			Aust	**90**	
	Mid-growth	YML	F				0.73-0.95			USA	**127**	
	Harvest	Foliage	Sand			0.2				Jam	**118**	
	Harvest	LB	Sand	0.2						Ind	**15**	
Mg(%)	Harvest	WS	F				0.36			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB	Sand			0.12	0.15-0.35			Aust	**90**	
	Mid-growth	YML	F				0.4-0.8			USA	**127**	
	Harvest	Foliage	Sand			0.16				Jam	**118**	
	Harvest	LB	Sand	0.06						Ind	**15**	
	Harvest	Leaves	F	0.40			0.71			USA	**21**	
	Harvest	Tubers	F	0.06			0.06			USA	**21**	
Zn(mg/kg)	Harvest	WS	F				40.7-44.8			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB				11	12-40		85	Aust	**90**	
Mn(mg/kg)	Harvest	WS	F				175-185			Aust	**55**	cvv. White Maltese, Nemagold
	28 DAT	YMB	Sand			19	26-500		1600	Aust	**90**	
	Mid-growth	YML	F				40-100			USA	**127**	
	Harvest	LB	Sand	2						Ind	**15**	
Fe(mg/kg)	28 DAT	YMB				33	45-80			Aust	**90**	
B(mg/kg)	Mid-growth	WS	Sand	16			118			USA	**21**	
	28 DAT	YMB	Sand			40			300-1000	Aust	**90**	
Co(mg/kg)	Harvest	Tuber	F				0.03			USA	**21**	

TOMATO (*Lycopersicon esculentum*)

N(%)	13 leaves	WS	F	<3	3-4		4-6			Aust	**2**	Sample 1 cm above ground when 7 leaves >1 cm long
	Fl at 2nd node	YML	F	<5.2	5.2-5.5		5.5-6.0			Aust	**2**	
	1st mature fruit	YML	F,S,D			3	4-6			Aust	**129**	
	Peak harvest	YML	F			2.0	2.2-2.5			Aust	**94**	cv. K10
	28 DAT (Fruit set 1st truss)	YOL	Sand, F			4.90	5.05			Aust	**57**	cv. Floradade

TOMATO (*Lycopersicon esculentum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
N(%) (ctd)	42 DAT (Flower 4th truss)	YOL	Sand, F			4.68	4.70			Aust	**57**	cv. Floradade
	56 DAT	YOL	Sand, F			4.75	4.81			Aust	**57**	cv. Floradade
	70 DAT (1st mature fruit)	YOL	Sand, F			4.45	4.90			Aust	**57**	cv. Floradade
	84 DAT	YOL	Sand, F			4.50	4.51			Aust	**57**	cv. Floradade
	98 DAT	YOL	Sand, F				4.93			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	YOL	Sand, F				5.14			Aust	**57**	cv. Floradade
	Flowering	BL	Sand, G				4.7			Spain	**88**	cv. Marmande
	Mat	BL	Sand, G				4.2			Spain	**88**	cv. Marmande
	Fruit forming	Leaves	F	<2.60			3.10-3.95			Rom	**27**	
	Peak harvest	Mature fruit	F			3.0	3.4-3.8			Aust	**94**	cv. K10
NO_3-N(%)	21 DAT	YMB	F				0.27-0.32			USA	**86**	cv. Castle King
	45 DAT	YMB	F				0.15-0.53			USA	**86**	cv. Castle King
	73 DAT	YMB	F				0.05-0.45			USA	**86**	cv. Castle King
	46 DAT	PYMB	Sand			0.05				USA	**36**	
	Early FI	PYMB	F	<0.80			>1.20			USA	**71**	Canning cultivar
	Fruit, 2.5 cm diam.	PYMB	F	<0.60			>1.00			USA	**71**	Canning cultivar
	Fruit at 1st colour	PYMB	F	<0.20			>0.40			USA	**71**	Canning cultivar
	28 DAT	YOL	Sand, F			0.22	0.25			Aust	**57**	cv. Floradade
	42 DAT (Fruit set 1st truss)	YOL	Sand, F			0.15	0.30			Aust	**57**	cv. Floradade
	56 DAT (Flower 4th truss)	YOL	Sand, F			0.08	0.12			Aust	**57**	cv. Floradade
	70 DAT (1st mature fruit)	YOL	Sand, F			0.26	0.29			Aust	**57**	cv. Floradade

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	DAT 84	YOL	Sand, F			0.2	0.3			Aust	**57**	cv. Floradade
	DAT 98	YOL	Sand, F				0.31			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	YOL	Sand, F				0.29			Aust	**57**	cv. Floradade
NO_3-N (mg/kg) petiole sap	14 DAT	PYOL	Sand, F			770	1240			Aust	**57**	cv. Floradade
	28 DAT (Fruit set 1st truss)	PYOL	Sand, F			740	1170			Aust	**57**	cv. Floradade
	Early flowering	PYOL	Peat-ver				2140			USA	**24**	cv. Celebrity greenhouse
	42 DAT (Flower 4th truss)	PYOL	Sand, F			830	1210			Aust	**57**	cv. Floradade
	Small fruit	PYOL	Peat-ver				1090			USA	**24**	cv. Celebrity greenhouse
	56 DAT	PYOL	Sand, F			650	1190			Aust	**57**	cv. Floradade
	70 DAT (1st mature fruit)	PYOL	Sand, F			1120	1790			Aust	**57**	cv. Floradade
	84 DAT	PYOL	Sand, F				2152			Aust	**57**	cv. Floradade
	98 DAT	PYOL	Sand, F				1600			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	PYOL	Sand, F				2070			Aust	**57**	cv. Floradade
	Mat	PYOL	Peat-ver				640			USA	**24**	cv. Celebrity greenhouse
	Various	PYFEL	Peat-ver				1100			USA	**25**	cv. Caruso
P(%)	13 leaves	WS	F	<0.40	0.40-0.65		0.65-1.20			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	Peak harvest	YMB	Peat	<0.13			>0.40			UK		cv. Kirford Cross
	Fl at 2nd node	YML	F	0.3	0.3-0.4		0.4-0.6			Aust	**2**	
	1st mature fruit	YML	F,S,D			0.3	0.4-0.8			Aust	**129**	
	Peak harvest	YML	F			0.65	0.7-0.8			Aust	**94**	cv. K10
	28 DAT (Fruit set 1st truss)	YOL	Sand, F				0.98			Aust	**57**	cv. Floradade
	42 DAT (Flower 4th truss)	YOL	Sand, F				0.98			Aust	**57**	cv. Floradade
	56 DAT	YOL	Sand, F				0.78			Aust	**57**	cv. Floradade

TOMATO (*Lycopersicon esculentum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
P(%) (ctd)	70 DAT (1st mature fruit)	YOL	Sand, F				0.85			Aust	**57**	cv. Floradade
	84 DAT	YOL	Sand, F				0.56			Aust	**57**	cv. Floradade
	98 DAT	YOL	Sand, F				0.8			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	YOL	Sand, F				0.9			Aust	**57**	cv. Floradade
	Flowering	BL	Sand, G				0.55			Spain	**88**	cv. Marmande
	Fruit forming	Leaves	F	0.10-0.35			0.30-0.90			Rom	**27**	
	Mat	BL	Sand, G				0.43			Spain	**88**	cv. Marmande
	Peak harvest	Mature fruit	F			0.60	0.70-0.75			Aust	**94**	cv. K10
PO_4-P(%)	Early Fl	PYMB	F	<2			>3			USA	**71**	Canning cultivar
	Fruit, 2.5 cm diam.	PYMB	F	<2			>3			USA	**71**	Canning cultivar
K(%)	13 leaves	WS	F	<3	3-4		4-6			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	8th leaf fully expanded	YMB	F			1.3				USA	**30**	
	10th leaf fully expanded	YMB	Sand, Soil		0.9		1.1			UK	**11**	cvv. Moneymaker and Amberley Cross
	Harvest	YMB	Sand			3.8				UK	**12**	cvv. Moneymaker and Amberley Cross
	Mat (Final harvest)	YMB	F				3.4-5.4			USA	**47**	
	8th leaf fully expanded	PYMB	F			4.6				USA	**30**	
	Early Fl	PYMB	F	3			6			USA	**71**	Canning cultivar
	Fruit, 2.5 cm diam	PYMB	F	2			4			USA	**71**	Canning cultivar
	Fruit at 1st colour	PYMB	F	1			3			USA	**71**	Canning cultivar
	10th leaf fully expanded	YML	Sand, Soil	1.2			1.4			UK	**11**	cvv. Moneymaker and Amberley Cross
	Fl at 2nd node	YML	F	<2	2-3		3-5			Aust	**2**	
	1st mature fruit	YML	F,S,D			2.5	3.0-5.0			Aust	**129**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	Peak harvest	YML	F			2	2.0-2.2			Aust	**94**	cv. K10
	Harvest	YML	Sand			5.2				UK	**12**	cvv. Moneymaker and Amberley Cross
	28 DAT (Fruit set 1st truss)	YOL	Sand, F				4.59			Aust	**57**	cv. Floradade
	42 DAT (Flower 4th truss)	YOL	Sand, F				4.32			Aust	**57**	cv. Floradade
	56 DAT	YOL	Sand, F				3.93			Aust	**57**	cv. Floradade
	70 DAT (1st mature fruit)	YOL	Sand, F				3.85			Aust	**57**	cv. Floradade
	84 DAT	YOL	Sand, F				4			Aust	**57**	cv. Floradade
	98 DAT	YOL	Sand, F				3.85			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	YOL	Sand, F				4.1			Aust	**57**	cv. Floradade
	Flowering	BL	SC,G				3.4			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				2.5			Spain	**88**	cv. Marmande
	Fruit forming	Leaves	F	0.3-1.2			1.4-5.3			Rom	**27**	
	10th leaf fully expanded	P	Sand, Soil		1.3		2.1			UK	**11**	cvv. Moneymaker and Amberley Cross
	Harvest	P	Sand			8.1				UK	**12**	cvv. Moneymaker and Amberley Cross
	Peak harvest	Mature fruit	F			4.0	4.2-5.2			Aust	**94**	cv. K10
S(%)	Peak harvest	YML	Soil				1.25			Neth	**116**	
	Fruit forming	Leaves+ stems	F	0.1			0.2			Rom	**27**	
	Peak harvest	Mature fruit	Soil				0.21-0.23			Neth	**116**	
Ca(%)	13 leaves	WS	F	<1.0	1.0-1.5		1.5-2.5			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	8th leaf fully expanded	YMB	F			1.2				USA	**30**	
	8th leaf fully expanded	PYMB	F			0.5				USA	**30**	
	Fl at 2nd node	YML	F	<1.0	1.0-1.5		1.5-2.5			Aust	**2**	
	1st mature fruit	YML	F,S,D				1.4-4.0			Aust	**129**	
	Peak harvest	YML	F			3.5	4.0-4.3			Aust	**94**	cv. K10
	28 DAT (Fruit set 1st truss)	YOL	Sand, F				2.2			Aust	**57**	cv. Floradade

TOMATO (*Lycopersicon esculentum*) (ctd)

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
Ca(%) (ctd)	42 DAT	YOL	Sand, F				1.78			Aust	**57**	cv. Floradade
	56 DAT	YOL	Sand, F				2.35			Aust	**57**	cv. Floradade
	70 DAT (1st mature fruit)	YOL	Sand, F				1.98			Aust	**57**	cv. Floradade
	84 DAT	YOL	Sand, F				2.05			Aust	**57**	cv. Floradade
	98 DAT	YOL	Sand, F				1.99			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	YOL	Sand, F				1.42			Aust	**57**	cv. Floradade
	Flowering	BL	SC,G				0.7			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				0.9			Spain	**88**	cv. Marmande
	Fruit forming	Leaves	F	0.58-1.30			3.20-5.70			Rom	**27**	
	Peak harvest	Foliage	F				5.35			USA	**18**	
	Peak harvest	Mature fruit	F			0.10	0.12-0.30			Aust	**94**	cv. K10
	Peak harvest	Fruit	F				0.09			USA	**18**	
Mg(%)	13 leaves	WS	F	<0.3	0.3-0.4		0.4-0.8			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	8th leaf fully expanded	YMB	F			0.1				USA	**30**	
	8th leaf fully expanded	PYMB	F			0.1				USA	**30**	
	Fl at 2nd node	YML	F	<0.25	0.25-0.40		0.40-0.60			Aust	**2**	
	1st mature fruit	YML	F,S,D			0.3	0.4-0.9			Aust	**129**	
	Peak harvest	YML	F			1.0	1.1-1.2			Aust	**94**	cv. K10
	28 DAT (Fruit set 1st truss)	YOL	Sand, F				0.71			Aust	**57**	cv. Floradade
	42 DAT (Flower 4th truss)	YOL	Sand, F				0.65			Aust	**57**	cv. Floradade
	56 DAT	YOL	Sand, F				0.69			Aust	**57**	cv. Floradade
	70 DAT (1st mature fruit)	YOL	Sand, F				0.51			Aust	**57**	cv. Floradade
	84 DAT	YOL	Sand,F				0.47			Aust	**57**	cv. Floradade

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
	98 DAT	YOL	Sand, F				0.51			Aust	**57**	cv. Floradade
	112 DAT (Final harvest)	YOL	Sand, F				0.52			Aust	**57**	cv. Floradade
	Flowering	BL	SC,G				0.7			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				0.9			Spain	**88**	cv. Marmande
	Fruit forming	Leaves	F	0.06-0.20			0.25-1.00			Rom	**27**	
	Peak harvest	Mature fruit	F			0.20	0.25			Aust	**94**	cv. K10
Na(%)	Fl at 2nd node	YML	F					0.4		Aust	**2**	
Cl(%)	Fl at 2nd node	YML	F					2		Aust	**2**	
	Peak harvest	YML	F				4.6-4.8			Aust	**94**	cv. K10
	Peak harvest	Mature fruit	F				1.3-1.4			Aust	**94**	cv. KI0
Cu(mg/kg)	13 leaves	WS	F				5-15			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	Fl at 2nd node	YML	F				5-15			Aust	**2**	
	1st mature fruit	YML	S,D				5-10			Aust	**129**	
	1st mature fruit	YML	F	<5			8-15		>15	Can	**39**	
	Flowering	BL	SC,G				13			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				13			Spain	**88**	cv. Marmande
Zn(mg/kg)	13 leaves	WS	F	<20	20-30		30-200			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	Budding	WS	Soil				50-150		250-500	USA	**14**	
	Fl at 2nd node	YML	F	<20	20-30		30-200			Aust	**2**	
	Mature fruit	YML	F	17			24-60			USA	**21**	
	Flowering	BL	SC,G				21			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				14			Spain	**88**	cv. Marmande
Mn(mg/kg)	13 leaves	WS	F	<25	25-50		50-500			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	Fl at 2nd node	YML	F	<25	25-50		50-500			Aust	**2**	
	1st mature fruit	YML	S,D			20	50-100			Aust	**129**	
	Flowering	BL	SC,G				21			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				14			Spain	**88**	cv. Marmande
Fe(mg/kg)	13 leaves	WS	F				100-300			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	Fl at 2nd node	YML	F				100-300			Aust	**2**	
	1st mature fruit	YML	S,D				100-300			Aust	**129**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic	Country	Ref	Comments
TOMATO (*Lycopersicon esculentum*) (ctd)												
Fe(mg/kg) (ctd)	Flowering (I)	BL	SC,G				254			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				170			Spain	**88**	cv. Marmande
Al(mg/kg)	Fl at 2nd node	YML	Soil				<200			USA	**62**	
B(mg/kg)	Plant 15 cm high	WS	Soil	<12			51-88		>172	Can	**40**	
	13 leaves	WS	F				40-100			Aust	**2**	Sample 1 cm above ground when 7 leaves > 1 cm long
	Fl at 2nd node	YML	F	<10			40-100			Aust	**2**	
	1st mature fruit	YML	S,D				30-100			Aust	**129**	
	1st mature fruit	YML	S	<10			30-75			Can	**38**	
	Flowering	BL	SC,G				20			Spain	**88**	cv. Marmande
	Mat	BL	SC,G				40			Spain	**88**	cv. Marmande
	Vegetative	BL	Sand	15			52			Spain	**19**	cv. Marglobe
	Early flowering	BL	Sand	20			60-85			Spain	**19**	cv. Marglobe
	Full flowering	BL	Sand	18-25			70-90			Spain	**19**	cv. Marglobe
Mo(mg/kg)	8 weeks	Leaves	Soil	0.13			0.68			Can	**42**	
	Fl at 2nd node	YML	F				0.6			Aust	**2**	
WATERMELON (*Citrullus lanatus*)												
N(%)	Mid-growth	YML	S,D			2	2.5-4.5			Aust	**129**	
NO_3-N(%)	Early fruiting	Sap of PYMB (6th leaf from terminal)	F	0.25	0.50		0.50-0.70			Rom	**27**	
	Early fruiting	Sap of PYMB (6th leaf from terminal)	F	0.5			0.9			USA	**71**	
	Early fruiting	Sap of PYMB (6th leaf from terminal)	F			0.7				USA	**34**	
P(%)	Mid-growth	YML	S,D			0.25	0.30-0.70			Aust	**129**	
	Mat	YMB	F				0.38-0.49			USA	**47**	

Nutrient	Growth Stage	Plant Part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Toxic			
PO_4-P(%)	Early fruiting	Sap of PYMB (6th leaf from terminal)	F	0.07	0.15		0.15-0.25			Rom	**27**	
	Early fruiting	Sap of tendril (7-8 days old)	F	0.17-0.30	0.45-0.70		0.75			Rom	**27**	
	Early fruiting	Sap of PYMB (6th leaf from terminal)	F	0.15			0.25			USA	**71**	
	Early fruiting	Sap of PYMB (6th leaf from terminal)	F			0.2				USA	**34**	
K(%)	Mid-growth	YML	S,D			2.0	2.5-3.7			Aust	**129**	
	Early fruiting	Sap of PYMB (6th leaf from terminal)	F	3			5			USA	**71**	
	Mat	YMB	F				2.6-2.9			USA	**47**	
K_20-K(%)	Early fruiting	Sap of PYMB (6th leaf from terminal)	F	1.5	3.0		3.5			Rom	**27**	
	Early fruiting	Sap of tendril (7-8 days old)	F	1.6-1.8	3.3-4.2		4.5			Rom	**27**	
	Early fruiting	Sap of PYMB (6th leaf from terminal)	F			4				USA	**34**	
Ca(%)	Mid-growth	YML	S,D				2.2-5.5			Aust	**129**	
	Mid-growth	YML	F				2.5-3.5			USA	**127**	
Mg(%)	Mid-growth	YML	S,D			0.15	0.40-1.20			Aust	**129**	
	Mid-growth	YML	F				0.6-0.8			USA	**127**	
Cu(mg/kg)	Mid-growth	YML	S,D			4	5-7			Aust	**129**	
	Mid-growth	YML	F				4-8			USA	**127**	
Zn(mg/kg)	Mid-growth	YML	S,D			17	20-60			Aust	**129**	
Mn(mg/kg)	Mid-growth	YML				15	60-240			Aust	**129**	
	Mid-growth	YML							>250	Aust	**102**	
Fe(mg/kg)	Mid-growth	YML	S,D				120-335			Aust	**129**	
B(mg/kg)	Mid-growth	YML	S,D			20	35-200			Aust	**129**	
	Mid-growth	YML	F				30-80			USA	**127**	
	Mid-growth	YML	F	<25						Aust	**102**	

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Summarised Guidelines for Diagnosing Nutrient Disorders in Selected Vegetable Crops

The main tabular compilation in this chapter provides a diverse range of plant tests for diagnosing nutrient deficiencies and confirming nutrient adequacy in vegetable crops. These involve sampling different plant plarts at various stages of growth for different nutrients or nutrient fractions.

The purpose of the tables produced below is to summarise this body of information into a set of interpretation guidelines for diagnosing nutrient deficiencies and adequacy for four important vegetable crops. The authors consider these guidelines are well supported by published research and can be used with confidence, provided they are treated with caution until validated by local experience.

For each species, the guidelines are derived for a specified plant part sampled at two or more stages of growth. They have been derived from the main table of this chapter, with emphasis being placed on experimental calibrations, validated by commercial surveys for crops grown outdoors in Australia.

LETTUCE (head) (*Lactuca sativa*)

Nutrient	Growth Stage	Plant Part	Critical	Adequate
N(%)	20 DAT	YML	4.9	5.2
	Head	YML (WL)	4	4.1-4.5
	Maturity	YML (WL)	3.3-4.0	3.5-4.5
NO_3-N(%)	Head	MRWL		0.8
	Maturity	MRWL		0.6
NO_3-N petiole sap	20 DAT	PYML	500	1000
(mg/kg)	Head	PYML(WL)	950	1600
	Maturity	PYML(M)	900	1500
P(%)	20 DAT	YML		0.44-0.76
	Head	YML(WL)	0.3	0.50-0.60
	Maturity	YML (WL)	0.4	0.50-0.70
K(%)	20 DAT	YML		7.4-10.5
	Head	YML (WL)		7.5-10.4
	Maturity	YML(WL)		7.0-10.6
Ca(%)	20 DAT	YML		0.68-1.70
	Head	YML (WL)	1.3	1.40-1.50
	Maturity	YML (WL)		1.49-1.86
Mg(%)	20 DAT	YML		0.32-0.39
	Head	YML(WL)		0.30-0.70
	Maturity	YML(WL)		0.35-0.71
S(%)	20 DAT	YML		0.21-0.27
	Head	YML(WL)		0.28-0.32
	Maturity	YML(WL)		0.27-0.35
Cu (mg/kg)	Head	YML(WL)		7-35
	Maturity	YML(WL)		7-35
Zn (mg/kg)	Head	YML(WL)	20	25-100
	Maturity	YML(WL)		24-70

LETTUCE (head) (*Lactuca sativa*)				
Nutrient	**Growth Stage**	**Plant Part**	**Critical**	**Adequate**
Mn (mg/kg)	Head	YML(WL)		30-200
	Maturity	YML(WL)		30-200
Fe (mg/kg)	Head	YML(WL)		50-200
	Maturity	YML(WL)		50-200
Al (mg/kg)	Head	YML(WL)		<100
	Maturity	YML(WL)		<100
B (mg/kg)	Head	YML(WL)	20	25-55
	Maturity	YML(WL)		11-31
Mo (mg/kg)	Head	YML(WL)		0.08-0.14

TOMATO (fresh market) (*Lycopersicon esculentum*)			
Plant part: YOL			
Nutrient	**Growth Stage**	**Critical**	**Adequate**
N(%)	Early flower	4.9	5.0-6.0
	Early fruit set		4.6-6.0
	1st mature fruit	4.45	4.50-4.60
	Mid harvest		4.5-5.5
NO_3-N petiole sap (mg/kg)	Early flower	760	1100-2140
	Early fruit set	760	1000-1200
	1st mature fruit	1120	1790
	Mid harvest		1600
P(%)	Early flower		0.4-0.9
	Early fruit set		0.3-0.9
	1st mature fruit		0.4-0.9
	Mid harvest		0.6-0.8
K(%)	Early flower		3.8-6.0
	Early fruit set		3.3-5.0
	1st mature fruit		3.0-5.0
	Mid harvest		3.4-5.2
Ca(%)	Early flower		1.5-2.5
	Early fruit set		1.4-3.2
	1st mature fruit		1.4-4.0
	Mid harvest		2.0-4.3
Mg(%)	Early flower		0.4-0.6
	Early fruit set		0.39-0.71
	1st mature fruit		0.4-1.2
	Mid harvest		0.51-1.30
Na(%)	Early flower		0.1-0.4
Cl(%)	Early flower		0.5-2.5

TOMATO (fresh market) (*Lycopersicon esculentum*)			
Nutrient	**Growth Stage**	**Plant Part**	**Critical**
Cu (mg/kg)	Early flower		5-15
	Early fruit set		5-15
Zn (mg/kg)	Early flower		30-100
	Early fruit set		30-100
Mn (mg/kg)	Early flower		50-250
	Early fruit set		50-100
Fe (mg/kg)	Early flower		60-300
	Early fruit set		60-300
Al (mg/kg)	Early flower		<200
B (mg/kg)	Early flower		30-100
	Early fruit set		30-100
Mo (mg/kg)	Early flower		0.6

SWEET POTATO (*Ipomoea batatas*)				
Nutrient	**Growth Stage**	**Plant Part**	**Critical**	**Adequate**
N(%)	28 DAT	YML	4.2	4.3-4.5
	Mid growth	YML		2.7-4.5
	Harvest	WS		2.3-3.3
P(%)	28 DAT	YML	0.22	0.26-0.45
	Mid growth	YML		0.20-0.30
	Harvest	WS		0.28-0.45
K(%)	28 DAT	YML	4.0	4.7-6.0
	Mid growth	YML		2.9-5.0
	Harvest	WS		4.6-5.4
Ca(%)	28 DAT	YML	0.76	0.90-1.20
	Mid growth	YML		0.73-0.95
	Harvest	WS		0.73-0.74
Mg(%)	28 DAT	YML	0.12	0.15-0.35
	Harvest	WS		0.36
S(%)	28 DAT	YML	0.34	0.35-0.45
Zn (mg/kg)	28 DAT	YML	11	12-40
	Harvest	WS		20-45
Mn(mg/kg)	28 DAT	YML	19	26-500
	Mid growth	YML		40-100
	Harvest	WS		40-200
Fe (mg/kg)	28 DAT	YML	33	45-80
B (mg/kg)	28 DAT	YML	40	45-75
	Harvest	WS		118

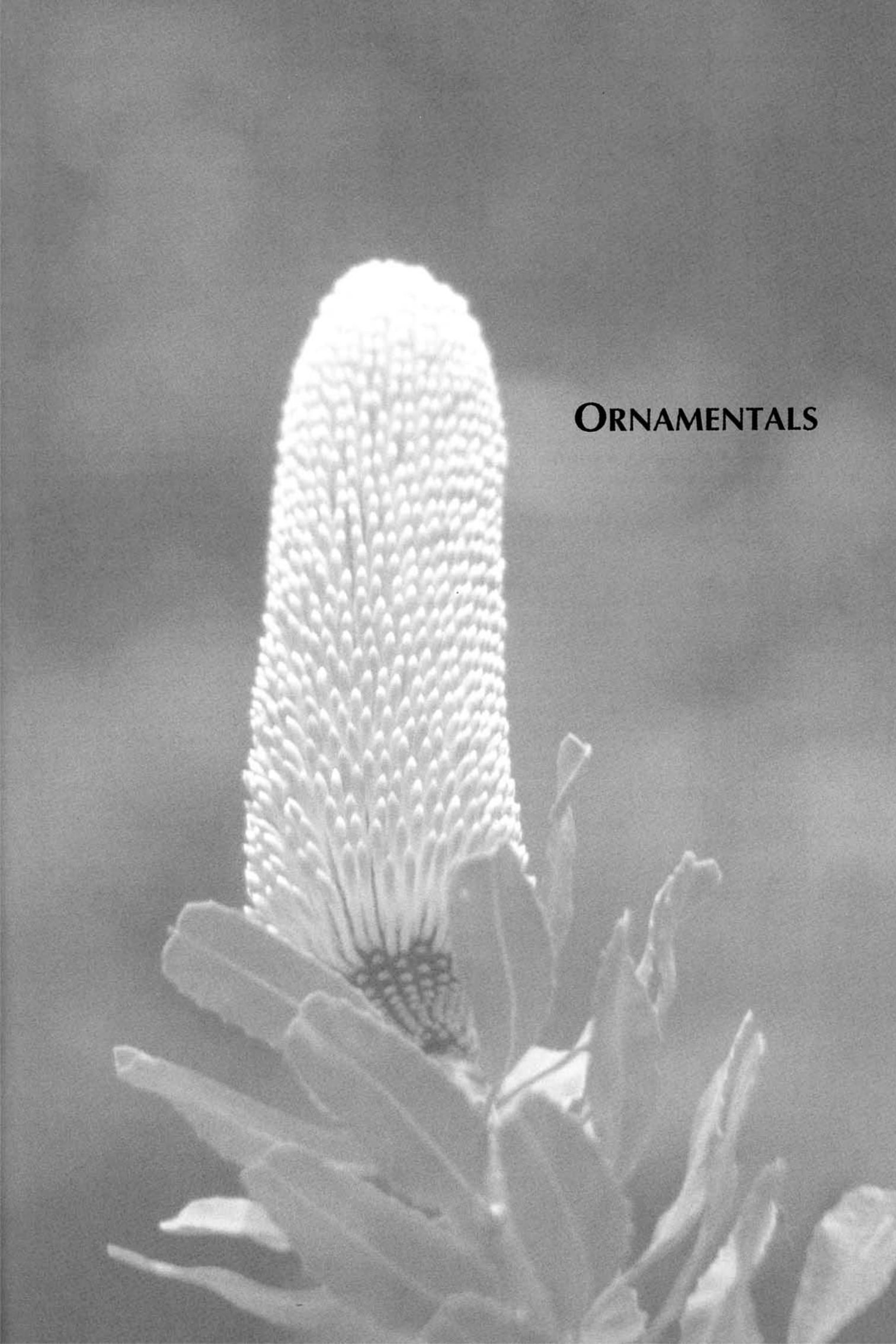
POTATO, IRISH POTATO (*Solanum tuberosum* L.)

Solanum tuberosum L. cv. differences in diagnostic standards relate to differences in maturity.

Growth stage: Defined by the tuber size ie. length of longest tuber.

Plant Part: Petiole-rachis (Petiole) of 5th leaf from growing terminal. (4-5 leaf is often referred to as YML) = PYML

Nutrient	Growth Stage	Def	Low	Adequate	High	Cultivar
NO_3-N(%)	5 mm	<1.4	1.4-1.7	1.8-3.0	>3.00	cv. Atlantic
	50 mm	<1.2	1.20-1.49	1.50-2.75	>2.75	
	5 mm	<1.8	1.80-2.24	2.25-3.50	>3.5	cv. Kennebec
	30 mm	<1.2	1.20-1.49	1.50-2.75	>2.75	
	5 mm	<1.4	1.4-1.7	1.8-2.8	>2.8	cv. Russet
	90 mm	<1.2	1.2-1.4	1.5-2.5	>2.5	Burbank
K(%)	5 mm	<8	8-9	10-16	>16	cv. Atlantic
	90 mm	<6	6-7	8-14	>14	
	15 mm	<9	9	10-16	>16	cv. Kennebec
	120 mm	<6	6-7	8-13	>13	
	5 mm	<8	<8-9	10-15	>15	cv. Russet
	150 mm	<6	6-7	8-13	>13	Burbank
P(%)	5 mm	<0.32	0.32-0.39	0.40-0.60	>0.60	cv. Atlantic
	40 mm	<0.24	0.24-0.29	0.30-0.50	>0.50	
	15 mm	<0.40	0.40-0.47	0.48-0.65	>0.65	cv. Kennebec
	40 mm	<0.24	0.24-0.29	0.30-0.45	>0.45	
	5 mm	<0.30	0.30-0.34	0.35-0.60	>0.60	cv. Russet
	60 mm	<0.25	0.25-0.29	0.30-0.55	>0.55	Burbank
Ca(%)	5 mm	<0.3	0.3-0.4	0.5-1.5	>1.5	
	90 mm	<0.3	0.3-0.5	0.6-1.8	>1.8	
Mg(%)	5 mm	<0.15	0.15-0.29	0.30-0.75	>0.75	
	90 mm	<0.15	0.15-0.59	0.60-1.60	>1.6	
S(%)	5 mm	<0.16	0.16-0.19	0.20-0.35	>0.35	
	90 mm	<0.12	0.12-0.14	0.15-0.30	>0.30	
Cu(mg/kg)	5 mm	<2	2-4	5-16	>16	
	90 mm	<2	2	3-10	>10	
Zn(mg/kg)	5 mm	<20	20-29	30-110	>110	
	90 mm	<15	15-19	20-80	>80	
Mn(mg/kg)	5 mm	<10	10-19	20-100	>100	
	90 mm	<15	15-29	30-225	>225	
B(mg/kg)	5 mm	<10	10-19	20-40	>40	



ORNAMENTALS

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9. ORNAMENTALS

G.H. Price, G.C. Cresswell and K.A. Handreck

INTRODUCTION

Many ornamental plants are valued for their appearance and shelf-life and are grown in soilless media or intensively grown in the greenhouse or field. They are often fertilized with major and micro-nutrients at luxury rates. In the case of soilless media, either extreme leaching of soluble nutrients such as nitrogen and potassium, or higher applications of micronutrients may cause damage to the saleable parts of the plant. Hence, ornamentals are prone to a wider range of nutrient disorders than other species and yet plant analysis criteria for these plants remain poorly developed.

In this chapter, the primary aim is to present values for nutrient concentrations of whole plants or plant parts, and particularly for those ornamental species which are grown commercially in Australia. The data were obtained from published papers, as well as from personal communications with researchers working with these species.

A secondary aim is to provide a starting point from which Australian researchers may further investigate the nutrient status of exotic, native and ornamental species and thereby refine the data which are now available.

In grain, vegetable and fruit crops, the nutrient status of the plant is often related to a measurable yield. In ornamental species, the assessment of optimum or maximum yield is mainly subjective. Hence, the criteria stated are much less rigid than for most other crops. Product quality may also be influenced by nutrition.

Most of the data in this collection have come from surveys of growers, sand or potting mix culture and glasshouse studies. Where a number of workers have studied the same species and nutrients independently, and there is no way of deciding the relative merits of the data, each data set has been included. The reader should be aware of the hazards of interpreting plant tissue analysis values in the absence of reliable information concerning the site where the plant is growing and its water and nutrient management.

There are no specific values given in the tables for micronutrient standards for some of the ornamental plants. Table 1 (redrawn from Bunt (1976)) may be helpful for interpreting analytical values for these nutrients.

The assistance of Drs D.J. Reuter, J.B. Robinson, K.I. Peverill and Mr N. Maier in providing data, references and documents is gratefully acknowledged.

TABLE 1 Average ranges found for micronutrients in leaf tissue of ornamental plants (mg/kg dry matter)

Element	Deficient	Normal	Excessive
Copper	<5	10–25	>70
Zinc	<15	30–100	>200
Manganese	<20	30–200	>1000
Boron	<20	30–80	>150
Molybdenum	<0.1	0.1–3	>70

Australian Wax Flower (*Chamelaucium spp.*)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
N(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				1.0-2.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				1.5-2.5			Aust	27	
P(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				0.15-0.25			Aust	27	
	Dec	Shoot tips 30-40 or 40-50 mm long	F				0.17-0.26			Aust	27	
	Jan	Shoot tips 30-40 or 40-50 mm long	F				0.14-0.22			Aust	27	
	Feb	Shoot tips 30-40 or 40-50 mm long	F				0.12-0.18			Aust	27	
K(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				0.5-1.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				0.9-1.4			Aust	27	
S(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				0.12-0.18			Aust	27	
	Dec	Shoot tips 30-40 or 40-50 mm long	F				0.18-0.24			Aust	27	
	Jan	Shoot tips 30-40 or 40-50 mm long	F				0.16-0.22			Aust	27	
	Feb	Shoot tips 30-40 or 40-50 mm long	F				0.15-0.22			Aust	27	
Ca(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				0.6-1.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				0.4-0.8			Aust	27	
Mg(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				0.2-0.4			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				0.15-0.3			Aust	27	
Na(%)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				0.1-0.3			Aust	27	

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				0.1-0.3			Aust	27	
Cl(%)	Sept	Shoot tips 30-40 or 40-50 mm long	F				~ 0.7			Aust	27	
	Jan	Shoot tips 30-40 or 40-50 mm long	F				0.4-0.5			Aust	27	
Cu(mg/kg)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				3.0-9.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				6.0-15.0			Aust	27	
Zn(mg/kg)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				15.0-20.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				16.0-24.0			Aust	27	
Mn(mg/kg)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				50.0-100.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				20.0-60.0			Aust	27	
Fe(mg/kg)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				30.0-100.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				40.0-80.0			Aust	27	
B(mg/kg)	July-Sept	Shoot tips 30-40 or 40-50 mm long	F				50.0-100.0			Aust	27	
	Dec-Feb	Shoot tips 30-40 or 40-50 mm long	F				30.0-60.0			Aust	27	

Azalea (*Rhododendron indicum*)

N(%)	Fl	YMB on Fl shoot	U	<1.8			2.0-3.0		>3.0	USA	29	
	Fl	YMB on Fl shoot	D		<2.0		2.0-3.2		>3.2	Aust	35	Preferred N fertilizer NH_4^+ and NO_3^-
P(%)	Fl	YMB on Fl shoot	U	<0.20			0.29-0.50		>0.65	USA	29	
	Fl	YMB on Fl shoot	D		<0.16		0.16-0.45	>0.45		Aust	35	
K(%)	Fl	YMB on Fl shoot	U	<0.75			0.80-1.60			USA	29	
	Fl	YMB on Fl shoot	D		<1.0		1.0-2.0	>2.0		Aust	35	
S(%)	Fl	YMB on Fl shoot	D		<0.16		0.16-0.35	>0.35		Aust	35	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Azalea (*Rhododendron indicum*) (ctd)												
Ca(%)	Fl	YMB on Fl shoot	U	<0.20			0.22-1.60			USA	29	
	Fl	YMB on Fl shoot	D		<0.40		0.40-1.60	>1.60		Aust	35	
Mg(%)	Fl	YMB on Fl shoot	U	<0.16			0.17-0.50			USA	29	
Na(%)	Fl	YMB on Fl shoot	D		<0.10		0.10-0.30	>0.30		Aust	35	
Cl(%)	Fl	YMB on Fl shoot	D		<0.30		0.30-1.0	>1.0		Aust	35	
Cu(mg/kg)	Fl	YMB on Fl shoot	U	<5			6.0-15.0			USA	29	
	Fl	YMB on Fl shoot	D		<5		5.0-30.0	>30		Aust	35	
Zn(mg/kg)	Fl	YMB on Fl shoot	U	<15			15-60			USA	29	
	Fl	YMB on Fl shoot	D		<10		10-100	>100		Aust	35	
Mn(mg/kg)	Fl	YMB on Fl shoot	U	<30			30-300		>400	USA	29	
	Fl	YMB on Fl shoot	D		<50		50-400	>400		Aust	35	
Fe(mg/kg)	Fl	YMB on Fl shoot	U	<50			50-150			USA	29	
	Fl	YMB on Fl shoot	D		<100		100-700	>700		Aust	35	
Al(mg/kg)	Fl	YMB on Fl shoot	U					Very tolerant		USA	29	
B(mg/kg)	Fl	YMB on Fl shoot	U	<16			17-100		>200	USA	29	
	Fl	YMB on Fl shoot	D		<20		20-100	>100		Aust	35	
Mo(mg/kg)	Fl	YMB on Fl shoot	D		<0.l		0.1-1.0	>1.0		Aust	35	
Banksia (*Banksia ericifolia*), Coast Banksia (*Banksia integrifolia*)												
N(%)	10 weeks	WS	Sand	0.78			1.00-1.14			Aust	33	Growth reduction in deficient plants
P (%)	Seedl	WS	Pmix				0.06-0.16		>0.17	Aust	14	Banksia ericifolia
	10 weeks	WS	Sand				0.17-0.62			Aust	33	
K(%)	10 weeks	WS	Sand	0.21			0.46-0.73			Aust	33	Deficient plants necrotic
Ca(%)	10 weeks	WS	Sand				0.42-0.79			Aust	33	
Mg(%)	10 weeks	WS	Sand				0.11-0.29			Aust	33	

Boronia (*Boronia megastigma* Nees)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
N(%)	Fl initiat.	Lat	F		<1.2		1.3-1.7	>1.7		Aust	41	
	Post harvest	Lat	F		<1.0		1.1-1.5	>1.5		Aust	41	

Boston Fern (*Nephrolepis exaltata*)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
N(%)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil	<1.2			2.0-3.0	>3.0		USA	12	Experiments conducted on plants growing in hanging baskets
P(%)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				0.5-0.7			USA	12	Experiments conducted on plants growing in hanging baskets
K(%)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				3.0-4.0			USA	12	Experiments conducted on plants growing in hanging baskets
Ca(%)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				0.35-0.50			USA	12	Experiments conducted on plants growing in hanging baskets
Mg (%)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				0.45-0.60			USA	12	Experiments conducted on plants growing in hanging baskets
Cu(mg/kg)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				5.0-10.0			USA	12	Experiments conducted on plants growing in hanging baskets
Zn(mg/kg)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				35-50			USA	12	Experiments conducted on plants growing in hanging baskets
Mn(mg/kg)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				50-140			USA	12	Experiments conducted on plants growing in hanging baskets
Fe(mg/kg)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				50-80			USA	12	Experiments conducted on plants growing in hanging baskets
B(mg/kg)	5-10 months after planting	Pinnae from whole fronds or 10-12 cm mid-section	Soil				25-50			USA	12	Experiments conducted on plants growing in hanging baskets

Caladium x hortulanum Birdsey

Nutrient	Plant part	Concentration range: Adequate	Critical (toxicity)	Country	Ref
N(%)	Leaves	3.6-4.9	>4.8	USA	18
P(%)	Leaves	0.37-0.68	>0.7	USA	18
K(%)	Leaves	2.3-4.1	>4.5	USA	18

Carnation (*Dianthus caryophyllus*)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
N(%)	Before Fl buds visible	5th pr leaves from A of Lat	S	<3.0			3.0-5.0			UK	6	
	Before Fl buds visible	5th pr leaves from A of Lat	S	<3.0			3.0-5.0			USA	32	Adequate range determined from survey data
	Before Fl buds visible	5th pr leaves from A of Lat	U				3.2-3.6			USA	19	
	Before Fl buds visible	5th pr leaves from A of Lat	U	<3.0			3.3-4.8			USA	30	
	Before Fl buds visible	5th pr leaves from A of Lat	Soil	<2.0-2.3						UK	45	Described as 'deficiency less than about'
	17 months after planting	5th pr leaves from A of Lat	Soil				3.0-3.5			UK	45	Higher value desirable in second season
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<3.0			3.2-5.2			USA	29	Monitoring for life of crop
P(%)	Before Fl buds visible	5th pr leaves from A of Lat	S	<0.05			0.25-0.45			UK	6	
	Before Fl buds visible	5th pr leaves from A of Lat	S	<0.05			0.25-0.45			USA	32	Adequate range determined from survey data
	Before Fl buds visible	5th pr leaves from A of Lat	U	<0.15			0.20-0.40			USA	30	
	5 months after planting	5th pr leaves from A of Lat	Soil	<0.10-0.15						UK	45	Described as 'deficiency less than about'
	17 months after planting	5th pr leaves from A of Lat	Soil				0.25-0.30			UK	45	Higher value desirable in second season
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<0.05			0.20-0.30			USA	29	Monitoring for life of crop
K(%)	Before Fl buds visible	5th pr leaves from A of Lat	S	<2.0			2.5-4.0			UK	6	

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
	Before Fl buds visible	5th pr leaves from A of Lat	S	<2.0			2.5-4.0			USA	32	Adequate range determined from survey data.
	Before Fl buds visible	5th pr leaves from A of Lat	U				2.9-3.3			USA	19	
	Before Fl buds visible	5th pr leaves from A of Lat	U	<1.8			2.2-3.5			USA	30	
	5 months after planting	5th pr leaves from A of Lat	Soil	<1.5-2. 0						UK	45	Described as 'deficiency less than about'
	17 months after planting	5th pr leaves from A of Lat	Soil				3.0-4.0			UK	45	Higher value desirable in second season
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<2.0			2.5-6.0			USA	29	Monitoring for life of crop
Ca(%)	Before Fl buds visible	5th pr leaves from A of Lat	S	<0.6			1.0-2.0			UK	6	
	Before Fl buds visible	5th pr leaves from A of Lat	S	<0.6			1.0-2.0			USA	32	Adequate range determined from survey data
	Before Fl buds visible	5th pr leaves from A of Lat	U	<0.5			1.0-2.00			USA	30	
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<0.60			1.0-2.0			USA	29	Monitoring for life of crop
Mg(%)	Before Fl buds visible	5th pr leaves from A of Lat	S	<0.15			0.2-0.5			UK	6	
	Before Fl buds visible	5th pr leaves from A of Lat	S	<0.15			0.2-0.5			USA	32	Adequate range determined from survey data
	Before Fl buds visible	5th pr leaves from A of Lat	U	<0.18			0.22-0.40			USA	30	
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<0.15			0.25-0.50			USA	29	Monitoring for life of crop

Carnation (*Dianthus caryophyllus*) (ctd)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Na(%)	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D						>0.60	USA	29	Monitoring for life of crop
Cu(mg/kg)	Before Fl buds visible	5th pr leaves from A of Lat	U	<2			4.0-20.0			USA	30	
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<5			10.0-30.0			USA	29	Monitoring for life of crop
Zn(mg/kg)	Before Fl buds visible	5th pr leaves from A of Lat	U	<15			25-75			USA	30	
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<15			25-75			USA	29	Monitoring for life of crop
Mn(mg/kg)	Before Fl buds visible	5th pr leaves from A of Lat	U	<30			80-300			USA	30	
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<30			100-300		>800	USA	29	Monitoring for life of crop
Fe(mg/kg)	Before Fl buds visible	5th pr leaves from A of Lat	U	<30			50-150			USA	30	
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<30			50-150			USA	29	Monitoring for life of crop
B(mg/kg)	Before Fl buds visible	5th pr leaves from A of Lat	U	<20			30-100			USA	30	
	5 months after planting	5th pr leaves from A of Lat	Soil	<15						UK	45	Described as 'deficiency less than about'

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
	17 months after planting	5th pr leaves from A of Lat	Soil				20-40			UK	45	Higher value desirable in second season
	6-8 weeks after planting, then every 2 months	Unpinched plants-4th and 5th pr leaves from base. Pinched plants-as above, but when buds form, 5th and 6th pr leaves from A of Lat without buds	D	<25			30-100		>700	USA	29	Monitoring for life of crop
Mo(mg/kg)	Before Fl buds visible	5th pr leaves from A of Lat	U	<0.3			1.0-5.0			USA	30	

Chrysanthemum (*Chrysanthemum morifolium*)

N(%)	70 DAT	WS	D		<3.0		3.0-5.0	>5.0		Aust	35	cv. White Sands
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<3.0		4	4.5-6.0			USA	25	cv. Good News
	Pre-Fl	YL	Sand,S	<2.0			2.5-4.5			Aust	36	
P(%)	70 DAT	WS	D		<0.25		0.25-1.00	>1.0		Aust	35	cv. White Sands
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<0.21			0.26-1.15			USA	25	cv. Good News
	Pre-Fl	YL	Sand, S	<0.2			0.3-0.8			Aust	36	
K(%)	70 DAT	WS	D		<2.80		2.80-8.00	>8.0		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<2.0		2.75	3.5-10.0			USA	25	cv. Good News
	Pre-Fl	YL	Sand, S				4.0-7.0			Aust	36	
S(%)	70 DAT	WS	D		<0.18		0.18-0.40	>0.40		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<0.19			0.30-0.74			USA	25	cv. Good News
	Pre-Fl	YL	Sand, S				0.2-0.4			Aust	36	
Ca(%)	70 DAT	WS	D		<0.40		0.40-2.00	>2.00		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<0.28		0.4	0.50-4.6			USA	25	cv. Good News; levels steady with leaf age
	Pre-Fl	YL	Sand, S				0.6-1.5			Aust	36	
Mg(%)	70 DAT	WS	D		<0.20		0.20-0.60	>0.60		Aust	35	Data from five cultivars

Chrysanthemum (*Chrysanthemum morifolium*) (ctd)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Mg(%) (ctd)	Veg-Fl diam <1.5 cm	Lower leaf on Fl stem	Sand, SC	<0.045			0.06-1.50			USA	25	cv. Good News; levels steady with leaf age
	Pre-Fl	YL	Sand				0.3-0.6			Aust	36	
Na(%)	70 DAT	WS	D		<0.10		0.10-2.0	>2.0		Aust	35	Data from five cultivars
	Pre-Fl	YL	Sand				0.02-1.0		>2.0	Aust	36	Chlorosis and reduced growth at toxic levels
Cl(%)	70 DAT	WS	D		<0.30		0.30-3.0	>3.0		Aust	35	Data from five cultivars
	Pre-Fl	YL	Sand				0.3-2.5		>5.0	Aust	36	
Cu(mg/kg)	70 DAT	WS	D		<5		5.0-50.0	>50		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Middle leaves on Fl stem	Sand, SC	<4.7		5	10-?			USA	25	cv. Good News
	Pre-Fl	YL	Sand				8.0-15.0			Aust	36	
	Fl	all leaves	Pmix			1.5	1.5-2.8			Aust	13	For maximum vegetative growth
	Fl	all leaves	Pmix			13	13-28			Aust	13	For maximum flower production
Zn(mg/kg)	70 DAT	WS	D		<10		10-100	>100		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Lower leaf on Fl stem	Sand, SC	<6.8		7	7.0-26.0			USA	25	cv. Good News
	Pre-Fl	YL	Sand				40-100			Aust	36	
Mn(mg/kg)	70 DAT	WS	D		<20		20-150	>150		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<4			195-260			USA	25	cv. Good News
	Pre-Fl	YL	Sand				50-300		>500	Aust	36	Necrotic spots at toxic levels
Fe(mg/kg)	70 DAT	WS	D		<40		40-200	>200		Aust	35	Data from five cultivars
	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<35						USA	25	cv. Good News
B(mg/kg)	Veg-Fl diam <1.5 cm	Upper leaf on Fl stem	Sand, SC	<19.5		20	25-200		240	USA	25	cv. Good News
	Pre-Fl	YL	Sand				30-100			Aust	36	
	Fl	YOL	Sand				9-12		>50	Japan	20	cv. Seikonohana
Mo(mg/kg)	Pre-Fl	YL	Sand				>0.3			Aust	36	

Cyclamen (*Cyclamen persicum*)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
N(%)	50 DAT	WS	Peat				2.2-2.7			NZ	39	cv. Rosamunde
	1st Fl	YMB					2.4-3.4			Ger	5	
	Harvest (97 DAT)	WS	Peat				2.1-2.4			NZ	39	cv. Rosamunde
P(%)	50 DAT	WS	Peat				0.14-0.22			NZ	39	cv. Rosamunde
	1st Fl	YMB					0.25-0.4			Ger	5	
	Harvest (97 DAT)	WS	Peat				0.14-0.17			NZ	39	cv. Rosamunde
K(%)	50 DAT	WS	Peat				2.2-5.7			NZ	39	cv. Rosamunde
	1st Fl	YMB					2.6-4.5			Ger	5	
Ca(%)	1st Fl	YMB					0.8-1.2			Ger	5	
Mg(%)	1st Fl	YMB					0.25-0.5			Ger	5	
Cu(mg/kg)	1st Fl	YMB					5.0-12.0			Ger	5	
Zn(mg/kg)	1st Fl	YMB					20-60			Ger	5	
Mn(mg/kg)	1st Fl	YMB					30-100			Ger	5	
B(mg/kg)	1st Fl	YMB					25-60			Ger	5	
Mo(mg/kg)	1st Fl	YMB					0.15-0.4			Ger	5	

Dieffenbachia (*Dieffenbachia exotica*)

N(%)	Well grown	YMB	D				2.7-3.5			USA	22	
P(%)	Well grown	YMB	D				0.2-0.35			USA	22	
K(%)	Well grown	YMB	D				3.5-4.5			USA	22	
Ca(%)	Well grown	YMB	D				1.0-1.5			USA	22	
Mg(%)	Well grown	YMB	D				0.3-0.6			USA	22	
Cu(mg/kg)	Well grown	YMB	D				10.0-40.0			USA	22	
Zn(mg/kg)	Well grown	YMB	D				25-150			USA	22	
Mn(mg/kg)	Well grown	YMB	D				50-200			USA	22	
Fe(mg/kg)	Well grown	YMB	D				50-150			USA	22	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Freesia (*Freesia refracta*)												
N(%)	End Fl	WS	U				1.60-2.34			NZ	43	
		YMB					2.7-5.6			USA	9	
P(%)	End Fl	WS	U				0.09-0.26			NZ	43	
		YMB					0.4-1.2			USA	9	
K(%)	End Fl	WS	U				2.3-4.7			NZ	43	
		YMB					3.1-5.9			USA	9	
Ca(%)	End Fl	WS	U				1.40-1.73			NZ	43	
		YMB					0.4-1.0			USA	9	
Mg(%)	End Fl	WS	U				0.50-0.70			NZ	43	
		YMB					0.3-1.8			USA	9	
Cu(mg/kg)		YMB					5-130			USA	9	
Zn(mg/kg)		YMB					40-110			USA	9	
Mn(mg/kg)		YMB					30-540			USA	9	
Fe(mg/kg)		YMB					80-115			USA	9	
B(mg/kg)		YMB					30-100			USA	9	
Geranium (*Pelargonium zonale*)												
N(%)	U	Leaves	SC	0.99			2.18			Bra	24	
	Fl	YMB	U	<2.40			3.3-4.80			USA	29	
P(%)	U	Leaves	SC	0.2			0.35			Bra	24	
	Fl	YMB	U	<0.28			0.40-0.67			USA	29	
K(%)	U	Leaves	SC	0.46			2.14			Bra	24	
	Fl	YMB	U	<0.70			2.50-4.50			USA	29	
S(%)	U	Leaves	SC	0.02			0.1			Bra	24	
Ca(%)	U	Leaves	SC	0.77			1.45			Bra	24	
	Fl	YMB	U	<0.77			0.81-1.20			USA	29	
Mg(%)	U	Leaves	SC	0.24			0.53			Bra	24	
	Fl	YMB	U	<0.14			0.20-0.52			USA	29	

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
Na(%)	Fl	YMB	U						>0.60	USA	29	
Cu(mg/kg)	Fl	YMB	U	<5.5			7.0-16.0			USA	29	
Zn(mg/kg)	Fl	YMB	U	<6			8.0-40.0			USA	29	
Mn(mg/kg)	Fl	YMB	U	<9			42-174		>800	USA	29	
Fe(mg/kg)	U	Leaves	SC	92			265			Bra	24	
	Fl	YMB	U	<60			70-270			USA	29	
B(mg/kg)	U	Leaves	SC	58			110			Bra	24	
	Fl	YMB	U	<18			30-280		>700	USA	29	

Gladiolus (*Gladiolus tristis*)

N(%)	Head	4th fully expanded true leaf	S				2.5-3.0			Aust	31	
	U	YMB cut at junction of stem	U				3.0-4.0			USA	30	
P(%)	Head	4th fully expanded true leaf	S				0.30-0.45			Aust	31	
	U	YMB cut at junction of stem	U				0.30-0.40			USA	30	
K(%)	Head	4th fully expanded true leaf	S				3.0-4.0			Aust	31	
	U	YMB cut at junction of stem	U				2.0-3.0			USA	30	
Ca(%)	Head	4th fully expanded true leaf	S		0.50-0.80		0.80-1.50			Aust	31	
	U	YMB cut at junction of stem	U				0.60-1.30			USA	30	
Mg(%)	Head	4th fully expanded true leaf	S		0.10-0.20		0.20-0.40			Aust	31	
	U	YMB cut at junction of stem	U				0.12-0.25			USA	30	
Na(%)	Head	4th fully expanded true leaf	S					>0.50		Aust	31	
Cl(%)	Head	4th fully expanded true leaf	S				<0.70		>2.50	Aust	31	
Cu(mg/kg)	Head	4th fully expanded true leaf	S				5.0-10.0			Aust	31	
	U	YMB cut at junction of stem	U				3.0-15.0			USA	30	
Zn(mg/kg)	Head	4th fully expanded true leaf	S				20-100			Aust	31	
	U	YMB cut at junction of stem	U				20-60			USA	30	
Mn(mg/kg)	Head	4th fully expanded true leaf	S		50-200		200-500			Aust	31	
	U	YMB cut at junction of stem	U				100-300			USA	30	
Fe(mg/kg)	Head	4th fully expanded true leaf	S				100-200			Aust	31	
	U	YMB cut at junction of stem	U				80-200			USA	30	
B(mg/kg)	U	YMB cut at junction of stem	U				25-60		>300	USA	30	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Grevillea (*Grevillea* spp.)												
N(%)	70 DAE	WS	Sand	0.46			0.87-1.91			Aust	33	*G. rosmarinifolia*; reduced growth at deficient level.
	46 DAE	Leaves	Sand				1.76			Aust	34	cv. Poorinda Firebird
P(%)	1 month after potting up to 250 mm	Leaves	S				0.1		>0.15	Aust	36	cv. Clearview Robyn; at toxic levels stunted and discoloured leaves and retarded root development.
	1 month after potting up to 250 mm	Leaves	S				0.15		>0.25	Aust	36	*G. victoriae* var. tenuifolia; at toxic levels stunted and discoloured leaves and retarded root development.
	1 month after potting up to 250 mm	Leaves	S				0.2		>0.30	Aust	36	cv. Poorinda Elegance; at toxic levels stunted and discoloured leaves and retarded root development.
	1 month after potting up to 250 mm	Leaves	S				0.2		>0.25	Aust	36	cv. Poorinda Elegance; at toxic levels stunted and discoloured leaves and retarded root development.
	70 DAE	WS	Sand	0.01			0.21-0.58			Aust	33	*G. rosmarinifolia*; reduced growth at deficient level.
	46 DAE	Leaves	Sand	<0.08			0.09		>0.27	Aust	34	cv. Poorinda Firebird; interactions between P and N, Ca and K.
K(%)	70 DAE	WS	Sand	0.26			0.42-0.98			Aust	33	*G. rosmarinifolia*; reduced growth at deficient level.
	46 DAE	Leaves	Sand				1.21			Aust	34	cv. Poorinda Firebird
Ca(%)	70 DAE	WS	Sand				0.46-1.07			Aust	33	G. rosmarinifolia
	46 DAE	Leaves	Sand				0.81			Aust	34	cv. Poorinda Firebird
Mg(%)	70 DAE	WS	Sand				0.12-0.37			Aust	33	G. rosmarinifolia
	46 DAE	Leaves	Sand				0.23			Aust	34	cv. Poorinda Firebird
Hibiscus (*Hibiscus rosa-sinensis*)												
N(%)		ML	U	2.88			3.96			Sing	10	
P(%)		ML	U	0.22			0.49			Sing	10	
K(%)		ML	U	0.63			2.6			Sing	10	
Ca(%)		YF	U	0.22			1.24			Sing	10	

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
Mg(%)		ML	U	0.22			0.51			Sing	10	
Cu(mg/kg)		YF	U	3			8			Sing	10	
Mn(mg/kg)		YF	U	31			188			Sing	10	
Fe(mg/kg)		YF	U	137			173			Sing	10	
B(mg/kg)		YF	U	30			51			Sing	10	

Holly (*Ilex aquifolium*)

N(%)		Leaves	U	1.18-1.38			1.62-1.84			USA	44	
P(%)		Leaves	U				0.1-0.14			USA	44	
K(%)		Leaves	U				0.79-1.0			USA	44	
Ca(%)		Leaves	U				1.03-1.13			USA	44	
Mg(%)		Leaves	U				0.35-0.42			USA	44	
B(mg/kg)		Leaves	U				30-45			USA	44	

Hydrangea (*Hydrangea macrophylla*)

N(%)		YMB	U		2.5-2.99		3-5.5	>5.5		USA	4	
	Veg	YEB pair	SC				2.15-3.6			USA	3	
P(%)		YMB	U		0.18-0.24		0.25-0.7	>0.7		USA	4	
	Veg	YEB pair	SC			0.09	0.28-1.14			USA	3	
K(%)		YMB	U		1.5-2.01		2.2-5.0	>5.0		USA	4	
	Veg	YEB pair	SC			0.54	3.03-6.66			USA	3	
S(%)		YMB	U		0.13-0.19		0.20-0.7	>0.7		USA	4	
Ca(%)		YMB	U		0.4-0.59		0.6-1.8	>1.8		USA	4	
	Veg	YEB pair	SC			0.61	0.93-2.21			USA	3	
Mg(%)		YMB	U		0.18-0.21		0.22-0.5	>0.5		USA	4	
	Veg	YEB pair	SC			0.04	0.16-0.35			USA	3	
Cu(mg/kg)		YMB	U		4.0-5.0		6.0-50	>50		USA	4	
Zn(mg/kg)		YMB	U		15-19		20-200	>200		USA	4	
	Veg	YEB pair	SC			29	30-56			USA	3	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Hydrangea (*Hydrangea macrophylla*) (ctd)												
Mn(mg/kg)		YMB	U		40-49		50-300	>300		USA	4	
	Veg	YEB pair	SC			8	37-311			USA	3	
Fe(mg/kg)		YMB	U		40-49		50-300	>300		USA	4	
	Veg	YEB pair	SC			46	59-224			USA	3	
B(mg/kg)		YMB	U		16-19		20-50	>50		USA	4	
	Veg	YEB pair	SC			23	54-118			USA	3	
Mo(mg/kg)	Veg	YEB pair	SC			1	2.0-7.0			USA	3	
Impatiens, New Guinea, Impulse Violet (*Impatiens wallerana*)												
N(%)		YMB	U				3.3-4.9			USA	9	
P(%)		YMB	U				0.3-0.8			USA	9	
K(%)		YMB	U				1.9-2.7			USA	9	
Ca(%)		YMB	U				1.9-2.7			USA	9	
Mg(%)		YMB	U				0.3-0.8			USA	9	
Cu(mg/kg)		YMB	U				5.0-10			USA	9	
Zn(mg/kg)		YMB	U				40-85			USA	9	
	Fl	WS	Pot				80		>100	Aust	17	
Mn(mg/kg)		YMB	U				140-245			USA	9	
	Fl	WS	Pot	10.0-20.0			190-240			Aust	17	
Fe(mg/kg)		YMB	U				160-890			USA	9	
B(mg/kg)		YMB	U				50-60			USA	9	
Ixodia daisy (*Ixodia achillaeioides* ssp. *alata*)												
N(%)	Stem >30 cm long	5th leaf below growing terminal	F		<1.25		1.4-1.7			Aust	28	
P(%)	Stem >30 cm long	5th leaf below growing terminal	F		<0.1		0.13-0.2			Aust	28	

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
K(%)	Stem >30 cm long	5th leaf below growing terminal	F		<1.0		1.0-1.5			Aust	28	
S(%)	Stem >30 cm long	5th leaf below growing terminal	F				0.41-0.48			Aust	28	
Ca(%)	Stem >30 cm long	5th leaf below growing terminal	F				1.0-1.2			Aust	28	
Mg(%)	Stem >30 cm long	5th leaf below growing terminal	F				0.24-0.32			Aust	28	
Na(%)	Stem >30 cm long	5th leaf below growing terminal	F				0.65-0.81			Aust	28	
Cu(mg/kg)	Stem >30 cm long	5th leaf below growing terminal	F				9.0-21.0			Aust	28	
Zn(mg/kg)	Stem >30 cm long	5th leaf below growing terminal	F				42-60			Aust	28	
Mn(mg/kg)	Stem >30 cm long	5th leaf below growing terminal	F				150-203			Aust	28	
Fe(mg/kg)	Stem >30 cm long	5th leaf below growing terminal	F				61-81			Aust	28	
Al(mg/kg)	Stem >30 cm long	5th leaf below growing terminal	F				190-233			Aust	28	
B(mg/kg)	Stem >30 cm long	5th leaf below growing terminal	F				49-57			Aust	28	

Leucadendron, Silvan Red/Safari Sunset (*Leucadendron* spp.)

N(%)	Nov-Jan Period of active growth	YFEL	S				0.7-1.0			Aust	8	For high yielding Silvan Red/Safari Sunset
	Nov-Jan Period of active growth	YFEL	S				0.6-0.8			Aust	8	For low yielding Silvan Red/Safari Sunset
	Aug-Oct	YFEL	S				0.5-0.7			Aust	8	For high yielding Silvan Red/Safari Sunset
	Aug-Oct	YFEL	S				0.4-0.5			Aust	8	For low yielding Silvan Red/Safari Sunset
P(%)	Nov-Jan Period of active growth	YFEL	S				0.08-0.1			Aust	8	Silvan Red/Safari Sunset
	Aug-Oct	YFEL	S				0.2 -0.4			Aust	8	For high yielding Silvan Red/Safari Sunset

Leucadendron, Silvan Red/Safari Sunset (*Leucadendron* spp.) (ctd)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
P(%) (ctd)	Aug-Oct	YFEL	S				0.08-0.1			Aust	8	For low yielding Silvan Red/Safari Sunset
K(%)	Nov-Jan Period of active growth	YFEL	S				0.21-0.36			Aust	8	Silvan Red/Safari Sunset
S(%)	Nov-Jan Period of active growth	YFEL	S				0.1-0.16			Aust	8	Silvan Red/Safari Sunset
Ca(%)	Nov-Jan Period of active growth	YFEL	S				0.25-0.4			Aust	8	Silvan Red/Safari Sunset
Mg(%)	Nov-Jan Period of active growth	YFEL	S				0.15-0.22			Aust	8	Silvan Red/Safari Sunset
Na(%)	Nov-Jan Period of active growth	YFEL	S				0.55-0.7			Aust	8	For high yielding Silvan Red/Safari Sunset
	Nov-Jan Period of active growth	YFEL	S				0.65-0.8			Aust	8	For low yielding Silvan Red/Safari Sunset
	Aug-Oct	YFEL	S				0.3-0.35			Aust	8	For high yielding Silvan Red/Safari Sunset
	Aug-Oct	YFEL	S				0.4-0.45			Aust	8	For low yielding Silvan Red/Safari Sunset
Cu(mg/kg)	Nov-Jan Period of active growth	YFEL	S				2.0-12.0			Aust	8	Silvan Red/Safari Sunset
Zn(mg/kg)	Nov-Jan Period of active growth	YFEL	S				16.0-30.0			Aust	8	Silvan Red/Safari Sunset
Mn(mg/kg)	Nov-Jan Period of active growth	YFEL	S				70.0-120.0			Aust	8	Silvan Red
	Nov-Jan Period of active growth	YFEL	S				100-300			Aust	8	Safari Sunset
Fe(mg/kg)	Nov-Jan Period of active growth	YFEL	S				15-30			Aust	8	Silvan Red/Safari Sunset

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
B(mg/kg)	Nov-Jan Period of active growth	YFEL	S				12.0-16.0			Aust	8	Silvan Red/Safari Sunset

Maidenhair Fern (*Adiantum raddianum* cv. Elegans)

N(%)	50-120 days after treatment started	Fronds	Peat	<2.0			2.4-2.7			Aust	36	Hysol* fertilizer study; fronds on -Hysol (pale green) diagnosed as N deficient
P(%)	50-120 days after treatment started	Fronds	Peat				0.2-0.4			Aust	36	Hysol* fertilizer study
K(%)	50-120 days after treatment started	Fronds	Peat				2.5-4.0			Aust	36	Hysol* fertilizer study
S(%)	50-120 days after treatment started	Fronds	Peat				0.2-0.3			Aust	36	Hysol* fertilizer study
Ca(%)	50-120 days after treatment started	Fronds	Peat				0.3-0.5			Aust	36	Hysol* fertilizer study
Mg(%)	50-120 days after treatment started	Fronds	Peat				0.25-0.5			Aust	36	Hysol* fertilizer study
Na(%)	50-120 days after treatment started	Fronds	Peat				0.05-0.15			Aust	36	Hysol* fertilizer study
Cl(%)	50-120 days after treatment started	Fronds	Peat				0.3-0.6			Aust	36	Hysol* fertilizer study

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Maidenhair Fern (*Adiantum raddianum* cv. Elegans) (ctd)												
Cu(mg/kg)	50-120 days after treatment started	Fronds	Peat				3.0-5.0			Aust	36	Hysol* fertilizer study
Zn(mg/kg)	50-120 days after treatment started	Fronds	Peat				15-30			Aust	36	Hysol* fertilizer study
Mn(mg/kg)	50-120 days after treatment started	Fronds	Peat				<100			Aust	36	Hysol* fertilizer study
B(mg/kg)	50-120 days after treatment started	Fronds	Peat				30-60			Aust	36	Hysol* fertilizer study
Needlewood (*Hakea leucoptera*)												
P(%)	Seedl	WS	Pmix				0.05-0.09			Aust	16	
Orchid, Cattleya (*Cattleya* sp.), Cymbidium Orchid (*Cymbidium* sp.)												
N(%)	U	5 cm segments of leaf tips of youngest mature growth	U			0.6	1.30-1.70		2.5	USA	1	*Cattleya* sp. Fewer flowers produced at low N supply
	U	15 cm tips of mature leaves on immature growth	U			1.3	2.0-2.50		3.3	USA	1	*Cymbidium* sp.
P(%)	U	5 cm segments of leaf tips of youngest mature growth	U			0.07	0.11-0.17		0.25	USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U			0.07	0.11-0.17		0.25	USA	1	*Cymbidium* sp.
K(%)	U	5 cm segments of leaf tips of youngest mature growth	U			1.1	1.80-2.80		3.7	USA	1	*Cattleya* sp. Poole and Seeley (ref. 37) reported values as high as 4.6% in apparently healthy plants grown in solution culture

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
	U	15 cm tips of mature leaves on immature growth	U			1.1	1.80-2.80		3	USA	1	*Cymbidium* sp. Poole and Seeley (ref. 37) reported values as high as 3.06% in apparently healthy plants grown in solution culture
Ca(%)	U	5 cm segments of leaf tips of youngest mature growth	U			0.8	1.50-3.50		4.5	USA	1	*Cattleya* sp. Deficiency caused burning of leaf tips and die-back of new growth
	U	15 cm tips of mature leaves on immature growth	U			0.3	0.60-1.30			USA	1	*Cymbidium* sp.
Mg(%)	U	5 cm segments of leaf tips of youngest mature growth	U			0.2	0.30-0.60		1	USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U			0.12	0.18-0.30		0.5	USA	1	*Cymbidium* sp.
Na(%)	U	5 cm segments of leaf tips of youngest mature growth	U				0-0.15		0.2	USA	1	*Cattleya* sp. Excess Na causes burning of leaf tips
	U	15 cm tips of mature leaves on immature growth	U				0-0.25		0.5	USA	1	*Cymbidium* sp.
Cu(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U				4.0-10.0			USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U				3.0-8.0			USA	1	*Cymbidium* sp.
Zn(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U				20-40			USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U				20-40			USA	1	*Cymbidium* sp.
Mn(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U				100-1000			USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U				20-100			USA	1	*Cymbidium* sp.
Fe(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U				50-150			USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U				100-300			USA	1	*Cymbidium* sp.
B(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U				20-100		400	USA	1	*Cattleya* sp.
	U	15 cm tips of mature leaves on immature growth	U				25-150			USA	1	*Cymbidium* sp.

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Orchid, Cattleya (*Cattleya* sp.), Cymbidium Orchid (*Cymbidium* sp.) (ctd)												
Mo(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U				1-?			USA	1	*Cattleya* sp.
Orchid, Phalaenopsis (*Phalaenopsis* sp.)												
N(%)	U	5 cm segments of leaf tips of youngest mature growth	U			1	1.50-2.50		4	USA	1	
P(%)	U	5 cm segments of leaf tips of youngest mature growth	U			0.1	0.30-0.70		1	USA	1	High P gives good quality flowers
K(%)	U	5 cm segments of leaf tips of youngest mature growth	U			2	2.50-4.0		6.5	USA	1	Poole and Seeley (ref. 37) reported values as high as 7.9% in apparently healthy plants grown in solution culture
Ca(%)	U	5 cm segments of leaf tips of youngest mature growth	U			2	3.0-5.0			USA	1	
Mg(%)	U	5 cm segments of leaf tips of youngest mature growth	U			0.2	0.60-1.00			USA	1	
Na(%)	U	5 cm segments of leaf tips of youngest mature growth	U						0.5	USA	1	
Cu(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U			2.5	4.0-12.0			USA	1	
Zn(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U			15	25-100			USA	1	
Mn(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U			50	100-2000			USA	1	
Fe(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U			50	100-400			USA	1	
B(mg/kg)	U	5 cm segments of leaf tips of youngest mature growth	U			20	40-100			USA	1	
Petunia (*Petunia hybrida*)												
N(%)	U	YMB	U				2.8-5.8			USA	9	
P(%)	U	YMB	U				0.5-1.2			USA	9	

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
K(%)	U	YMB	U				3.5-5.5			USA	9	
Ca(%)	U	YMB	U				0.6-4.8			USA	9	
	Fl	WS	Pot	0.08-0.17						Aust	15	
Mg(%)	U	YMB	U				0.3-1.4			USA	9	
Cu(mg/kg)	U	YMB	U				5.0-45			USA	9	
	U	YMB	U						>149	USA	2	
	Y	YOL	Pot				3.0-81			USA	23	
Zn(mg/kg)	U	YMB	U				30-90			USA	9	
	U	YMB	U						>1630	USA	2	
	Y	YOL	Pot				87	>439		USA	23	
Mn(mg/kg)	U	YMB	U				90-185			USA	9	
	U	YMB	U						>2560	USA	2	
	Y	YOL	Pot				142-749			USA	23	
Fe(mg/kg)	U	YMB	U				40-700			USA	9	
	Y	YOL	Pot				170-504			USA	23	
B(mg/kg)	U	YMB	U				20-50			USA	9	
	U	YMB	U						>412	USA	2	
	Y	YOL	Pot				33-651			USA	23	
Mo(mg/kg)	Y	YOL	Pot						>484	USA	2	

Poinsettia (*Euphorbia pulcherrima*)

N(%)	Just before Fl	YMB	U	<3.0			4.0-6.0		>7.3	USA	29	
	38 DAE	WS	Peat				3.8-4.6			NZ	39	
	70 DAE	WS	Peat				3.2-3.6			NZ	39	
P(%)	Just before Fl	YMB	U	<0.20			0.30-0.70		>0.7	USA	29	
	70 DAE	WS	Peat				0.30-0.37			NZ	39	
K(%)	Just before Fl	YMB	U	<1.00			1.50-3.50		>4.0	USA	29	
Ca(%)	Just before Fl	YMB	U	<0.50			0.70-2.00			USA	29	
Mg(%)	Just before Fl	YMB	U	<0.20			0.40-1.00			USA	29	
Na(%)	Just before Fl	YMB	U						>0.60	USA	29	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Poinsettia (*Euphorbia pulcherrima*) (ctd)												
Cu(mg/kg)	Just before FI	YMB	U	<5			6.0-15.0			USA	29	
Zn(mg/kg)	Just before FI	YMB	U	<15			25-60			USA	29	
Mn(mg/kg)	Just before FI	YMB	U	<30			100-200		>250	USA	29	
Fe(mg/kg)	Just before FI	YMB	U	<50			100-500			USA	29	
B(mg/kg)	Just before FI	YMB	U	<20			30-100		>200	USA	29	Leaf necrosis at 200 mg/kg
Queen Protea (*Protea* spp.)												
N(%)	2-3 years old at FI bud initiat. (Aug)	YMB on any shoot	S				1.2-1.3			Aust	33	*P. cynaroides* (King protea)
	FI bud initiat. (Aug)	YMB on stem with flower buds	S				1.4-1.6			Aust	33	P. repens
	After FI	YL	S				0.8-1.0			Aust	35	*P. magnifica* (Queen protea)
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				0.82-0.83			Aust	26	Protea Pink Ice. Adequate can be as high as 1.24 % N when N fertilizer is used.
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				0.7-0.9			Aust	26	Protea Pink Ice. Adequate range derived by survey. (G. Barth pers. comm.)
P(%)	2-3 years old at FI bud initiat. (Aug)	YMB on any shoot	S				0.04-0.06			Aust	33	P. cynaroides
	FI bud initiat. (Aug)	YMB on stem with flower buds	S				0.09-0.10		0.17	Aust	33	*P. repens*
	After FI	YL	S				0.09-0.10			Aust	35	*P. magnifica* (Queen protea)
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				0.06-0.07			Aust	26	Protea Pink Ice

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
K(%)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				0.34-0.73			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				0.31-0.52			Aust	33	*P. repens*
	After Fl	YL	S				0.3-0.4			Aust	35	*P. magnifica* (Queen protea)
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				0.37-0.41			Aust	26	Protea Pink Ice
S(%)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				0.18-0.24			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				0.24-0.29			Aust	33	*P. repens*
	After Fl	YL	S				0.09-0.10			Aust	35	*P. magnifica* (Queen protea)
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				0.11-0.13			Aust	26	Protea Pink Ice
Ca(%)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				0.52-1.00			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				0.45-0.73			Aust	33	*P. repens*
	After Fl	YL	S				0.3-0.4			Aust	35	*P. magnifica* (Queen protea)
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				0.46-0.51			Aust	26	Protea Pink Ice
Mg(%)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				0.10-0.12			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				0.06-0.16			Aust	33	*P. repens*

Queen Protea (*Protea* spp.) (ctd)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Na(%)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				0.13-0.21			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				0.04-0.07			Aust	33	*P. repens*
Cl(%)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				0.12-0.14			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				0.02-0.04			Aust	33	*P. repens*
Cu(mg/kg)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				2.0-3.0			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				4			Aust	33	*P. repens*
	After Fl	YL	S				2.0-4.0			Aust	35	*P. magnifica* (Queen protea)
Zn(mg/kg)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				19-27			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				26-35			Aust	33	*P. repens*
	After Fl	YL	S				10.0-20.0			Aust	35	*P. magnifica* (Queen protea)
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				12.0-15.0			Aust	26	Protea Pink Ice
Mn(mg/kg)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				145-265			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				208-220			Aust	33	*P. repens*
	After Fl	YL	S				50-400			Aust	35	*P. magnifica* (Queen protea)

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
	Shoots >40 cm long with dormant terminal bud during Jan-Feb	Hardened YFEL	S				43.0-44.0			Aust	26	Protea Pink Ice
Fe(mg/kg)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				38-51			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				76-115			Aust	33	*P. repens*
Al(mg/kg)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				80-150			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				105-155			Aust	33	*P. repens*
B(mg/kg)	2-3 years old at Fl bud initiat. (Aug)	YMB on any shoot	S				14-24			Aust	33	*P. cynaroides* (King protea)
	Fl bud initiat. (Aug)	YMB on stem with flower buds	S				19-24			Aust	33	P. repens
	After Fl	YL	S				10.0-20.0			Aust	35	*P. magnifica* (Queen protea)

Rose, Floribunda (*Rosa floribunda*)

N(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil	2.14			3.0-3.3			Swe	21	
P(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil	0.14			0.28-0.36			Swe	21	
K(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil	1.01			1.9-2.2			Swe	21	
Ca(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil	0.39			1.3			Swe	21	
Mg(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil	0.2			0.3			Swe	21	
Na(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil				0.4			Swe	21	
Cl(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoots	Soil				0.03			Swe	21	

Rose, Hybrid Tea (*Rosa* spp.)

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
N(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoot	Soil				3.4-3.6			Swe	21	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				3.45			USA	42	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	U	<3.0			3.2-4.5			UK	6	
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<3.0			3.0-5.0		>5.1	Aust	31	
P(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoot	Soil				0.28-0.36			Swe	21	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				0.3			USA	42	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	U	<0.2			0.20-0.30			UK	6	
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<0.2			0.2-0.3			Aust	31	
K(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoot	Soil				2.3-2.6			Swe	21	Gammon and McFadden (ref. 11) found *R. odorata* and *R. fortuniana* rootstocks supplied more and *R. manetti* less K (1.7 cf. 1.3) to the scion under low K status soils, but *R. manetti* was a strong K accumulator
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				2.33-2.38			USA	42	Gammon and McFadden (ref. 11) found *R. odorata* and *R. fortuniana* rootstocks supplied more and *R. manetti* less K (1.7 cf. 1.3) to the scion under low K status soils, but *R. manetti* was a strong K accumulator
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	U	<1.8			1.8-3.0			UK	6	Gammon and McFadden (ref. 11) found *R. odorata* and *R. fortuniana* rootstocks supplied more and *R. manetti* less K (1.7 cf. 1.3) to the scion under low K status soils, but *R. manetti* was a strong K accumulator

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<1.8			1.8-3.0			Aust	31	Gammon and McFadden (ref. 11) found *R. odorata* and *R. fortuniana* rootstocks supplied more and *R. manetti* less K (1.7 cf. 1.3) to the scion under low K status soils, but *R. manetti* was a strong K accumulator
S(%)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	S	<0.20			0.20-0.50			Aust	7 31	
Ca(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoot	Soil				0.95-1.3			Swe	21	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				1.06-1.30			USA	42	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	U	<1.0			1.0-1.5			UK	6	
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<1.0			1.0-1.5			Aust	31	
Mg(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoot	Soil				0.4			Swe	21	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				0.30-0.31			USA	42	
	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	U	<0.25			0.25-0.35			UK	6	
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<0.25			0.25-0.35			Aust	31	
Na(%)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil						>0.60	Aust	31	
K(%)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	S				0.02-0.04			Aust	7	
Cl(%)	1 day before harvest	2nd and 3rd 5-leaflet leaves from Fl shoot	Soil				0.01			Swe	21	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Rose, Hybrid Tea (*Rosa* spp.) (ctd)												
Cl(%) (ctd)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	S				0.24			Aust	7	
Cu(mg/kg)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<5			5.0-15.0			Aust	31	Gammon and McFadden (ref. 11) found Cu uptake by *R. fortuniana* was low (4.8) and by *R. odorata* ISU 5710-2 was high (6.4)
Zn(mg/kg)	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				24			USA	39	Gammon and McFadden (ref. 11) found Zn uptake by *R. fortuniana* was high (45) and by *R. odorata* ISU 5710-2 was low (38)
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<15			15-50			Aust	31	Gammon and McFadden (ref. 11) found Zn uptake by *R. fortuniana* was high (45) and by *R. odorata* ISU 5710-2 was low (38)
Mn(mg/kg)	1 day before Fl	2nd and 3rd 5-leaflet leaves from Fl shoot	SC				101			USA	42	Gammon and McFadden (ref. 11) found much higher Mn levels in cultivars grown on rootstock *R. fortuniana* (664) and lower levels in cultivars on *R. multiflora* ISU 62-5 (131) and *R. odorata* ISU 5710-2 rootstocks (130)
	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<30			30-250		>800	Aust	31	Gammon and McFadden (ref. 11) found much higher Mn levels in cultivars grown on rootstock *R. fortuniana* (664) and lower levels in cultivars on *R. multiflora* ISU 62-5 (131) and *R. odorata* ISU 5710-2 rootstocks (130)
Fe(mg/kg)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<50			50-150			Aust	31	
B(mg/kg)	When flower bud is size of pea to 1st colour	1st and 2nd 5-leaflet leaves from top of Fl shoot	Soil	<30			30-60		>400	Aust	31	
Swan River Pea Bush (*Brachysema lanceolatum*)												
N(%)	10 weeks	WS	Sand				1.09-1.65			Aust	33	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
P(%)	10 weeks	WS	Sand	0.01			0.32-0.60			Aust	33	Growth reduced in deficient plants
K(%)	10 weeks	WS	Sand				0.54-1.09			Aust	33	
Ca(%)	10 weeks	WS	Sand				0.40-0.69			Aust	33	
Mg(%)	10 weeks	WS	Sand				0.10-0.26			Aust	33	

Tea-Tree (*Leptospermum* spp.)

N(%)	70 DAT cuttings	WS	Sand	0.63			1.11-1.29			Aust	33	*L. lanigerum*; reduced growth at deficient level.
	70 DAT cuttings	WS	Sand	0.88			1.29-1.79			Aust	33	*L. rotundifolium*; reduced growth at deficient level.
P(%)	70 DAT cuttings	WS	Sand	0.01			0.09-0.23			Aust	33	*L. lanigerum*; reduced growth at deficient level.
	70 DAT cuttings	WS	Sand	0.05			0.48-0.85			Aust	33	*L. rotundifolium*; reduced growth at deficient level.
K(%)	70 DAT cuttings	WS	Sand	0.15			0.69-0.89			Aust	33	*L. lanigerum*; reduced growth at deficient level.
	70 DAT cuttings	WS	Sand	0.39			0.98-1.59			Aust	33	*L. rotundifolium*; reduced growth at deficient level.
Ca(%)	70 DAT cuttings	WS	Sand				0.76-1.04			Aust	33	*L. lanigerum*
	70 DAT cuttings	WS	Sand				0.90-1.52			Aust	33	*L. rotundifolium*
Mg(%)	70 DAT cuttings	WS	Sand				0.14-0.32			Aust	33	*L. lanigerum*
	70 DAT cuttings	WS	Sand				0.13-0.33			Aust	33	*L. rotundifolium*

Umbrella Plant (*Schefflera actinophylla*)

N(%)	U	Central leaflet	Soil				2.5-3.5			USA	38	
	U	Central leaflet	Soil, Sand	<2.0						USA	30	
P(%)	U	Central leaflet	Soil				0.20-0.35			USA	38	
K(%)	U	Central leaflet	Soil				2.5-3.5			USA	38	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Umbrella Plant (*Schefflera actinophylla*) (ctd)												
K(%) (ctd)	U	Central leaflet	Soil, Sand	<1.50						USA	30	
Ca(%)	U	Central leaflet	Soil				1.0-1.5			USA	38	
Mg(%)	U	Central leaflet	Soil, Sand				0.3-0.6			USA	30	
Cu(mg/kg)	U	Central leaflet	Soil, Sand				5.0-20.0			USA	30	
Zn(mg/kg)	U	Central leaflet	Soil, Sand				30-70			USA	30	
Mn(mg/kg)	U	Central leaflet	Soil, Sand				100-450		>1000	USA	30	
Fe(mg/kg)	U	Central leaflet	Soil, Sand				50-250		>1900	USA	30	
B(mg/kg)	U	Central leaflet	Soil, Sand	<20			25-60			USA	30	
Waratah, New South Wales (*Telopea speciossissima*)												
N(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				1.3-1.6			Aust	33	
P(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.07-0.10			Aust	33	Possible toxicity at 0.83%
K(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.45-0.53			Aust	33	Possible deficiency at 0.17%

Nutrient	Growth stage	Plant part	How established	Concentration range						Country	Ref	Comments
				Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)			
S(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.20-0.26			Aust	33	
Ca(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.39-0.53			Aust	33	
Mg(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.12-0.15			Aust	33	
Na(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.013-0.058			Aust	33	
Cl(%)	2nd year during dormancy (Aug)	YMB below flower bud	S				0.07-0.15			Aust	33	
Cu(mg/kg)	2nd year during dormancy (Aug)	YMB below flower bud	S				2.0-3.0			Aust	33	
Zn(mg/kg)	2nd year during dormancy (Aug)	YMB below flower bud	S				8.0-9.0			Aust	33	
Mn(mg/kg)	2nd year during dormancy (Aug)	YMB below flower bud	S				220-318			Aust	33	
Fe(mg/kg)	2nd year during dormancy (Aug)	YMB below flower bud	S				50-90			Aust	33	
Al(mg/kg)	2nd year during dormancy (Aug)	YMB below flower bud	S				175-380			Aust	33	

Nutrient	Growth stage	Plant part	How established	Concentration range: Deficient	Marginal	Critical (deficiency)	Adequate	High	Critical (toxicity)	Country	Ref	Comments
Waratah, New South Wales (*Telopea speciosissima*) (ctd)												
B(mg/kg)	2nd year during dormancy (Aug)	YMB below flower bud	S				15-21			Aust	33	
Wattle (*Acacia* spp.)												
P(%)	1 month after potting up to 250 mm pot	Leaves	S				0.16		>0.20	Aust	35	*A. baileyana*; in toxic range, stunting, discoloration of leaves and retarded root development.
	1 month after potting up to 250 mm pot	Leaves	S				0.2		>0.25	Aust	35	*A. retinoides*; in toxic range, stunting, discoloration of leaves and retarded root development.
	1 month after potting up to 250 mm pot	Leaves	S				0.18		>0.20	Aust	35	*A. decurrens*; in toxic range, stunting, discoloration of leaves and retarded root development.
	1 month after potting up to 250 mm pot	Leaves	S				0.2		>0.25	Aust	35	*A. iteaphylla*; in toxic range, stunting, discoloration of leaves and retarded root development.
Zinnia (*Zinnia elegans*)												
N(%)	F	YMB	U				2.0-5.0			Ger	5	
P(%)	F	YMB	U				0.2-0.45			Ger	5	
K(%)	F	YMB	U				2.2-5.5			Ger	5	
Ca(%)	F	YMB	U				0.8-2.0			Ger	5	
Mg(%)	F	YMB	U				0.2-0.6			Ger	5	
Cu(mg/kg)	F	YMB	U				4.0-10.0			Ger	5	
Zn(mg/kg)	F	YMB	U				25-70			Ger	5	
Mn(mg/kg)	F	YMB	U				40-120			Ger	5	
B(mg/kg)	F	YMB	U				25-70			Ger	5	
	F	Buds	SC	9			73-114	206		USA	40	
Mo(mg/kg)	F	YMB	U				0.3-1.0			Ger	5	

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Forest Plantations

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10. Forest Plantations

R. Boardman, R.N. Cromer, M.J. Lambert and M.J. Webb.

Leaf analysis is an established basis for the diagnosis of nutritional disorders of long-lived species of trees, but the reliable interpretation of foliar data needs much care. The scope of this chapter is to set out sampling protocols for plantations and to classify data so obtained to aid diagnosis of nutritional disorders in tree species which are of particular interest to managers and advisers in the Australasian region.

Stages of growth

The entries in this chapter refer to even-aged plantations in which the trees pass from seedling through juvenile and sapling stages to a long-lived mature state. We have taken the view that:

1. The seedling stage commences once a shoot has developed above the cotyledons and continues until the first lateral branch has emerged. This end-stage is when seedlings are commonly transplanted into the forest.
2. The juvenile stage begins once the second set of first order lateral branches has developed. In plantations this occurs usually within a few months of transplanting.
3. The mature stage begins when the leaves on the lowest branches die from insufficient resources, the leafy canopy 'lifts' and branches begin to die on the lower bole. Trees interact strongly with each other once the leafy canopy has closed. The trees now dominate the site and must share nutrients and other resources.

These stages often show marked changes in the physical development of trees, and may be associated with changes in leaf characteristics. The stages of development are illustrated in Figure 4.1 (Chapter 4) for four types of tree development commonly found in plantations of the Australasian region.

Plant parts

The tables of criteria apply to trees growing in well-stocked plantations. Data are restricted to a relatively limited range of plant parts. In seedlings, these are the whole shoot (WS) or foliage (L). In juvenile and mature stages, entries have been used for the youngest mature foliage (YMF), the youngest mature leaf-blade or leaflet (YMB), or the youngest mature petiolar organ (YMP). YMP is also used for compound or pinnate leaf samples which include rachis and petiole or are phyllodes. There are a number of crown positions which have been used in standardised sampling. In evergreen species a range in leaf ages may also be included. Tissues other than foliage have been studied as alternative or complementary samples to assist diagnosis (Grove, 1990; Dell *et al.*, 1987, 1995; Dighton and Jones, 1992; Cromer *et al.*, 1995). We took the view that a database that incorporated all these would be too large for a manual of this kind.

Sampling position

A number of standard crown positions have been used in forestry. The preferred part of the crown to sample is the zone of greatest demand, the youngest, fully developed foliage closest to the top. We have elected to limit data to foliage collected from the 'top' position of the crown of juvenile and mature trees (see Figure 3.3). Whilst this foliage is most difficult to sample, its disadvantage is outweighed by data consistency and ease of interpretation.

Sampling strategies

Once the mature stage is reached it is customary to standardise sampling procedures to achieve a desirable level of consistency in nutrient diagnosis. In Australia it is common to sample trees of *average bole volume*. This means sampling 'co-dominant trees' within the third quartile of the stand. This is a stratum midway in size between trees of average diameter and height and the largest trees present. Experience has shown these trees are most sensitive to large variations in the supply of nutrient resources and they are normally vigorous enough to persist in the stand for many years.

A defined level of sampling intensity at a selected site is important to minimise the effect of genetic variation and to improve the precision in results when extrapolated to a stand basis. Not less than four samples per location are advisable, collected within a plot of about 0.05–0.10 ha, depending on stocking level.

The season of sampling can affect interpretation of data. This is the case where critical levels have been determined in a certain sampling season. The season preferred for sampling is a period when growth rates

are lowest for the year. Sampling in spring is not normally recommended. Most foliage monitoring is conducted in autumn or winter.

Sampling strategies and interpretation will also differ between tree genera, since the relationship between nutrient concentrations and growth may not be constant. Analysis of data from a wide range of eucalypt species in Australia show that coefficients of variation within a species are very low, despite wide variation in productivity and soil fertility (Lambert and Turner, 1983). Thus, eucalypts often respond rapidly to enhanced nutrient availability by producing more foliage from their naked buds without any substantial change in nutrient concentration. By contrast, the majority of temperate hardwoods and conifers have resting buds with bud scales and well defined growth patterns, partially determined in the previous season. These species are more limited in their capacity to respond to changes in nutrient status.

Nutrient concentrations

Nutrient concentration data are expressed on an oven-dry weight basis for leaf tissue. A discussion of the relative merits of using 100-needle weight and oven-dry weight is given in Aronssen, Elowson and Ingestad (1977).

Quality of the information

In compiling the information it became apparent that there were two levels of reliability associated with the data.

Where possible we have provided the ***most dependable*** information, for 'top' sample positions for those plantation species which have been extensively and comprehensively studied in the Australian region. This classification is based on the authors' consensus derived from verified foliar concentrations, diagnostic criteria based on statistical analysis of growth rate, visual symptoms and, in a number of cases, is supported by internal biochemical or physiological states (Teasdale and Richards, 1990; Lambert and Turner, 1977; Palomaki and Holopainen, 1994; Palomaki and Raitio, 1995). Even so, the degree of reliability in the classification does vary between species and is related to our current state of knowledge. For example, nutrient criteria reported for Eucalypts are not intended to provide values which can be used solely for nutrient management decisions or for detecting deficiencies in eucalypt plantations.

In addition, where data for a species are incomplete or information on certain growth stages is lacking we have included ***best available*** data. In these cases, concentration values have only been related to one, or two productivity indicators (e.g. symptoms, growth rates or responses to nutrients applied in experiments). Thus, the limits of the ranges quoted are shown as (<...>). These are **not** to be interpreted as 'critical levels' because it cannot be presumed that other nutrients were not limiting growth.

Finally, although some information on diagnostic values has been collated, notably for tropical broadleaved species (e.g. Drechsel and Zech, 1991), we have normally only included data in the tables that could be validated from the original publications or the value of which was known to us personally.

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Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
ACACIA AURICULIFORMIS (Northern Black Wattle)											
Adequate values from apparently healthy trees. Deficient values associated with reduced growth and extreme chlorosis. Plant part assumed to be YMP.											
N(%)	Juv	YMP	F	<0.81-0.84>		<1.68-2.81>			Phil	200	Deficiency value from chlorotic plants
P(%)	Juv	YMP	F	<0.034-0.064>		<0.12-0.25>			Phil	200	Deficiency value from chlorotic plants
K(%)	Juv	YMP	F	<0.19>					Phil	202	Based on deficiency symptoms
K(%)	Juv	YMP	F			<0.80-1.14>			Phil	200	
Ca(%)	Juv	YMP	F			<0.85-1.21>			Phil	200	
Mg(%)	Juv	YMP	F			<0.32-0.49>			Phil	200	
S(%)	Juv	YMP	F	<0.031-0.037>		<0.061-0.094>			Phil	200	Deficiency value from chlorotic plants
Cu(mg/kg)	Juv	YMP	F			<4-9>			Phil	200	
Zn(mg/kg)	Juv	YMP	F			<13-22>			Phil	200	
Mn(mg/kg)	Juv	YMP	F			<61-83>			Phil	200	
Fe(mg/kg)	Juv	YMP	F			<87-126>			Phil	200	
B(mg/kg)	Juv	YMP	F			<11-32>			Phil	200	
ACACIA CYANOPHYLLA (see *Acacia saligna*)											
ACACIA DEALBATA (Silver Wattle)											
N(%)	Mat	YMF	F	<1.8		2.4-3.9			Aust	97	
P(%)	Mat	YMF	F			0.1-0.17			Aust	97	
K(%)	Mat	YMF	F			0.55-0.93			Aust	97	
S(%)	Mat	YMF	F			0.16-0.27			Aust	97	
Ca(%)	Mat	YMF	F			0.12-0.86			Aust	97	
Mg(%)	Mat	YMF	F	<0.12		0.14-0.22			Aust	97	
Na(%)	Mat	YMF	F			0.01-0.06			Aust	97	
ACACIA DECURRENS (Green Wattle)											
B(mg/kg)	Mat	YMP	F	7.2-11.2		20.4			Tang	177	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
ACACIA MANGIUM (Brown Salwood)											
P(%) Total	Seedl	WS YMP	sand/pots	<0.2-0.5 <0.2-0.35		0.5-0.8 0.35-0.5		>0.8 >0.5	Aust	163	Values are sometimes dependent on seed provenance. Crit. value curves are presented for 2 provenances.
N(%)	Juv	YMP	F			<2.04-3.0>			Mala	4 113	Lower canopy Lateral, upper-crown branches
P(%)	Juv	YMP	F			<0.11-0.15>		>0.5	Mala	4 113	Lower canopy Lateral, upper-crown branches
K(%)	Juv	YMP	F	<0.4-0.6		0.65-1.0>			 Mala 	3 4 113	K deficiency in plants with 0.4%K Upper canopy Lateral, upper-crown branches
S(%)	Juv	YMP	F	<0.10>					Mala	4 113	Lateral, upper crown branches
Ca(%)	Juv	YMP	F	<0.2>		<0.33-0.47>			Mala	4 113	Lateral, upper crown branches
Mg(%)	Juv	YMP	F	<0.11>		<0.15-0.20>			Mala	4 113	Upper canopy Lateral, upper-crown branches.
Cu(mg/kg)	Juv	YMP	F	<3>						113	Lateral, upper-crown branches
Zn(mg/kg)	Juv	YMP	F	<10>		<23-29>			Mala	4 113	Upper canopy Lateral, upper-crown branches
Mn(mg/kg)	Juv	YMP	F			<195-325>			Mala	4	Upper canopy
B(mg/kg)	Juv	YMP	F	<10>						113	Lateral, upper-crown branches
ACACIA MELANOXYLON (Blackwood)											
Conc. assoc with optimal treatment											
N(%)	Seedl	S	perlite			2.66			NZ	87	
N:P	Seedl	S	perlite			11.7			NZ	87	
P(%)	Seedl	S	perlite			0.23			NZ	87	
S(%)	Seedl	S	perlite			0.16			NZ	87	
S/N	Seedl	S	perlite			0.059			NZ	87	
S/P	Seedl	S	perlite			0.7			NZ	87	
N(%)	Seedl	WS	perlite			2.41			NZ	87	
P(%)	Seedl	WS	perlite			0.20			NZ	87	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
S(%)	Seedl	WS	perlite			0.17			NZ	87	
N(%)	Juv	YMP				2.41-2.74			NZ	87	
P(%)	Juv	YMP				0.20-0.27			NZ	87	
S(%)	Juv	YMP				0.16			NZ	87	

ACACIA SALIGNA (Golden Wreath Wattle)

Na(%)	Seedl	S	Sand			<0.1485>		3	USA	146	Toxic conc. reduced growth. Visual toxic symptoms at 6.63% Na.
Cl(%)	Seedl	S	Sand			<0.536>		4	USA	146	Toxic conc. reduced growth. Visual toxic symptoms at 12.24% Cl
Zn(mg/kg)	Seedl	S	Sand			<17>			USA	146	
Mn(mg/kg)	Seedl	S	Sand			<42>			USA	146	
Fe(mg/kg)	Seedl	S	Sand			<52>			USA	146	
Ca(%)	Seedl	S	Sand			<0.69>			USA	146	
Mg(%)	Seedl	S	Sand			<0.17>			USA	146	
N(%)	Seedl	S	Sand			<2.74>			USA	146	
P(%)	Seedl	S	Sand			<0.27>			USA	146	
K(%)	Seedl	S	Sand			<5.56>			USA	146	
K(%)	Juv	S	F			5.56			USA	146	
Ca(%)	Juv	S	F			0.90			USA	146	
Mg(%)	Juv	S	F			0.17			USA	146	
Na(%)	Juv	S	F			0.15			USA	146	
Cl(%)	Juv	S	F			0.54			USA	146	
Zn(mg/kg)	Juv	S	F			17			USA	146	
Mn(mg/kg)	Juv	S	F			42			USA	146	
Fe(mg/kg)	Juv	S	F			52			USA	146	

ARAUCARIA CUNNINGHAMII (Hoop Pine)

N(%)	Mat	ML				1.35				130	
P(%)	Mat	ML				0.11				130	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
ARAUCARIA HETEROPHYLLA (Norfolk Island Pine)											
N(%)	Mat	ML	D			1.4-2.6			Aust	44	
P(%)	Mat	ML	D			0.16-0.3			Aust	44	
K(%)	Mat	ML	D			1.0-1.8			Aust	44	
Ca(%)	Mat	ML	D			1.4-2.0			Aust	44	
Mg(%)	Mat	ML	D			0.3-0.5			Aust	44	
Na(%)	Mat	ML	D			0.15-0.8	1.5+		Aust	44	
Cl(%)	Mat	ML	D			0.6-1.0	1.5+		Aust	44	
Zn(mg/kg)	Mat	ML	D			35-80			Aust	44	
Mn(mg/kg)	Mat	ML	D			10-70			Aust	44	
Fe(mg/kg)	Mat	ML	D			100-400			Aust	44	
Al(mg/kg)	Mat	ML	D			80-600			Aust	44	
B(mg/kg)	Mat	ML	D			12-30			Aust	44	
CASUARINA CUNNINGHAMANIA (River Sheoak)											
N(%)	Seedl	WS	Soil			0.85 1.07-1.43			Egypt	108	Uninoculated plants Frankia-inoculated plants
K(%)	Seedl	WS	Soil				15.6-21.8		Ind	11	
Na(%)	Seedl	WS	Soil				1.8-6.2		Ind	11	
N(%)	Seedl	S	Soil F	<1.85> <1.9-2.2>		<2.42> <2.6>			Zim	136	Levels derived from field survey data in soil described as being N, P and S deficient.
P(%)	Seedl	S	Soil F			<0.17-0.26> <0.7-0.9>			Zim	136	Levels derived from field survey data in soil described as being N, P and S deficient.
K(%)	Seedl	S	Soil			<0.31-0.32>			Zim	136	Levels derived from field survey data in soil described as being N, P and S deficient.
Ca(%)	Seedl	S	Soil			<1.11-1.41>			Zim	136	Levels derived from field survey data in soil described as being N, P and S deficient.
Mg(%)	Seedl	S	Soil			<0.37>			Zim	136	Levels derived from field survey data in soil described as being N, P and S deficient.
Mn(%)	Seedl	S	Soil			<0.17-0.30>			Zim	136	Levels derived from field survey data in soil described as being N, P and S deficient.

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Na(%)	Seedl	S	Sand				32		Aust	6	Moderately salt tolerant varieties
Cl(%)	Seedl	YS	Sand			1.38	49		Aust	6	Moderately salt tolerant varieties
Co(mg/kg)	Seedl	S	SC	0.07		0.11-1.1			UK	22 69	Deficiency symptoms due to N deficiency
Cu(mg/kg)	Seedl	Roots	SC			4.8-9.9			UK	21	No effect at these levels between Cu supplemented plants and the control.
N(%)	Juv		F	1.9-2.2		2.6			Indon Zim	136	
P(%)	Juv		F			0.7-0.9			Indon Zim	136	
K(%)	Juv		F			0.4-0.56			Indon Zim	136	
Ca(%)	Juv		F			1.11-1.41			Indon Zim	136	
Mg(%)	Juv		F			0.37			Indon Zim	136	
Na(%)	Juv		F			0.08-0.27			Indon Zim	136	
Cu(mg/kg)	Juv		F			4.8-9.9			Indon Zim	136	
Mn(mg/kg)	Juv		F			0.17-0.30			Indon Zim	136	

CASUARINA EQUISETIFOLIA (Horsetail Casuarina, Whistling Pine)

N(%)	Seedl	YS	Sand	<1.4		<2.53>			USA	181	
P(%)	Seedl	YS	Sand	<0.15		<0.25>			USA	181	
K(%)	Seedl	YS	Sand	<0.45		<1.36>			USA	181	
Ca(%)	Seedl	YS	Sand	<0.40		<1.30>			USA	181	
Mg(%)	Seedl	YS	Sand	<0.10		<0.25>			USA	181	
Na((%)	Seedl	YS	Sand				10.4		Aust	6	Apical shoot. Highly salt tolerant provenance
Cl(%)	Seedl	YS	Sand				16.0		Aust	6	Apical shoot. Highly salt tolerant provenance
N(%)	Seedl	WS	Soil			<0.88> <0.88-1.14>			Egypt	108	Uninoculated plants. Frankia-inoculated plants. Soil was N-deficient, and had 15N added to measure N uptake.
Na(%)	Seedl	WS	Soil				2.3-5.9		Ind	11	

CASUARINA EQUISETIFOLIA (Horsetail Casuarina, Whistling Pine) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
K(%)	Seedl	WS	Soil				9.0-19.1		Ind	11	
Na(%)	Seedl	WS	Soil			0.12-0.25			Ind	11	

CASUARINA GLAUCA (Swamp Sheoak, Beefwood)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Seedl	WS	Soil			0.83 1.10-1.45			Egypt	108	Uninoculated plants Frankia-inoculated plants
K(%)	Seedl	WS	Soil				16-21.8		Ind	11	
Na(%)	Seedl	WS	Soil				6.2-6.9		Ind	11	
Na(%)	Seedl	S	Sand				6.9		Aust	6	Highly salt tolerant varieties
Cl(%)	Seedl	S	Sand				9.85		Aust	6	Highly salt tolerant varieties
N(%)	Juv	YMF	F			1.10-1.45	2.14-2.44		Aust Egypt	20 108	Irrigated
P(%)	Juv	YMF	F			0.11-0.16			Aust	20	Irrigated
K(%)	Juv	YMF	F			0.4-0.6	1.10-1.45		Aust	20	Irrigated
S(%)	Juv	YMF	F			0.12-0.17			Aust	20	Irrigated
Ca(%)	Juv	YMF	F			0.49-0.81			Aust	20	Irrigated
Mg(%)	Juv	YMF	F			0.08-0.11			Aust	20	Irrigated
Na(%)	Juv	YMF	F			0.2-0.3	0.71-0.78		Aust	6 20	Irrigated
Cl(%)	Juv	YMF	F			0.2-0.3	1.93-2.13		Aust	6 20	Irrigated
Cu(mg/kg)	Juv	YMF	F			4-8			Aust	20 21	Irrigated
Zn(mg/kg)	Juv	YMF	F			24-39			Aust	20	Irrigated
Mn(mg/kg)	Juv	YMF	F			99-188			Aust	20	Irrigated
Fe(mg/kg)	Juv	YMF	F			92-96			Aust	20	Irrigated
Al(mg/kg)	Juv	YMF	F			81-136			Aust	20	Irrigated
B(mg/kg)	Juv	YMF	F			33-47			Aust	20	Irrigated
N(%)	Mat	YMF	F			1.98			Aust	20	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
P(%)	Mat	YMF	F	0.09		>0.1			Aust	20	Irrigated
K(%)	Mat	YMF	F			0.95-1.50			Aust	20	Irrigated
S(%)	Mat	YMF	F			0.10-0.12			Aust	20	Irrigated
Ca(%)	Mat	YMF	F				1.14-1.54		Aust	20	Irrigated
Mg(%)	Mat	YMF	F			0.09-0.17			Aust	20	Irrigated
Na(%)	Mat	YMF	F				0.16-0.30		Aust	20	Irrigated
Cl(%)	Mat	YMF	F				0.98-1.52		Aust	20	Irrigated
Cu(mg/kg)	Mat	YMF	F			4-5.5			Aust	20	Irrigated
Zn(mg/kg)	Mat	YMF	F			22-30			Aust	20	Irrigated
Mn(mg/kg)	Mat	YMF	F			164-232			Aust	20	Irrigated
Fe(mg/kg)	Mat	YMF	F			90-134			Aust	20	Irrigated
Al(mg/kg)	Mat	YMF	F				132-237		Aust	20	Irrigated
B(mg/kg)	Mat	YMF	F			48-65			Aust	20	Irrigated

CEDRELA ODORATA (West Indian Cedar)

Healthy tree from experimental plot with luxury dose of fertiliser

N(%)	Seedl	YMB	F			<4.5>			SI	185	
P(%)	Seedl	YMB	F			<0.6-0.38>			SI	185	
K(%)	Seedl	YMB	F			<3.0-3.3>			SI	185	
S(%)	Seedl	YMB	F			<0.49-0.52>			SI	185	
Ca(%)	Seedl	YMB	F			<1.6-1.9>			SI	185	
Mg(%)	Seedl	YMB	F			<0.29-0.30>			SI	185	
Cu(mg/kg)	Seedl	YMB	F			<10-13>			SI	185	
Zn(mg/kg)	Seedl	YMB	F			<25-29>			SI	185	
Mn(mg/kg)	Seedl	YMB	F			<110-142>			SI	185	
Fe(mg/kg)	Seedl	YMB	F			<66-135>			SI	185	
B(mg/kg)	Seedl	YMB	F			<25-28>			SI	185	
N(%)	Seedl	YMP	F			<1.1-1.4>			SI	185	
P(%)	Seedl	YMP	F			<0.16-0.22>			SI	185	
K(%)	Seedl	YMP	F			<3.4-3.6>			SI	185	
S(%)	Seedl	YMP	F			<0.11-0.14>			SI	185	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
***CEDRELA ODORATA* (West Indian Cedar) (ctd)**											
Ca(%)	Seedl	YMP	F			<0.55-0.64>			SI	185	
Mg(%)	Seedl	YMP	F			<0.19>			SI	185	
Cu(mg/kg)	Seedl	YMP	F			<12-13>			SI	185	
Zn(mg/kg)	Seedl	YMP	F			<14-15>			SI	185	
Mn(mg/kg)	Seedl	YMP	F			<27-29>			SI	185	
Fe(mg/kg)	Seedl	YMP	F			<22-25>			SI	185	
B(mg/kg)	Seedl	YMP	F			<13>			SI	185	
N(%)	Juv	YML	F			<3.07>			Liber	201	
P(%)	Juv	YML	F			<0.23>			Liber	201	
K(%)	Juv	YML	F			<2.4>			Liber	201	
Ca(%)	Juv	YML	F			<1.3>			Liber	201	
Mg(%)	Juv	YML	F			<0.24>			Liber	201	
Cu(mg/kg)	Juv	YML	F			<6>			Liber	201	
Zn(mg/kg)	Juv	YML	F			<17>			Liber	201	
Mn(mg/kg)	Juv	YML	F			<25>			Liber	201	
Fe(mg/kg)	Juv	YML	F			<145>			Liber	201	
Al(mg/kg)	Juv	YML	F			<148>			Liber	201	
B(mg/kg)	Juv	YML	F			<27>			Liber	201	
***CERATOPETALUM APETALUM* (Coachwood)**											
N(%)	Mat	YMF	F			0.6-1.2			Aust	97	
P(%)	Mat	YMF	F			0.04-0.08			Aust	97	
K(%)	Mat	YMF	F			0.4-0.78			Aust	97	
Ca(%)	Mat	YMF	F			0.3-1.1			Aust	97	
Mg(%)	Mat	YMF	F			0.24-0.32			Aust	97	
Na(%)	Mat	YMF	F			0.04-0.07			Aust	97	
Cl(%)	Mat	YMF	F			0.1-0.3			Aust	97	
Mn(mg/kg)	Mat	YMF	F			0.15-0.41			Aust	97	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Al(mg/kg)	Mat	YMF	F			0.8-1.6			Aust	97	
B(mg/kg)	Mat	YMF	F			20-35			Aust	97	

CORYMBIA (see *Eucalyptus*)

EUCALYPTUS CAMALDULENSIS (River Red Gum)

N(%)	Juv	YMF	F	<1.0	1.0-1.4		<2.26-2.86>		Aust	20	Irrigated
						1.4-1.8	2.0+			97	Non-irrigated
									China	77	
P(%)	Juv	YMF	F	<0.08	0.08-0.10		<0.21-0.33>		Aust	20	Irrigated
						0.1-0.14				97	Non-irrigated
									China	77	
K(%)	Juv	YMF	F			0.6-1.0			Aust	20	Irrigated
										97	Non-irrigated
S(%)	Juv	YMF	F			0.1-1.4			Aust	20	Irrigated
										97	Non-irrigated
Ca(%)	Juv	YMF	F			0.5-1.2			Aust	20	Irrigated
										97	Non-irrigated
									China	77	
Mg(%)	Juv	YMF	F			0.18-0.25			Aust	20	Irrigated
										97	Non-irrigated
									China	77	
Na(%)	Juv	YMF	F			0.1-0.43			Aust	20	Irrigated
										97	
Cl(%)	Juv	YMF	F			0.1-0.4	>0.6		Aust	20	Irrigated
										97	
									China	77	
Cu(mg/kg)	Juv	YMF	F				5-11		Aust	20	Irrigated
						3-5				97	
Zn(mg/kg)	Juv	YMF	F				42-48		Aust	20	Irrigated
						16-41				23	Non irrigated
Mn(mg/kg)	Juv	YMF	F			80-500			Aust	20	Irrigated
										24	Non irrigated
Fe(mg/kg)	Juv	YMF	F			84-170			Aust	20	Irrigated
										97	

EUCALYPTUS CAMALDULENSIS (River Red Gum) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
Al(mg/kg)	Juv	YMF	F			30-250			Aust	20 24	Irrigated
B(mg/kg)	Juv	YMF	F			20-120			Aust	20 97	Irrigated
N(%)	Mat	YMF	F	<0.74	<1.2-1.5>	<1.46-2.1>			Ind Aust Phil	17 20 24 97 200	 Irrigated
P(%)	Mat	YMF	F	<0.07	0.08-0.18	0.18-0.22>			Ind Aust Phil	17 20 24 97 200	 Irrigated
K(%)	Mat	YMF	F	<0.6		<0.6-0.8>			Aust Phil	20 97 200	Irrigated
S(%)	Mat	YMF	F			0.11-0.16			Aust	20 97	Irrigated
Ca(%)	Mat	YMF	F			0.50-1.01			Aust	20 97	Irrigated
Mg(%)	Mat	YMF	F			0.17-0.37			Aust Ind	20 97 17	Irrigated
Na(%)	Mat	YMF	F			0.22-0.36			Aust	20 97	Irrigated
Cl(%)	Mat	YMF	F			0.17-0.46			Aust	20 97	Irrigated
Cu(mg/kg)	Mat	YMF	F		2.3-2.9	3-5			Aust	20 97	Irrigated
Zn(mg/kg)	Mat	YMF	F			13-41			Aust Ind	20 24 97 17	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Mn(mg/kg)	Mat	YMF	F			190-600			Aust	20 24 97	Irrigated
Fe(mg/kg)	Mat	YMF	F			110-170			Aust	20 97	Irrigated
Al(mg/kg)	Mat	YMF	F			120-260			Aust	20 97	Irrigated
B(mg/kg)	Mat	YMF	F			144-200	200-430		Aust	20 97	Irrigated

EUCALYPTUS [syn. *CORYMBIA*] *CITRIODORA* (Lemon-scented Gum)

B(mg/kg)	Juv			35		40-70	400+		Bra	107	

EUCALYPTUS DELEGATENSIS (Alpine Ash)

N(%)	Mat	YMF	F	<1.2		<1.4-1.9>			NZ Aust	89 97	
P(%)	Mat	YMF	F	<0.09		<0.11-0.17>			NZ Aust	89 97	
K(%)	Mat	YMF	F			<0.6-0.9>			NZ Aust	89 97	
S(%)	Mat	YMF	F			<0.14>			NZ	89	
Ca(%)	Mat	YMF	F			<0.4-0.7>			NZ Aust	89 97	
Mg(%)	Mat	YMF	F			<0.17-0.26>			NZ Aust	89 97	
Na(%)	Mat	YMF	F			<0.005-0.03>			NZ Aust	89 97	
Cl(%)	Mat	YMF	F			<0.3>			NZ Aust	89 97	
Cu(mg/kg)	Mat	YMF	F			<3.0>			NZ	89	
Zn(mg/kg)	Mat	YMF	F			<21>			NZ	89	
Mn(mg/kg)	Mat	YMF	F			<400-860>			NZ Aust	89 97	
Fe(mg/kg)	Mat	YMF	F			<62>			NZ	89	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
EUCALYPTUS DELEGATENSIS (Alpine Ash) (ctd)											
Al(mg/kg)	Mat	YMF	F			<60-260>			NZ Aust	89 97	
B(mg/kg)	Mat	YMF	F			<14-30>			NZ Aust	89 97	
EUCALYPTUS DIVERSICOLOR (Karri)											
N(%)	Mat	YMF	F		<1.1	<1.1-1.3>			Aust	60 70	
P(%)	Mat	YMF	F			<0.06>			Aust	60 70	
K(%)	Mat	YMF	F			<0.6-0.9>			Aust	60 70	
S(%)	Mat	YMF	F			<0.11-0.13>			Aust	60 70	
Ca(%)	Mat	YMF	F			<0.9-1.6>			Aust	60 70	
Mg(%)	Mat	YMF	F			<0.24-0.32>			Aust	60 70	
Na(%)	Mat	YMF	F			<0.19-0.29>			Aust	60 70	
Cl(%)	Mat	YMF	F			<0.37-0.44>			Aust	60 70	
Mn(mg/kg)	Mat	YMF	F			<410-2200>			Aust	60 70	
Cu(mg/kg)	Mat	YMF	F			<2-9>			Aust	60 70 154	
Zn(mg/kg)	Mat	YMF	F			<6-7>			Aust	60 70	
EUCALYPTUS DUNNII (Dunn's White Gum)											
N(%)	Mat	YMF	F	<1.4		<1.8-2.8>			Aust	97	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
P(%)	Mat	YMF	F	<0.09		<0.11-0.22>			Aust	97	
K(%)	Mat	YMF	F			<0.8-1.5>			Aust	97	
Ca(%)	Mat	YMF	F			<0.4-0.8>			Aust	97	
Mg(%)	Mat	YMF	F			<0.18-0.28>			Aust	97	
Na(%)	Mat	YMF	F			<0.06-0.20>			Aust	97	
Al(mg/kg)	Mat	YMF	F			<80-200>			Aust	97	
B(mg/kg)	Mat	YMF	F			<16-40>			Aust	97	

EUCALYPTUS FASTIGATA (Brown Barrel)

N(%)	Juv	YMF	F			<2.29>			NZ	89	
P(%)	Juv	YMF	F			<0.11>			NZ	89	
K(%)	Juv	YMF	F			<0.79>			NZ	89	
S(%)	Juv	YMF	F			<0.16>			NZ	89	
Ca(%)	Juv	YMF	F			<0.30>			NZ	89	
Mg(%)	Juv	YMF	F			<0.16>			NZ	89	
Mn(mg/kg)	Juv	YMF	F			<154>			NZ	89	
Fe(mg/kg)	Juv	YMF	F			<73>			NZ	89	
Cu(mg/kg)	Juv	YMF	F			<5>			NZ	89	
Zn(mg/kg)	Juv	YMF	F			<17>			NZ	89	
B(mg/kg)	Juv	YMF	F			<14>			NZ	89	
N(%)	Mat	YMF	F	<1.1-1.4		<2.0-2.3>			NZ	88	
P(%)	Mat	YMF	F			<0.15>			NZ	88	
K(%)	Mat	YMF	F			<0.8>			NZ	88	
Ca(%)	Mat	YMF	F			<0.35>			NZ	88	
Mg(%)	Mat	YMF	F			<0.18>			NZ	88	
Fe(mg/kg)	Mat	YMF	F			<31>			NZ	88	
Cu(mg/kg)	Mat	YMF	F			<4.8-6.5>			NZ Aust	88 154	
Zn(mg/kg)	Mat	YMF	F			<9>			NZ	88	
B(mg/kg)	Mat	YMF	F			<22>			NZ	88	

EUCALYPTUS GLOBULUS (Tasmanian Blue Gum)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Seedl	YMF	F	<1.0	1.7-2.0	2-2.8		>4.3	Aust	147 148	
N(%)	Juv	YMF	F	<1.0	1.7-2.0	2.0-2.8			Var	9 20 42 56 93 121	Irrigated
P(%)	Juv	YMF	F	<0.10	0.12-0.14	0.14-0.26			Var	9 20 42 56 93 121 148	Irrigated
K(%)	Juv	YMF	F	<0.4		0.8-1.2			Var	9 20 42 56 93 121 148	Irrigated
S(%)	Juv	YMF	F	<0.12		0.15-2.0			Var	9 20 42 56 93 121 148	Irrigated
Ca(%)	Juv	YMF	F			0.4-1.3			Var	9 20 42 56 93 121 148	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Mg(%)	Juv	YMF	F			0.10-0.22			Var	9	
										20	Irrigated
										42	
										56	
										93	
										121	
										148	
Na(%)	Juv	YMF	F			0.1-0.4			Var	9	
										20	Irrigated
										56	
										93	
										121	
										148	
Cl(%)	Juv	YMF	F			<0.33>	0.6+		Var	9	
										20	Irrigated
										56	
										93	
										121	
										148	
Cu(mg/kg)	Juv	YMF	F	<2.5	<3	4-24			Var	9	
										20	Irrigated
										42	
										56	
										93	
										121	
										148	
Zn(mg/kg)	Juv	YMF	F	<10		15-50			Var	9	
										20	Irrigated
										42	
										56	
										93	
										121	
										148	
Mn(mg/kg)	Juv	YMF	F	<20		100-2000			Var	9	
										20	Irrigated
										42	
										56	
										93	
										121	
										148	

EUCALYPTUS GLOBULUS (Tasmanian Blue Gum) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Fe(mg/kg)	Juv	YMF	F	<8	<74	30-700			Var	9 20 42 56 93 121 148 157	Irrigated
Al(mg/kg)	Juv	YMF	F			30 -100			Var	9 20 42 56 93 121 148	Irrigated
B(mg/kg)	Juv	YMF	F	<10		<12-50>	100+		Var	9 20 42 56 121 148	Irrigated
N(%)	Mat	YMF	F	<1.2		<1.2-1.9>			Var	9 20 33 79 93 110 121 147	Irrigated
P(%)	Mat	YMF	F	<0.09		0.11 -0.18			Var	9 20 79 93 121	Irrigated
K(%)	Mat	YMF	F	<0.45		0.5 -1.2			Var	9 20 56 79 93 110 121	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
S(%)	Mat	YMF	F		<0.08	0.1-0.14			Var	9 20 93 121	Irrigated
Ca(%)	Mat	YMF	F			<0.4-2.1>			Var	9 20 93 110 121	Irrigated
Mg(%)	Mat	YMF	F			<0.16-0.27>			Var	9 20 93 110 121	Irrigated
Na(%)	Mat	YMF	F			<0.14-0.40>			Aust	20	Irrigated
Cl(%)	Mat	YMF	F				<0.44-0.7>		Aust	20	Irrigated
Cu(mg/kg)	Mat	YMF	F		<3	4-12			Var	9 20 93 110 121	Irrigated
Zn(mg/kg)	Mat	YMF	F			11-15			Var	9 20 93 110 121	Irrigated
Mn(mg/kg)	Mat	YMF	F			150-600	600-950		Var	20 55 93 110 121	Irrigated
Fe(mg/kg)	Mat	YMF	F			60-180			Var	9 20 55 93 110 121	Irrigated
Al(mg/kg)	Mat	YMF	F			40-230			Aust	20	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
EUCALYPTUS GLOBULUS (Tasmanian Blue Gum) (ctd)											
B(mg/kg)	Mat	YMF	F	<10		30 -267			Var	9 20 93 55 110 121	Irrigated
EUCALYPTUS GRANDIS (Flooded or Australian Rose Gum)											
N(%)	Juv	YMF	F	<0.7	<1.48-1.8>	1.8-3.4	3.5+		Var	20 33 42 66 77 78 122 123 140 173	Irrigated
P(%)	Juv	YMF	F	<0.07	<0.09>	<0.1-0.3>	0.30+		Var	20 33 42 66 77 78 122 123 140 173	Irrigated
K(%)	Juv	YMF	F	<0.5		<0.6-1.8>			Var	20 33 42 66 77 78 122 123 140 173	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
S(%)	Juv	YMF	F	<0.1		<0.1-0.3>			Var	20 33 42 66 123 173	Irrigated
Ca(%)	Juv	YMF	F	<0.08>		<0.3-1.0>			Var	20 33 42 66 77 122 123 173	Irrigated
Mg(%)	Juv	YMF	F	<0.06		<0.1-0.35>			Var	20 33 42 66 77 122 123 173	Irrigated
Na(%)	Juv	YMF	F			0.30-0.42			Var	20 33 42 66 123 173	Irrigated
Cl(%)	Juv	YMF	F				0.4+		Aust	20	Irrigated
Cu(mg/kg)	Juv	YMF	F	<2		6-15 2-7			Var	20 33 42 66 122 123 173	Irrigated
Zn(mg/kg)	Juv	YMF	F	<7		14-46			Var	20 33 42 66 122 123 173	Irrigated

EUCALYPTUS GRANDIS (Flooded or Australian Rose Gum) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
Mn(mg/kg)	Juv	YMF	F	<8		220-700> 150-600	1000+		Var	20 33 42 66 122 123 173	Irrigated
Fe(mg/kg)	Juv	YMF	F	<17		<60-130>	300+		Var	20 33 42 66 122 123 173	Irrigated
Al(mg/kg)	Juv	YMF	F			<22-160>			Var	20 33 42 66 123 173	Irrigated
B(mg/kg)	Juv	YMF	F	<8		<15-30>	<54-82>	100+	Var	20 33 42 66 77 122 123 173	Irrigated
N(%)	Mat	YMF	F	<1.0	1.0-1.6	1.6-2.9	>3		Var	18 20 42 61 67 68 125 143 173	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
P(%)	Mat	YMF	F	<0.08		<0.1-0.3>	0.30+		Var	18 20 42 67 68 125 143 173	Irrigated
K(%)	Mat	YMF	F	<0.5		<0.6-1.8>			Var	20 42 67 68 143 173	Irrigated
S(%)	Mat	YMF	F		<0.15	0.15-2.0			Var	20 42 67 68 143 173	Irrigated
Ca(%)	Mat	YMF	F	<0.1		0.20-0.4			Var	20 42 67 68 125 143 173	Irrigated
Mg(%)	Mat	YMF	F	<0.08		<0.1-0.3>			Var	20 42 59 67 68 125 143 173	Irrigated
Na(%)	Mat	YMF	F			0.1-0.6	0.7	1.0+	Var	20 67 68 143 173	Irrigated
Cl(%)	Mat	YMF	F				<0.5-1.0>	1.0+	Var	20 67 68 143 173	Irrigated

EUCALYPTUS GRANDIS (Flooded or Australian Rose Gum) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
Cu(mg/kg)	Mat	YMF	F	<4		<4-12>			Var	20 67 68 143 173	Irrigated
Zn(mg/kg)	Mat	YMF	F	<10		<15-46>			Var	20 42 59 67 68 143 173	Irrigated
Mn(mg/kg)	Mat	YMF	F			<190-700>			Var	20 42 59 67 68 143 173	Irrigated
Fe(mg/kg)	Mat	YMF	F			<50-156>			Var	20 42 59 67 68 143 173	Irrigated
Al(mg/kg)	Mat	YMF	F			<90-270>	400+		Var	20 67 68 143 173	Irrigated
B(mg/kg)	Mat	YMF	F	<12		<15-100>	100-180		Var	20 42 67 68 143 173	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
EUEUCALYPTUS [syn _CORYMBIA_] _MACULATA_ (Spotted Gum)											
N(%)	Juv	YMF	F	1.0-1.2		1.7-2.6			Aust	41	
P(%)	Juv	YMF	F	0.4-0.5	0.8	1.0-2.6			Aust	41	
K(%)	Juv	YMF	F	0.4	0.5-0.8	1.0-1.7			Aust	41	
S(%)	Juv	YMF	F	1.2-1.3	1.4-1.7	1.8-4.2			Aust	41	
Ca(%)	Juv	YMF	F	0.15-0.2	<0.22-2.9>	<2.9-4.0>			Aust	41	
Mg(%)	Juv	YMF	F	0.3	0.4-0.8	0.9-2.4			Aust	41	
Cu(mg/kg)	Juv	YMF	F	0.5-1.5	2-5	6-12			Aust	41	
Zn(mg/kg)	Juv	YMF	F	4-8	9-11	12-54			Aust	41	
Mn(mg/kg)	Juv	YMF	F	12-15	16-21	22-32			Aust	41	
Fe(mg/kg)	Juv	YMF	F	15	20-30	39-50			Aust	41	
N(%)	Mat	YMF	F	<1.2		1.4-2.4			Aust	41	
P(%)	Mat	YMF	F	<0.13		0.14-0.23			Aust	41	
K(%)	Mat	YMF	F	<0.4	0.5-0.7	0.8-1.7			Aust	41	
Ca(%)	Mat	YMF	F		<0.21	0.22-0.6			Aust	41	
Mg(%)	Mat	YMF	F	<0.04		0.18-0.3			Aust	41	
Na(%)	Mat	YMF	F			0.1-0.3			Aust	41	
Cu(mg/kg)	Mat	YMF	F	0.5-1.5	2	6-12			Aust	38 41	
Mn(mg/kg)	Mat	YMF	F	<20		20-250			Aust	41	
Fe(mg/kg)	Mat	YMF	F	<15	20-30	40-50			Aust	41	
Al(mg/kg)	Mat	YMF	F			30-200			Aust	41	
EUCALYPTUS MICROCORYS (Tallowwood)											
N(%)	Mat	YMF	F			0.8-1.5			Aust	97	
P(%)	Mat	YMF	F			0.05-0.06			Aust	97	
K(%)	Mat	YMF	F			0.4-0.61			Aust	97	
Ca(%)	Mat	YMF	F			0.53-0.74			Aust	97	
Mg(%)	Mat	YMF	F			0.17-0.41			Aust	97	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
EUCALYPTUS MICROCORYS (Tallowwood) (ctd)											
Na(%)	Mat	YMF	F			0.38-0.78			Aust	97	
Mn(mg/kg)	Mat	YMF	F			600-800			Aust	97	
Al(mg/kg)	Mat	YMF	F			160-210			Aust	97	
EUCALYPTUS NITENS (Shining Gum)											
N(%)	Juv	YMF	F	<1.3		<2.0-3.5>			Aust	35 79 168	
P(%)	Juv	YMF	F	<0.1		<0.1-0.2>			NZ Aust	103 168	
K(%)	Juv	YMF	F	<0.4		<0.8>			Aust	168	
Ca(%)	Juv	YMF	F			<0.3-0.5>			Aust	168	
Mg(%)	Juv	YMF	F			<0.09-0.15>			Aust	168	
Mn(mg/kg)	Juv	YMF	F			<960-1400>			Aust	168	
Fe(mg/kg)	Juv	YMF	F			<23-75>			Aust	168	
Cu(mg/kg)	Juv	YMF	F	<1.4	1.4	<4.9>			Aust	168	
Zn(mg/kg)	Juv	YMF	F			<9-19>			Aust	168	
B(mg/kg)	Juv	YMF	F			<10-30>			Aust	168	
Al(mg/kg)	Juv	YMF	F			<8-50>			Aust	168	
N(%)	Mat	YMF	F	<1.3		1.33-2.16	2.16-2.33		Aust NZ	79 103 168	
P(%)	Mat	YMF	F	<0.13		<0.13-0.15>			Aust NZ	79 103	
K(%)	Mat	YMF	F	0.39-0.78		0.78-0.9			Aust NZ	79 103	
Ca(%)	Mat	YMF	F			0.35-0.7			Aust NZ	79 103	
Mg(%)	Mat	YMF	F			<0.15-0.2>			Aust NZ	79 103	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
***EUCALYPTUS OBLIQUA* (Messmate)**											
N(%)	Juv	YMF	F			<1.28-1.45>			Aust	33	
P(%)	Juv	YMF	F			<0.095-0.12>			Aust	33	
***EUCALYPTUS OCCIDENTALIS* (Swamp Yate)**											
N(%)	Juv	YMF	F			<1.95-2.32>			Aust	20	Irrigated
P(%)	Juv	YMF	F			0.19-0.26			Aust	20	Irrigated
K(%)	Juv	YMF	F			0.52-0.72			Aust	20	Irrigated
S(%)	Juv	YMF	F			0.16-0.19			Aust	20	Irrigated
Ca(%)	Juv	YMF	F			0.39-0.43			Aust	20	Irrigated
Mg(%)	Juv	YMF	F			0.13-0.18			Aust	20	Irrigated
Na(%)	Juv	YMF	F			0.41-0.64			Aust	20	Irrigated
Cl(%)	Juv	YMF	F			0.34-0.70			Aust	20	Irrigated
Cu(mg/kg)	Juv	YMF	F			4.0-7.0			Aust	20	Irrigated
Zn(mg/kg)	Juv	YMF	F			23-31			Aust	20	Irrigated
Mn(mg/kg)	Juv	YMF	F			121-190			Aust	20	Irrigated
Fe(mg/kg)	Juv	YMF	F			67-71			Aust	20	Irrigated
Al(mg/kg)	Juv	YMF	F			28-32			Aust	20	Irrigated
B(mg/kg)	Juv	YMF	F			52-75			Aust	20	Irrigated
N(%)	Mat	YMF	F			1.48-1.86			Aust	20	Irrigated
P(%)	Mat	YMF	F			0.23-0.37			Aust	20	Irrigated
K(%)	Mat	YMF	F			0.45-0.69			Aust	20	Irrigated
S(%)	Mat	YMF	F			0.12-0.15			Aust	20	Irrigated
Ca(%)	Mat	YMF	F			0.30-0.48			Aust	20	Irrigated
Mg(%)	Mat	YMF	F			0.13-0.18			Aust	20	Irrigated
Na(%)	Mat	YMF	F			0.41-0.64			Aust	20	Irrigated
Cl(%)	Mat	YMF	F			0.34-0.56			Aust	20	Irrigated
Cu(mg/kg)	Mat	YMF	F		<2.7	3.0-4.3			Aust	20	Irrigated

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
EUCALYPTUS OCCIDENTALIS (Swamp Yate) (ctd)											
Zn(mg/kg)	Mat	YMF	F			13-16			Aust	20	Irrigated
Mn(mg/kg)	Mat	YMF	F			95-186			Aust	20	Irrigated
Fe(mg/kg)	Mat	YMF	F			100-186			Aust	20	Irrigated
Al(mg/kg)	Mat	YMF	F			107-262			Aust	20	Irrigated
B(mg/kg)	Mat	YMF	F			<171-258>			Aust	20	Irrigated
EUCALYPTUS PILULARIS (Blackbutt)											
N(%)	Juv	YMF	YMF		<0.9	1.3-1.6			Aust	33 97	
P(%)	Juv	YMF			<0.04	0.06-0.12			Aust	33 97	
K(%)	Juv	YMF			<0.3	0.35-0.5			Aust	33 97	
S(%)	Juv	YMF			<0.08	<0.1-0.15>			Aust	33 97	
Ca(%)	Juv	YMF				0.15-0.3			Aust	33 97	
Mg(%)	Juv	YMF				0.15-0.35			Aust	33 97	
Na(%)	Juv	YMF				0.16-0.26			Aust	33 97	
Cl(%)	Juv	YMF				0.1-0.4			Aust	33 97	
Al(mg/kg)	Juv	YMF				60-110			Aust	33 97	
B(mg/kg)	Juv	YMF				9-30			Aust	33 97	
N(%)	Mat	YMF	F		<0.7	0.9-1.3			Aust	97	
P(%)	Mat	YMF	F		<0.04	0.05-0.12			Aust	97	
K(%)	Mat	YMF	F			0.35-0.6			Aust	97	
S(%)	Mat	YMF	F		0.06	0.07-0.09			Aust	97	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Ca(%)	Mat	YMF	F			0.4-0.6			Aust	97	
Mg(%)	Mat	YMF	F			0.15-0.4			Aust	97	
Na(%)	Mat	YMF	F			0.14-0.46			Aust	97	
Cl(%)	Mat	YMF	F			0.2 - 0.75			Aust	97	
Mn(mg/kg)	Mat	YMF	F			170-2000			Aust	97	
Al(mg/kg)	Mat	YMF	F			5-580			Aust	97	
B(mg/kg)	Mat	YMF	F			15-35			Aust	97	

EUCALYPTUS REGNANS (Mountain Ash)

N(%)	Mat	YMF	F	<1.1		<1.6-1.9>			NZ	50 51 89	
P(%)	Mat	YMF	F			<0.1-0.15>			NZ	50 51 89	
K(%)	Mat	YMF	F			<0.6-0.8>			NZ	50 51 89	
S(%)	Mat	YMF	F			<0.14>			NZ	89	
Ca(%)	Mat	YMF	F			<0.4-0.7>			NZ	50 51 89	
Mg(%)	Mat	YMF	F			<0.2-0.25>			NZ	50 51 89	
Na(%)	Mat	YMF	F			<0.15>			NZ	89	
Cl(%)	Mat	YMF	F			<0.56>			NZ	89	
Cu(mg/kg)	Mat	YMF	F			<4-8>			NZ	50 51 89	
Zn(mg/kg)	Mat	YMF	F			<8-18>			NZ	50 51 89	
Mn(mg/kg)	Mat	YMF	F			<580-1200>			NZ	50 51 89	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
EUCALYPTUS REGNANS (Mountain Ash) (ctd)											
Fe(mg/kg)	Mat	YMF	F			<72>			NZ	89	
B(mg/kg)	Mat	YMF	F			<19>		140>	NZ	89	
Al(mg/kg)	Mat	YMF	F			<78>			NZ	89	
EUCALYPTUS SALIGNA (Sydney Blue Gum)											
N(%)	Juv	YMF	F			<2.9>			Haw	197	
P(%)	Juv	YMF	F			<0.2>			Haw	197	
K(%)	Juv	YMF	F			<1.1>			Haw	197	
Ca(%)	Juv	YMF	F			<0.6>			Haw	197	
N(%)	Mat	YMF	F	<0.6		<0.9-2.1>			Var	12 13 36 51 52 89 194 197	
P(%)	Mat	YMF	F		<0.07	<0.08-0.2>			Var	12 13 36 51 52 89 197	
K(%)	Mat	YMF	F	<0.4	0.45-0.8	0.85-1.5			Var	13 51 52 197 36 89	
S(%)	Mat	YMF	F	<0.12		0.14-0.2			Var	89 93 194 197	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Ca(%)	Mat	YMF	F			0.3-1.0			Var	13 52 89 140 194 197	
Mg(%)	Mat	YMF	F	<0.15	0.2-0.3	0.2-0.4			Var	12 13 51 52 89 194 197	
Na(%)	Mat	YMF	F			<0.16>			NZ	89	
Cl(%)	Mat	YMF	F			0.1-0.45			Var	93 89	
Cu(mg/kg)	Mat					4-7			Aust NZ	51 52 89	
Zn(mg/kg)	Mat					16-30			Var	12 51 52 89 194	
Mn(mg/kg)	Mat					100-800			Var	36 51 89 93 194	
Fe(mg/kg)	Mat	YMF	F			<70-86>			NZ Aust	89 194	
Al(mg/kg)	Mat	YMF	F			<90-200>			Var	89 93 194	
B(mg/kg)	Mat					25-45			Var	89 93 194	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
***EUCALYPTUS TERETICORNIS* (Forest Red Gum)**											
N(%)	Juv	YMF	F	<1.34		<1.84>			China	77	
P(%)	Juv	YMF	F			<0.1>			China	77	
K(%)	Juv	YMF	F			<1.19>			China	77	
Ca(%)	Juv	YMF	F			<0.89>			China	77	
Mg(%)	Juv	YMF	F			<0.13>			China	77	
N(%)	Mat	YMF	F	<).8		<1.0-1.57>			Ind Zim S Afr	115 136 140	
P(%)	Mat	YMF	F	<0.1		<0.17-0.25>			Ind S Afr	115 140	
K(%)	Mat	YMF	F	<0.7		<1.1-1.5>			Ind S Afr	115 140	
Ca(%)	Mat	YMF	F			<1.0-1.7>			Ind Zim S Afr	115 136 140	
Mg(%)	Mat	YMF	F	<0.13		<0.21-0.4>			Ind Zim S Afr	115 136 140	
Mn(mg/kg)	Mat	YMF	F	<60		<80-580>			Ind Zim S Afr	80 136 140	
Fe(mg/kg)	Mat	YMF	F			<110-425>			Ind S Afr	80 140	
Cu(mg/kg)	Mat	YMF	F	<6.7		<10-25>			Ind S Afr	80 140	
Zn(mg/kg)	Mat	YMF	F	<24		<32-41>			Ind S Afr	80 140	
B(mg/kg)	Mat	YMF	F			<116>			S Afr	140	
***EUCALYPTUS UROPHYLLA* (Timor Rose Gum)**											
N(%)	Juv	YMF	F	<0.86		<1.1-3.0>			China Phil	42 77	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
P(%)	Juv	YMF	F	0.05-0.09		<0.1-0.3>			China Phil	42 77	
K(%)	Juv	YMF	F			<0.8-1.4>			China Phil	42 77	
S(%)	Juv	YMF	F			<0.1-0.3>			China Phil	42	
Ca(%)	Juv	YMF	F			<0.3-1.1>			China Phil	42 77	
Mg(%)	Juv	YMF	F			<0.17-0.6>			China Phil	42 77	
Cu(mg/kg)	Juv	YMF	F	<0.8-1.3		<2-19>			China Phil	42	
Mn(mg/kg)	Juv	YMF	F			<130-660>			China Phil	42	
Fe(mg/kg)	Juv	YMF	F	<9-12		<33-54>			China Phil	42	
Zn(mg/kg)	Juv	YMF	F	<9-12		<16-47>			China Phil	42	
B(mg/kg)	Juv	YMF	F	<7-15		<16-52>			China Phil	42	

FLINDERSIA BRAYLEYANA (Queensland Maple)

Adequate values based on healthy plants.

N(%)	Seedl	ML	sand culture			<2.69>			Aust	164	Plant assumed healthy
P(%)	Seedl	ML	sand culture			<0.18>			Aust	164	Plant assumed healthy
N(%)	Seedl	All LB	sand culture			<2.80-2.84>			Aust	165	Plant assumed healthy
P(%)	Seedl	All LB	sand culture			<0.25-0.29>			Aust	165	Plant assumed healthy
N(%)	Seedl	Stem + petioles	sand culture			<1.12-1.63>			Aust	165	Plant assumed healthy
P(%)	Seedl	Stem + petioles	sand culture			<0.59-0.81>			Aust	165	Plant assumed healthy
N(%)	Juv	YMB	soil/pots	0.27>		<0.76>			Aust	185	
P(%)	Juv	YMB	soil/pots			<0.12-0.18>			Aust	185	
K(%)	Juv	YMB	soil/pots			<1.2-1.7>			Aust	185	
S(%)	Juv	YMB	soil/pots			<0.13-0.17>			Aust	185	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
FLINDERSIA BRAYLEYANA (Queensland Maple) (ctd)											
Adequate values based on healthy plants.											
Ca(%)	Juv	YMB	soil/pots			<0.7-0.9>			Aust	185	
Mg(%)	Juv	YMB	soil/pots			<0.12-0.32>			Aust	185	
Cu(mg/kg)	Juv	YMB	soil/pots			<1.0-3.8>			Aust	185	
Mn(mg/kg)	Juv	YMB	soil/pots			<550-1000>			Aust	185	
Fe(mg/kg)	Juv	YMB	soil/pots			<33-65>			Aust	185	
B(mg/kg)	Juv	YMB	soil/pots			<24-39>			Aust	185	
N(%)	Juv	YMP	soil/pots	0.29>		<0.4>			Aust	185	
P(%)	Juv	YMP	soil/pots			<0.07-0.21>			Aust	185	
K(%)	Juv	YMP	soil/pots			<0.6-1.4>			Aust	185	
S(%)	Juv	YMP	soil/pots			<0.03-0.06>			Aust	185	
Ca(%)	Juv	YMP	soil/pots			<0.30-0.65>			Aust	185	
Mg(%)	Juv	YMP	soil/pots			<0.05-0.12>			Aust	185	
Cu(mg/kg)	Juv	YMP	soil/pots			<0.8-3.2>			Aust	185	
Mn(mg/kg)	Juv	YMP	soil/pots			<135-350>			Aust	185	
Fe(mg/kg)	Juv	YMP	soil/pots			<14-20>			Aust	185	
B(mg/kg)	Juv	YMP	soil/pots			<9-15>			Aust	185	
GMELINA ARBOREA (White Beech)											
N(%)	Seedl	YMB	F/ Sand			<2.48-4.6>			Aust SI	34 185	Healthy tree, saturating rate of photosynthesis
P(%)	Seedl	YMB	F/ Sand			<0.18-0.44>			Aust SI	34 185	Healthy tree, saturating rate of photosynthesis
K(%)	Seedl	YMB	F			<1.4-2.3>			SI	185	Healthy tree from experimental plot with luxury dose of fertiliser
S(%)	Seedl	YMB	F			<0.16-0.23>			SI	185	Healthy tree from experimental plot with luxury dose of fertiliser
Ca(%)	Seedl	YMB	F			<0.39-0.69>			SI	185	Healthy tree from experimental plot with luxury dose of fertiliser

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Mg(%)	Seedl	YMB	F			<0.30-0.43>			SI	185	Healthy tree from experimental plot with luxury dose of fertiliser
Cu(mg/kg)	Seedl	YMB	F			<8.8-10.5>			SI	185	Healthy tree from experimental plot with luxury dose of fertiliser
Zn(mg/kg)	Seedl	YMB	F	<12>		<31-61>			SI	183 185	Symptom identification Healthy tree from experimental plot with luxury dose of fertiliser
Mn(mg/kg)	Seedl	YMB	F	<12>		<48-333>		1263	SI	183 185	Symptom identification Healthy tree, luxury dose of fertiliser
Fe(mg/kg)	Seedl	YMB	F	<21>		<35-68>			SI	183 185	Symptom identification Healthy tree, luxury dose of fertiliser
Al(mg/kg)	Seedl	YMB	F			<17-23>			SI	185	Healthy tree, luxury dose of fertiliser
B(mg/kg)	Seedl	YMB	F			<29-68>			SI	185	Healthy tree, luxury dose of fertiliser
N(%)	Seedl	YMP	F			<1.10-2.00>			SI	185	Healthy tree, luxury dose of fertiliser
P(%)	Seedl	YMP	F			<0.10-0.11>			SI	185	Healthy tree, luxury dose of fertiliser
K(%)	Seedl	YMP	F			<3.2-7.9>			SI	185	Healthy tree, luxury dose of fertiliser
S(%)	Seedl	YMP	F			<0.08-0.11>			SI	185	Healthy tree, luxury dose of fertiliser
Ca(%)	Seedl	YMP	F			<0.52-0.88>			SI	185	Healthy tree, luxury dose of fertiliser
Mg(%)	Seedl	YMP	F			<0.25-0.37>			SI	185	Healthy tree, luxury dose of fertiliser
Cu(mg/kg)	Seedl	YMP	F			<6.9-9.6>			SI	185	Healthy tree, luxury dose of fertiliser
Zn(mg/kg)	Seedl	YMP	F			<28-63>			SI	185	Healthy tree, luxury dose of fertiliser
Mn(mg/kg)	Seedl	YMP	F			<61-180>			SI	185	Healthy tree, luxury dose of fertiliser
Fe(mg/kg)	Seedl	YMP	F			<9-30>			SI	185	Healthy tree, luxury dose of fertiliser
Al(mg/kg)	Seedl	YMP	F			<8-55>			SI	185	Healthy tree, luxury dose of fertiliser
B(mg/kg)	Seedl	YMP	F			<30-43>			SI	185	Healthy tree, luxury dose of fertiliser

Apparently healthy trees. Deficient values established by statistical significant difference between healthy and unhealthy trees. Deficient values relate to unhealthy trees.

N(%)	Juv	YML	F	<1.4-1.8>	2.0	<2.5-3.2>			Var	161 199 200 203	
P(%)	Juv	YML	F	0.13-0.15		<0.15-0.27>			Var	161 199 200 203	

GMELINA ARBOREA (White Beech) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
K(%)	Juv	YML	F	<0.29-0.4>		<0.49-1.3>			Var	161 199 200 203	
S(%)	Juv	YML	F	<0.12	0.13	<0.19>			Cos R	161	
Ca(%)	Juv	YML	F			<0.6-2.2>			Var	161 199 200 203	
Mg(%)	Juv	YML	F			<0.30-0.74>			Var	199 200 203	
Cu(mg/kg)	Juv	YML	F			<6-17>			Var	161 199 200 203	
Zn(mg/kg)	Juv	YML	F	<6.0-7.2>		<14-27>			Var	199 200 203	Established by symptoms identification
Mn(mg/kg)	Juv	YML	F			<115-205>			Var	161 199 200 203	
Fe(mg/kg)	Juv	YML	F			<88-1310>			Var	161 199 200 203	
Al(mg/kg)	Juv	YML	F			<68-1240>			Var	161 199 200 203	
B(mg/kg)	Juv	YML	F			<25-49>			Var	161 199 200 203	
N(%)	Mat	YML	F			<1.86-3.2			PNG Cos R	46 161	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
P(%)	Mat	YML	F			<0.11-0.27>			PNG Cos R	46 161	
K(%)	Mat	YML	F			<0.7-1.6>			PNG Cos R	46 161	
Ca(%)	Mat	YML	F			<1.0>			PNG	46	
Mg(%)	Mat	YML	F			<0.3>			PNG	46	
Cu(mg/kg)	Mat	YML	F			<7>			PNG Cos R	46 161	
Zn(mg/kg)	Mat	YML	F			<15-40>			PNG Cos R	46 161	
Mn(mg/kg)	Mat	YML	F			<22-205>			PNG Cos R	46 161	
Fe(mg/kg)	Mat	YML	F			<40-135>			PNG Cos R	46 161	
B(mg/kg)	Mat	YML	F			<20-50>			PNG Mex	46 203	

GREVILLEA ROBUSTA ((Southern) Silky Oak)

Mn(mg/kg)	Seedl	WS	F			<262-880>		1940-4000>	E Afr	28	Based on symptoms
N(%)	Juv	YML	F			<1.3>			Rwa	139	
P(%)	Juv	YML	F			<0.08>			Rwa	139	
K(%)	Juv	YML	F			<0.6>			Rwa	139	
Ca(%)	Juv	YML	F			<0.46>			Rwa	139	
Mg(%)	Juv	YML	F			<0.15>			Rwa	139	
Zn(mg/kg)	Juv	YML	F			11-18			Rwa	139	
Mn(mg/kg)	Juv	YML	F			611			Rwa	139	
Fe(mg/kg)	Juv	YML	F			105			Rwa	139	
Al(mg/kg)	Juv	YML	F			308			Rwa	139	
B(mg/kg)	Juv	YML	F	<13>		13 17			 Ken	139 153	

HEVEA BRASILIENSIS (Rubber)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
N(%)	Seedl	YB	Pots, soils		1.68-1.75	<1.91-2.52>			Mala	196a	
P(%)	Seedl	YB	Pots, soils		0.127-0.131	<0.137-0.170>			Mala	196a	
K(%)	Seedl	YB	Pots, soils		0.75-0.79	<0.92-1.35>			Mala	196a	
Ca(%)	Seedl	YB	Pots, soils			<0.316-0.673>			Mala	196a	
Mg(%)	Seedl	YB	Pots, soils		<0.101-0.113>	<0.117-0.238>			Mala	196a	
N(%)	Seedl	YMB	Pots, soils		1.49-1.52	<1.61-2.26>			Mala	196a	3rd whorl
P(%)	Seedl	YMB	Pots, soils	<0.107>		<0.118-0.134>			Mala	196a	3rd whorl
K(%)	Seedl	YMB	Pots, soils		<0.40-0.56	<0.60-0.91>			Mala	196a	3rd whorl
Ca(%)	Seedl	YMB	Pots, soils			<0.427-0.634>			Mala	196a	3rd whorl
Mg(%)	Seedl	YMB	Pots, soils		<0.85-0.90>	<0.100-0.320>			Mala	196a	3rd whorl
B(mg/kg)	Seedl	YB	Pots			<316>		>500	Bra	23a	
Al(mg/kg)	Seedl	YB	Pots					>15	Bra	23b	
N(%)	Juv	YML	F	<2.70	2.71-3.09	3.10-3.90	>3.91		Mala	5	<5 years
P(%)	Juv	YML	F	<0.15	0.16-0.17	0.18-0.29	>3.00		Mala	5	<5 years
K(%)	Juv	YML	F	<0.85	0.86-0.96	0.97-1.60	>1.61		Mala	5	<5 years
Ca(%)											
Mg(%)	Juv	YML	F	<0.19	0.20-0.21	0.22-0.31	>0.32		Mala	5	<5 years
Mn(mg/kg)	Juv	YML	F	<50	50-100	101-250	>250	>500	Mala	5	<5 years
N(%)	Mat	ML	F	<3.00	3.00-3.30	3.31-3.90	>3.90		Mala, China	5 101a	Lowshade leaves
P(%)	Mat	ML	F	<0.17	0.17-0.19	0.20-0.27	>0.27		Mala	5	Lowshade leaves
K(%)	Mat	ML	F	<1.20	1.21-1.36	1.37-1.85	>1.86		Mala	5	Lowshade leaves
Ca(%)	Mat	ML	F		0.6-1.0				China	101a	Shaded leaves
Mg(%)	Mat	ML	F	<0.18	0.18-0.20	0.21-0.27	>0.27		Mala	5	Lowshade leaves
Mn(mg/kg)	Mat	ML	F	<50	51-100	101-200	>200	>500	Mala China	5 7 182a	Lowshade leaves

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
JUGLANS NIGRA L. (Black walnut)											
N(%)	Mat	ML	Lit	<2.00		>2.60			USA	119	
P(%)	Mat	ML	Lit	0.10		>0.25			USA	119	
K(%)	Mat	ML	Lit	<0.75	0.8-1.2	>1.30			USA	119	
S(%)	Mat	ML	Lit	<0.05		>0.25			USA	119	
Ca(%)	Mat	ML	Lit	<0.50	0.5-1.0	>1.10			USA	119	Deficiency threshold is high
Mg(%)	Mat	ML	Lit	<0.15		>0.45			USA	119	
Cu(mg/kg)	Mat	ML	Lit	<5		>10			USA	119	
Zn(mg/kg)	Mat	ML	Lit	<15		>50			Can	187	In minerotropic open peatland ditched at 1.8 m spacing
Mn(mg/kg)	Mat	ML	Lit	<30		>80			USA	119	
Fe(mg/kg)	Mat	ML	Lit	<40		>100			USA	119	
B(mg/kg)	Mat	ML	Lit	<20	20-50	>50			USA	119	
Mo(mg/kg)	Mat	ML	Lit	<0.05		>0.10			USA	119	
LEUCAENA LEUCOCEPHALA											
N(%)	Seedl	YMP	Soil	<2.89	<4.07>				Aust W Afr	45 134	N supplementation of cv. Cunningham
P(%)	Seedl	YMP	Soil	0.1	0.14-0.19	0.21-0.25			Aust W Afr	45 134	Rhizobium inoculated plants N supplementation of cv. Cunningham
K(%)	Seedl	YMP		0.23-0.24		<2.0>			Aust W Afr	45 134	Rhizobium inoculated plants N supplementation of cv. Cunningham
S(%)	Seedl	YFEL	Soil			<0.24>			W Afr	134	N supplementation of cv. Cunningham
Ca(%)	Seedl	YMP				<0.38-0.49>	0.69		Aust W Afr	45 134	Rhizobium inoculated plants N supplementation of cv. Cunningham
Mg(%)	Seedl	YMP					1.84		Aust W Afr	45 134	
Cu(mg/kg)	Seedl	YMP				<17-20>			Aust W Afr	45 134	
Zn(mg/kg)	Seedl	YMP				<20-24>			Aust W Afr	45 134	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
LEUCAENA LEUCOCEPHALA (ctd)											
Mn(mg/kg)	Seedl	YMP				<94-325>			Aust W Afr	45 134	Rhizobium inoculated plants N supplementation of cv. Cunningham
Fe(mg/kg)	Seedl	YMP				<220>			Aust W Afr	45 134	
Al(mg/kg)	Seedl	YMP				<147-223>			Aust W Afr	45 134	
N(%)	Juv	Leaves	F	<2.89>	<4.07-4.26>				W Afr	45	
P(%)	Juv	Leaves	F	0.1	0.14-0.19				W Afr	45	Chlorosis symptoms
K(%)	Juv	Leaves	F	0.23					W Afr	45	Chlorosis symptoms
Ca(%)	Juv	Leaves	F				0.69		W Afr	45	Chlorosis symptoms
Mg(%)	Juv	Leaves	F				1.84		W Afr	45	Chlorosis symptoms
Mn(mg/kg)	Juv	Leaves	F			<94>			W Afr	45	
Fe(mg/kg)	Juv	Leaves	F			<220>	<439>		W Afr	45	Chlorosis symptoms
Zn(mg/kg)	Juv	Leaves	F			<20-24>			W Afr	45	
Cu(mg/kg)	Juv	Leaves	F			<17-20>			W Afr	45	
Al(mg/kg)	Juv	Leaves	F			<147-223>	<382>		W Afr	45	Chlorosis symptoms
LOPHOSTEMON CONFERTUS (Brush Box)											
N(%)	Mat	YMF	F			1.1-1.4			Aust	97	
P(%)	Mat	YMF	F	<0.06		0.07-0.15			Aust	97	
K(%)	Mat	YMF	F			0.7-0.95			Aust	97	
Ca(%)	Mat	YMF	F			0.66-1.12			Aust	97	
Mg(%)	Mat	YMF	F			0.2-0.29			Aust	97	
Na(%)	Mat	YMF	F			0.005-0.10			Aust	97	
Cl(%)	Mat	YMF	F			0.21-0.52			Aust	97	
Mn(mg/kg)	Mat	YMF	F			30-600			Aust	97	
Al(mg/kg)	Mat	YMF	F			100-420			Aust	97	
B(mg/kg)	Mat	YMF	F			20-40			Aust	97	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			

PINUS BRUTIA (see *Pinus halepensis*)

PINUS CANARIENSIS (Canary Island Pine)

N(%)	Juv	YMF	F			1.19-2.09			Aust	20	
P(%)	Juv	YMF	F	<0.08	0.08-0.095	0.096-0.158			Aust	20	
K(%)	Juv	YMF	F			0.34-1.00			Aust	20	
Cl(%)	Juv	YMF	F			0.36	>0.50	>0.8	Aust	20	Up to 1.28% found
N(%)	Mat	YMF	F			1.19-2.09			Aust	20	
P(%)	Mat	YMF	F	<0.08	0.08-0.095	0.096-0.158			Aust	20	
K(%)	Mat	YMF	F			0.34-1.00			Aust	20	
Cl(%)	Mat	YMF	F			0.36	>0.50	>0.8	Aust	20	Up to 1.19% found
Cu(mg/kg)	Mat	YMF	F	<2.0		2.0->6.0			Aust	20	
Zn(mg/kg)	Mat	YMF	F			12.0-33.0			Aust	20	
Mn(mg/kg)	Mat	YMF	F	<10		11.0-46.0			Aust	20	4 mg/kg is lowest conc. found
Fe(mg/kg)	Mat	YMF	F			102-202			Aust	20	

PINUS CARIBAEA var. *Hordurensis* (Caribbean Pine)

N(%)	Mat	YMF	F	<0.80	0.9	1.29			Aust	15 149 150	
P(%)	Mat	YMF	F	<0.065		0.17			Aust	15 149 150	
K(%)	Mat	YMF	F	<0.30					Aust	149 150	
Ca(%)	Mat	YMF	F	<0.11					Aust	149 150	
Mg(%)	Mat	YMF	F	<0.80					Aust	149 150	
SO_4-S(%)	Mat	YMF	F		0.03	0.089			Aust	15	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
PINUS CARIBAEA var. Hordurensis (Caribbean Pine) (ctd)											
Cu(mg/kg)	Mat	YMF	F	<2.0		7.3			Aust	15 149 150	
Zn(mg/kg)	Mat	YMF	F			<21-55>			Aust	15 149 150	
B(mg/kg)	Mat	YMF	F	4-5	<10	33			Aust Phil	149 200	
PINUS CONTORTA (Lodgepole Pine)											
N(%)	Seedl	YMF	Lit	1.05	0.20	1.55			USA	114	var. latifolia
P(%)	Seedl	YMF	Lit	0.09	0.12	0.20-0.30			USA	114	var. latifolia
K(%)	Seedl	YMF	Lit	0.35	0.40-0.55	0.7-1.1			USA	114	var. latifolia
Ca(%)	Seedl	YMF	Lit	0.05	0.06-0.08	0.1-0.4			USA	114	var. latifolia
Mg(%)	Seedl	YMF	Lit			0.1-0.15			USA	114	var. latifolia
N(%)	Mat	YMF	F	1.05		1.55			USA	114	var. latifolia
P(%)	Mat	YMF	F	0.09		0.15-0.3			USA	114	var. latifolia
K(%)	Mat	YMF	F	0.35		0.7-1.1			USA	114	var. latifolia
Ca(%)	Mat	YMF	F	0.05		0.1-0.4			USA	114	var. latifolia
Mg(%)	Mat	YMF	F	0.06	0.07-0.09	0.10-0.15			USA	114	var. latifolia
Cu(mg/kg)	Mat	MF	F		4		17		USA	106	
B(mg/kg)	Mat	YMF	F	<3-10		15-25			Can	23	
PINUS ELLIOTTII var. elliottii (Slash Pine)											
B(mg/kg)	Seedl	Terminal buds	F	<1.9>					USA	53	Damaged shoot tips with partial necrosis of terminal buds.
P(%)	Mat	YMF	F		0.75-0.08				Aust	16 195	>90% of maximum basal area increment

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
K(%)	Juv, Mat	YMF	F	<0.3		0.35-0.4			USA Aust	14 15 150	
Ca(%)	Mat	YMF	F	<0.12					Aust	149 150	
Mg(%)	Mat	YMF	F	<0.80					Aust	149 150	
Na(%)	Mat	YMF	F	<0.20					Aust	149 150	
Cu(mg/kg)	Mat	YMF	F	<2		2-18			Aust S Afr	58	
Zn(mg/kg)	Mat	YMF	F	6-10		10-68			Aust S Afr	58	
Mn(mg/kg)	Mat	YMF	F		21	284			S Afr	58	
Fe(mg/kg)	Mat	YMF	F			65-404			Aust S Afr	58	
B(mg/kg)	Mat	YMF	F	<8-10					Aust	149	

PINUS HALEPENSIS (Aleppo pine)

P(%)	Seedl	Foliage	Soil	<0.064>		<0.147>			Isr	117	Adequate except in dune sand
K(%)	Seedl	Foliage	Soil			0.27-0.54			Isr	117	Adequate except in dune sand
Ca(%)	Seedl	Foliage	Soil			0.30-0.90			Isr	117	Adequate except in dune sand
Mg(%)	Seedl	Foliage	Soil			0.13-0.20			Isr	117	Adequate except in dune sand
N(%)	Juv/ Mat	Foliage	F	<0.95		0.95-1.5			Aust Tur Spa	20 27 90	*P. halepensis* *P. brutia*
P(%)	Juv/ Mat	Foliage	F	<0.095		0.1-0.2			Aust Tur Spa	20 27 90	*P. halepensis* *P. brutia*
K(%)	Juv/ Mat	Foliage	F			0.32-0.83			Aust Tur Spa	20 27 90	*P. halepensis* *P. brutia*
Ca(%)	Juv/ Mat	Foliage	F			0.33-0.74			Aust Tur Spa	20 27 90	*P. halepensis* *P. brutia*

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
PINUS HALEPENSIS (Aleppo pine) (ctd)											
Mg(%)	Juv/ Mat	Foliage	F			<0.1-0.25>			Tur Spa	27 90	*P. brutia* *P. halepensis*
Na(%)	Mat	Foliage	F				<0.29>		Aust	20	*P. halepensis*
Zn(mg/kg)	Mat	Foliage	F			<62>			Aust	20	*P. halepensis*
Fe(mg/kg)	Juv/ Mat	Foliage	F			45-146			Tur Spa	27 90	*P. brutia* *P. halepensis*
Mn(mg/kg)	Juv/ Mat	Foliage	F	<3		4-47			Tur Spa	27 90	*P. brutia* *P. halepensis*
B(mg/kg)	Juv/ Mat	Foliage	F	<6	6-9	10-24			Tur Spa	27 90	*P. brutia* *P. halepensis*
Cu(mg/kg)	Juv/ Mat	Foliage	F	<3		3.1-5.4			Tur Spa	27 90	*P. brutia* *P. halepensis*
PINUS INSULARIS (see *Pinus kesiya*)											
PINUS KESIYA (Benguet or Khasya pine)											
N(%)	Mat	Foliage	F	1.00					Phil	200	
P(%)	Mat	MF	F	0.101					Phil	200	
K(%)	Mat	Foliage	F	0.35					Phil	200	
PINUS NIGRA (Corsican or Black pine)											
N(%)	Mat	MF	F			1.5			UK	82	var. *Laricio*
P(%)	Mat	MF	F			0.13			UK	82	var. *Laricio*
K(%)	Mat	MF	F		0.30	0.8			Neth UK	57 82	var. *Laricio*
S(%)	Mat	MF	F			0.08			UK	82	var. *Laricio*
Ca(%)	Mat	MF	F			0.25			UK	82	var. *Laricio*
Mg(%)	Mat	MF	F	<0.06		0.10			UK Pol	82 129	var. *Laricio*

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Cl(%)	Mat	MF	F			0.10			UK	82	var. *Laricio*
Cu(mg/kg)	Mat	MF	F			4			UK	82	var. *Laricio*
Zn(mg/kg)	Mat	MF	F			30			UK	82	var. *Laricio*
Mn(mg/kg)	Mat	MF	F			200			UK	82	var. *Laricio*
Fe(mg/kg)	Mat	MF	F			200			UK	82	var. *Laricio*
B(mg/kg)	Mat	MF	F			20			UK	82	var. *Laricio*
Mo(mg/kg)	Mat	MF	F			1			UK	82	var. *Laricio*
Al(mg/kg)	Mat	Foliage	F				>670-880		Pol	129	var. *Austriaca*

PINUS PALUSTRIS (Longleaf pine)

K(%)	Juv	YMF	F	<0.3		0.35-0.4			USA	14	
B(mg/kg)	Mat	YMF	F	<~8					NZ	159	

PINUS PINASTER (Maritime Pine)

Cu(mg/kg)	Juv	YMF	F			3.4			Fra	137	Shoot deformation
Zn(mg/kg)	Juv	YMF	F			36.0			Fra	137	Shoot deformation
Mn(mg/kg)	Juv	YMF	F			80.4			Fra	137	Shoot deformation
N(%)	Mat	YMF	F	0.39-0.6		0.6-0.9			Aust	20 83 112	
P(%)	Mat	YMF	F	<0.054-0.56>	0.06-0.08	<0.10-0.20>			Aust Fra	20 83 112 138	
K(%)	Mat	YMF	F			0.25-0.8			Aust	20 83 112	
S(%)	Mat	YMF	F			0.05-0.16			Aust	20 83 112	
Ca(%)	Mat	YMF	F			0.35-2.33			Aust	20 83 112	

PINUS PINASTER (Maritime Pine) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
Mg(%)	Mat	YMF	F		0.16-0.22	0.25-1.61			Aust	20 83 112	
Cl(%)	Mat	YMF	F			<0.063-0.35	0.35-0.60	>1.65	Aust	20	Up to 7.85% Cl found
Cu(mg/kg)	Mat	YMF	F	<3.0	3.4	4.0-19	<81>		Var	20 58 91 137 138	
Zn(mg/kg)	Mat	YMF	F	<10		10.0-40	<61>		Var	20 58 137	
Mn(mg/kg)	Mat	YMF	F	7.0-10		14-427			Var	58 91	
Fe(mg/kg)	Mat	YMF	F	24		65-217	<404>		Var	20 58 91	
B(mg/kg)	Mat	YMF	F	5-6		16			Var	158 159	

PINUS RADIATA (Radiata pine)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
P(%)	Seedl	WS	SC	0.055-0.090	0.09-0.14	0.177-0.344			Aust Gre	180 167 114	Criteria established for height and dry weight. Al substituted for Mg at 0 to 0.35 meq/L.
K(%)	Seedl	WS	SC, F	<0.25	<0.35	0.26-1.8		>1.9	Var	180 190 125 19 127	< 6.4 meq%
Mg(%)	Seedl	WS	SC, F	<0.07	0.07-0.10	0.11-0.8			NZ	190	Foliar Ca + Mg combined should be ≥35 meq% provided that each is above threshold deficiency conc.
Mn(mg/kg)	Seedl	WS	SC	<5.0	5.0-20.0	20-400			NZ	188	Yellow/green (Munsell 5 GY 4/6) needles <4.0 mg/kg

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Fe(mg/kg)	Seedl	WS	CS	<35	40-80	70-200			Var	19 125 188 190 191	Washed foliage
Al(meq)	Seedl	WS	SC			9-122	320->1100	>1150	Aust	74 75 167	Increased P reduced the level of Al in shoots, while Ca and Mg concns. were reduced.
N(%)	Seedl	YMF	FC, RSC & F	0.5-1.0	1.0-1.2	1.6-2.4		>2.6	Var	102 104 109 125 190 192 193	N/P ratio should be 10:1 (119)
Zn(mg/kg)	Seedl	YMF	F	<6	11-12				Aust NZ	86 111	Deficient conc. based on chlorosis as 1st symptom.
Mn(mg/kg)	Seedl	YMF	FSC			40-70			Spa	109	Collected from 10 different stands
Mo(mg/kg)	Seedl	YMF	FSC, F	<0.01-0.02	0.02-0.06	0.06-40			Var	19 109 188	Genotype effect on deficiency level.
N(%)	Seedl	Foliage	Soil			1.6			Gre	114	
Zn(mg/kg)	Seedl	Apical primary leaves	F		11-12				Aust	19 111	Dry weight basis
N(%)	Juv	YMF	FC, RSC, F	0.5-0.9	<l.0-1.2	1.9-2.4		>2.6	Var	190 199 104 192 125 102	N/P ratio should be 10:1 (119)
P(%)	Juv	YMF	F	<0.10-<0.12	0.10-0.14	0.14-0.30		>0.8	Aust	125	
Ca(%)	Juv	YMF	F	<0.06	0.06-0.07	0.08-0.45			Var	20 125 190	
Mg(%)	Juv	YMF	F, Soil	<0.07	0.06-0.08	0.10-0.40			Aust NZ	1 19 125	
S(%)	Juv	YMF	F		<0.12	>0.13			Aust	73	
SO_4-S (mg/kg)	Juv	YMF	F	<80	125-400	>400			Aust	94 98	Sulphate must be sufficient to meet N requirement for organic-S:N ratio, 0.03:1 gram atom basis

PINUS RADIATA (Radiata pine) (ctd)

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
Na(%)	Juv	YMF	F	<0.002	0.002-0.003	0.004-0.05		>0.30	Aust	125 19	
Cl(%)	Juv	YMF	F	<0.006	0.007-0.010	0.01-0.30		>0.35	Aust	20	Washed foliage. Up to 3.6% found.
Cu(mg/kg)	Juv	YMF	F	<2.0	2.1-2.3	2.4- 9.0		>40	Var	71 76 86 118 167 176 188 194	
Zn(mg/kg)	Juv	YMF	F	<11.0	11.0-13.0	14-60		>200	Aust	125	
Mn(mg/kg)	Juv	YMF	F	<10.0	11.0-20	25-400		>700	Var	2 99 125 135	
Al(mg/kg)	Juv	YMF	F			125-1100		>2000	Aust NZ	74 188	Threshold P% deficiency level raised. Genotype effects on tolerance.
N(%)	Mat	YMF	F	<1.0	1.0-1.2	1.2-2.0	>2.1		Var	124 128 133 156 172 194	Growth response to nitrogen may be constrained by availability of S.
P(%)	Mat	YMF	F	<0.10	0.10-0.14	0.14-0.30		>0.8	Var	74 92 96 124 125 128 156 172	
K(%)	Mat	YMF	F	<0.35	0.35-0.5	>0.5			Var	127 133 171	
S(%)	Mat	YMF	F		<0.12	>0.13			Aust	73	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
SO_4-S (mg/kg)	Mat	YMF	F	<80	125-400	>400			Aust NZ	95 96 98	Sulphate must be sufficient to meet N requirement for organic-S:N ratio, 0.03:1 gram atom basis
Ca(%) $_t$	Mat	YMF	F	<0.06	0.06-0.07	0.08-0.45			Aust NZ	20 125 171 192	
Mg(%)	Mat	YMF	F	<0.05	0.06-0.08	0.10-0.40			Aust NZ	1 20 125 171 192	
Na(%)	Mat	YMF	F	<0.002	0.002-0.003	0.004-0.05		>0.30	Aust NZ	19 125 127	
Cl(%)	Mat	YMF	F	<0.006	0.007-0.010	0.01-0.30		>0.35	Aust NZ	20 170	Washed foliage
Cu(mg/kg)	Mat	YMF	F	<2.0	2.1-2.3	2.4- 9.0		>40	Var	71 76 86 105 118 127 175 176 183 188 196	
Zn(mg/kg)	Mat	YMF	F	<11	11-13	14-64	>200		Aust NZ S Afr	19 86 105 111 126 127 158 188	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
PINUS RADIATA (Radiata pine) (ctd)											
Mn(mg/kg)	Mat	YMF	F	<10.0	11.0-20	25-400		>700	Var	2 19 59 99 105 125 126 135 188	
Fe(mg/kg)	Mat	YMF	F	<35	40-70	70-200			Aust NZ	126	
Al(mg/kg)	Mat	YMF	F			125-1100	<1625>	>2000	NZ Aust	74 188	Threshold P% deficiency level raised. Genotype effects on tolerance.
B(mg/kg)	Mat	YMF	F	5-12	10.0-16.0	16-70	>70	>170	Var	49 72 73 95 105 125 152 158 159 188 192	Genotypic effect on deficiency level; content can increase towards distal end of needles. 357 mg/kg is highest recored.
Zn(mg/kg)	Mat	Terminal rosette of buds	F		10				NZ	166	
PINUS TAEDA (Loblolly Pine)											
P(%)	Seedl	YMF	F	<0.11					USA	187	Response to applied P when foliar content is <0.11%.
B(mg/kg)	Seedl	YMF	F		<1.9				USA	160	Soil low in silt, clay and OM.
N(%)	Seedl	U	Sand	1.38 1.68 1.89					Kor	101	Non-mycorrhizal inoculated plants *P. tinctorius* inoculated plants Unsterilized soil inoculation
K(%)	Seedl	Foliage	F	0.16-0.26					USA	162	
Ca(%)	Seedl	Foliage	F	<0.0033					USA	162	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Mg(%)	Seedl	Foliage	F		0.06-0.8				USA	162	
Pb(mg/kg)	Seedl							>60	USA	132	
K(%)	Juv	Foliage	F	<0.3		0.35-0.4			USA	14	Dormant season foliage. Note- values also apply to *Pinus elliottii, P. taeda, P. palustris* and *P. clausa.*
N(%)	Mat	YMF	F	<1.0	1.03				USA Aust	25 149	Condition resembles chlorosis caused by Fe deficiency.
P(%)	Mat	Foliage	F	<0.095	0.095-0.105	<0.11			Aust USA	16	Marginal conc. based on 90% max. basal area increment.
K(%)	Mat	Foliage	F	<0.30					Aust	16	
Cu(mg/kg)	Mat				5-22				S Afr	178	

POPULUS misc (Poplars incl. hybrids)

P(%)	Mat	F + S	F			<0.15>			Can	100	
Ca(%)	Mat	F + S	F			<0.71>			Can	100	
Cu(mg/kg)	Mat	F + S	F			14.2			Can	100	
Zn(mg/kg)	Mat	F + S	F			<67.1>			Can	100	
Mn(mg/kg)	Mat	F + S	F			<117.8>			Can	100	
Mo(mg/kg)	Mat	F + S	F			<0.09>			Can	100	
Co(mg/kg)	Mat	F + S	F			0.44			Can	100	
Mg(%)	Mat	Leaves	F			0.12-15			Neth	43	cv. Robusta

POPULUS DELTOIDES (Cottonwood)

N(%)	Mat	YMB	F			2.2			USA	47	
P ((%)	Mat	YMB	F	0.17		0.3			USA	47	
K(%)	Mat	YMB	F	1.00		1.5			USA	47	
S(%)	Mat	YMB	F			0.5			USA	47	
Mg(%)	Mat	YMB	F	0.12		0.15			USA	47	
Cu(mg/kg)	Mat	YMB	F	5					USA	47	
Zn(mg/kg)	Mat	YMB	F	20					USA	47	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
POPULUS DELTOIDES (Cottonwood) (ctd)											
Mn(mg/kg)	Mat	YMB	F	20					USA	47	
B(mg/kg)	Mat	YMB	F	9		<70-99>			USA	47 53	
POPULUS TREMULOIDES (Trembling aspen)											
Mn(mg/kg)	Seedl	YMF	Soil			<164>	<5304>		Can	150	
P(%)	Mat	F + S	F			<0.16>			Can	100	
Ca(%)	Mat	F + S	F			<0.57>			Can	100	
Cu(mg/kg)	Mat	F + S	F			<13.1>			Can	100	
Zn(mg/kg)	Mat	F + S	F			<67.9>			Can	100	
Mn(mg/kg)	Mat	F + S	F			<83.7>			Can	100	
Co(mg/kg)	Mat	F + S	F			<0.29>			Can	100	
Mo(mg/kg)	Mat	F + S	F			<0.09>			Can	100	
PSEUDOTSUGA MENZIESII (Douglas Fir)											
N(%)	Mat	YMF	F	1.20	1.30	1.45			USA	8 54 64 65 169 174	
P(%)	Mat	YMF	F	0.08	0.10	0.15			USA	8 54 64 65 169	
K(%)	Mat	YMF	F	0.35	0.45-0.80				USA	8 54 64 65 169	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
SO_4-S(%)	Mat	YMF	F	<0.008		0.008-0.012	>0.04		USA	8 54 64 65 169 174	
Ca(%)	Mat	YMF	F	0.10	0.15-0.20	0.25			USA	8 54 64 65 169	
Mg(%)	Mat	YMF	F	0.06	0.08-0.10	0.12			USA	8 54 64 65 169	
Cu(mg/kg)	Mat	YMF	F		1-2.6	4			USA	8 54 64 65 169	
Zn(mg/kg)	Mat	YMF	F	<9	9-14	15			USA	8 54 64 65 169	
Mn(mg/kg)	Mat	YMF	F	<4	15	25			USA	8 54 64 65 169	
Fe(mg/kg)	Mat	YMF	F		25	50			USA	8 54 64 65 169	
B(mg/kg)	Mat	YMF	F	12		15-20			USA	8 54 64 65 169 174	

Nutrient	Growth Stage	Plant part	How established	Concentration range: Deficient	Marginal	Adequate	High	Toxic	Country	Ref	Comments
SWIETENIA MACROPHYLLA (Mahogany)											
N(%)	Seedl	WS	F			<1.09-1.67>			Phil	196	Optimum growth, no response to increased N levels.
P(%)	Seedl	WS	F	<0.08-0.12>		<0.07-0.09>			Phil	196	Adequate conc. assumed with P added. Range of P% in adequate plants attributed to growth dilution.
K(%)	Seedl	WS	F			<1.51-1.58>			Phil	196	No response to additional K.
N(%)	Juv	YML	F	<1>					Mex	203	Symptoms of chlorosis of young leaves attributed to compound deficiencies of N, P and Mn.
P(%)	Juv	YML	F	<0.06-0.08>					Mex	203	Symptoms of chlorosis of young leaves attributed to compound deficiencies of N, P and Mn.
Mn(mg/kg)	Juv	YML	F	<13>					Mex	203	Symptoms of chlorosis of young leaves attributed to compound deficiencies of N, P and Mn.
TECTONA GRANDIS (Teak)											
For seedlings and mature adequate conc in apparently healthy trees. Assumed that 185 uses standard reported leaf sampling technique (ie. YMB)											
N(%)	Seedl	YMB	F			<3.92>			SI	185	
P(%)	Seedl	YMB	F			<0.6>			SI	185	
K(%)	Seedl	YMB	F			<3.6>			SI	185	
S(%)	Seedl	YMB	F			<0.28>			SI	185	
Ca(%)	Seedl	YMB	F			<0.4>			SI	185	
Mg(%)	Seedl	YMB	F			<0.35>			SI	185	
Cu(mg/kg)	Seedl	YMB	F			<24>			SI	185	
Zn(mg/kg)	Seedl	YMB	F			<36>			SI	185	
Mn(mg/kg)	Seedl	YMB	F			<334>			SI	185	
Fe(mg/kg)	Seedl	YMB	F			<42>			SI	185	
B(mg/kg)	Seedl	YMB	F			<23>			SI	185	
N(%)	Seedl	YMP	F			<2.05>			SI	185	
P(%)	Seedl	YMP	F			<0.47>			SI	185	
K(%)	Seedl	YMP	F			<6.9>			SI	185	
S(%)	Seedl	YMP	F			<0.18>			SI	185	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
Ca(%)	Seedl	YMP	F			<0.43>			SI	185	
Mg(%)	Seedl	YMP	F			<0.37>			SI	185	
Cu(mg/kg)	Seedl	YMP	F			<18>			SI	185	
Zn(mg/kg)	Seedl	YMP	F			<26>			SI	185	
Mn(mg/kg)	Seedl	YMP	F			<299>			SI	185	
Fe(mg/kg)	Seedl	YMP	F			<24>			SI	185	
B(mg/kg)	Seedl	YMP	F			<29>			SI	185	
K(%)	Mat	YMB	F	<0.18>					Niue	184	Deficiency assigned from visual symptoms.
K(%)	Mat	YMP	F	<0.18>					Niue	184	Deficiency assigned from visual symptoms.
N(%)	Mat	YML	F			<1.65-2.78>			Phil W Afr	200 202	
P(%)	Mat	YML	F			<0.14-0.23>			Phil W Afr	200 202	
K(%)	Mat	YML	Lit F	0.2-0.6 <0.17	0.4-0.9 <0.37>	0.7-2.4 <0.44-2.0>			Var Phil W Afr	81 200 202	
S(%)	Mat	YML	F			<0.1-0.16>			Phil W Afr	200 202	
Ca(%)	Mat	YML	F			<0.75-2.31>			Phil W Afr	200 202	
Mg(%)	Mat	YML	F			<0.27-0.35>			Phil W Afr	200 202	
Cu(mg/kg)	Mat	YML	F			<8-12>			Phil W Afr	200 202	
Zn(mg/kg)	Mat	YML	F			<17-25>			Phil W Afr	200 202	
Mn(mg/kg)	Mat	YML	F			<25-112>			Phil W Afr	200 202	
Fe(mg/kg)	Mat	YML	F			<79-320>			Phil W Afr	200 202	
Al(mg/kg)	Mat	YML	F			<240-320>			W Afr	202	
B(mg/kg)	Mat	?YML	F			<15>			Phil	200	

TOONA CILIATA (Australian Red Cedar)

Deficient conc set at 90(%) dry matter production, established from single nutrient omissions with 'complete nutrient' supplement.

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
N(%)	Seedl	All LB	Sand			<3.05-3.30>			Aust	165	
P(%)	Seedl	All LB	Sand			<0.25-0.29>			Aust	165	
N(%)	Seedl	Stem+ petioles	Sand			<1.14-1.22>			Aust	165	
P(%)	Seedl	Stem+ petioles	Sand			<0.17-0.24>			Aust	165	
N(%)	Seedl	YL	Soil/Pot	<1.8-2.3>		<2.8-2.9>			Aust	185	
P(%)	Seedl	YL	Soil/Pot	<0.16-0.23		0.14-3.0>			Aust	185	Overlap in range because of 'C-shaped' response curve.
K(%)	Seedl	YL	Soil/Pot	1.2-1.7>		<0.15-2.0>			Aust	185	
S(%)	Seedl	YL	Soil/Pot	0.11-0.16>		<0.13-0.18>			Aust	185	
Ca(%)	Seedl	YL	Soil/Pot	<0.58>		<0.66-1.07>			Aust	185	
Mg(%)	Seedl	YL	Soil/Pot			<0.24-0.47>			Aust	185	
Cu(mg/kg)	Seedl	YL	Soil/Pot			<6.7-15.8>			Aust	185	
Zn(mg/kg)	Seedl	YL	Soil/Pot			<31-43>			Aust	185	
Mn(mg/kg)	Seedl	YL	Soil/Pot			<48-198>			Aust	185	
Fe(mg/kg)	Seedl	YL	Soil/Pot			<35-285>			Aust	185	
B(mg/kg)	Seedl	YL	Soil/Pot			<27-34>			Aust	185	
P(%)	Seedl	YMB	Soil/Pot	<0.12		<0.15-0.24>			Aust Niue	185 186	
K(%)	Seedl	YMB	Soil/Pot	<0.8>		<1.2-1.3>			Niue	186	
S(%)	Seedl	YMB	Soil/Pot			<0.16-0.20>			Niue	186	
Ca(%)	Seedl	YMB	Soil/Pot			<0.13-0.21>			Niue	186	
Mg	Seedl	YMB	Soil/Pot			<0.29-0.35>			Niue	186	
Cu(mg/kg)	Seedl	YMB	Soil/Pot			<3.1-4.3>			Niue	186	
Zn(mg/kg)	Seedl	YMB	Soil/Pot	<11>					Niue	186	
Mn(mg/kg)	Seedl	YMB	Soil/Pot			<59-89>			Niue	186	
Fe(mg/kg)	Seedl	YMB	Soil/Pot			<72-95>			Niue	186	
B(mg/kg)	Seedl	YMB	Soil/Pot			<26-37>			Niue	186	

Nutrient	Growth Stage	Plant part	How established	Concentration range					Country	Ref	Comments
				Deficient	Marginal	Adequate	High	Toxic			
P(%)	Seedl	YMP	Soil/Pot	<0.06		<0.10-0.25>			Aust Niue	185 186	
K(%)	Seedl	YMP	Soil/Pot	<0.3>		<0.8-1.1>			Niue	186	
S(%)	Seedl	YMP	Soil/Pot			<0.09-0.13>			Niue	186	
Ca(%)	Seedl	YMP	Soil/Pot			<1.7-3.0>			Niue	186	
Mg(%)	Seedl	YMP	Soil/Pot			<0.25-0.29>			Niue	186	
Cu(mg/kg)	Seedl	YMP	Soil/Pot			<2.3-2.9>			Niue	186	
Zn(mg/kg)	Seedl	YMP	Soil/Pot	<8>					Niue	186	
Mn(mg/kg)	Seedl	YMP	Soil/Pot			<25-50>			Niue	186	
Fe(mg/kg)	Seedl	YMP	Soil/Pot			<34-65>			Niue	186	
B(mg/kg)	Seedl	YMP	Soil/Pot			<23-30>			Niue	186	

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Species in Tables

A. Scientific names

Acacia auriculiformis 507
Acacia cyanophylla (see *Acacia saligna*)
Acacia dealbata 507
Acacia decurrens 507
Acacia mangium 508
Acacia melanoxylon 508
Acacia saligna 509
Acacia spp. 500
Actinidia chinensis 364
Allium cepa 424
Allium sativum 419
Ammi visnaga 84
Anacardium occidentale L. 350
Ananas comosus 373
Andropogon gayanus 288
Annona spp. 360
Apium graveolens var. *dulce* 410
Arachis hypogaea 174
Araucaria cunninghamii 509
Araucaria heterophylla 510
Aristida armata 288
Asparagus officinalis 386
Avena sativa 169
Banksia ericifolia 470
Banksia ntegrifolia 470
Beta vulgaris 212, 392
Boronia megastigma Nees 471
Bothriochloa pertusa 288
Brachiaria brizantha 288
Brachiaria decumbens 288
Brachiaria humidicola 288
Brachiaria ruziziensis 288
Brachysema lanceolatum 496
Brassica campestris 97, 163
Brassica juncea 163
Brassica napus 97
Brassica oleracea L. var. *capitata* 397
Brassica oleracea var. *botrytis* 408
Brassica oleracea var. *gemmifera* 395
Brassica oleracea var. *italica* 394
Bromus diandrus 289
Bromus inermis 289
Bromus wildenowii 289
Buchloe dactyloides 289
Cajanus cajan 182
Caladium x *hortulanum* Birdsey 471
Camellia sinensis 230
Capsicum annuum var. *annuum* 402
Carica papaya 368
Carthamus tinctorius 192
Carya illinoensis 372
Castanea sativa 357
Casuarina cunninghamania 510
Casuarina equisetifolia 511
Casuarina glauca 512
Cattleya sp. 486
Cedrela odorata 513
Cenchrus ciliaris 289
Centrosema pubescens 290
Ceratopetalum apetalum 514
Chamelaucium spp. 468
Chloris barbata (*inflata*) 290
Chloris gayana 290
Chrysanthemum morifolium 475
Chrysopogon fallax 291
Cicer arietinum 108
Cichorium intybus 110
Citrullus lanatus 456
Citrus spp. 358
Cocos nucifera 359
Coffee arabica 359
Corylus avellana 363
Corymbia (see *Eucalyptus*)
Cucumis melo 441
Cucumis sativus 414
Cucurbita pepo 439
Cyamopsis tetragonoloba 147
Cyclamen persicum 477
Cymbidium sp. 486
Cymbopogon winterianus 110
Cynodon dactylon 291
Cyphomandra betacea 377
Dactylis glomerata 292
Danthonia richardsonii 293
Daucus carota L. 405
Desmodium intortum 293
Desmodium uncinatum 294
Dianthus caryophyllus 472
Dichanthium annulatum 294
Dieffenbachia exotica 477
Digitaria ammophila 294
Digitaria ciliaris 294
Digitaria eriantha (*decumbens, smutsii*) 295

Diospyros spp. 372
Dolichos lablab 297
Elaeis guineensis 367
Elytrigia pontica 295, 323
Eucalyptus camaldulensis 515
Eucalyptus delegatensis 517
Eucalyptus diversicolor 518
Eucalyptus dunnii 518
Eucalyptus fastigata 519
Eucalyptus globulus 520
Eucalyptus grandis 524
Eucalyptus microcorys 529
Eucalyptus nitens 530
Eucalyptus obliqua 531
Eucalyptus occidentalis 531
Eucalyptus pilularis 532
Eucalyptus regnans 533
Eucalyptus saligna 534
Eucalyptus tereticornis 536
Eucalyptus urophylla 536
Eucalyptus [syn. *Corymbia*] *Citriodora* 517
Eucalyptus [syn. *Corymbia*] *maculata* 529
Euphorbia pulcherrima) 489
Fagopyrum esculentum 97
Festuca arundinacea 295
Festuca pratensis 296
Ficus carica 360
Flindersia brayleyana 537
Fragaria sp. 376
Freesia refracta 478
Gladiolus tristis 479
Glycine max 202
Glycine tabacina 296
Gmelina arborea 538
Gossypium hirsutum 125
Grevillea spp. 480
Grevillea robusta 541
Hakea leucoptera 486
Helianthus annuus 226
Heteropogon contortus 296
Hevea brasiliensis 542
Hibiscus rosa-sinensis 480
Hibiscus cannabinus 150
Hordeum distichon 84
Hordeum leporinum 296
Hordeum vulgare 84
Humulus lupulus 149
Hydrangea macrophylla 481
Hyparrhenia rufa 297
Ilex aquifolium 481
Impatiens wallerana 482
Indigofera spicata 297
Ipomoea batatas 448
Ixodia achillaeioides ssp. *alata* 483
Juglans nigra L. 543
Juglans regia 378
Lablab purpureus (*Dolichos lablab*) 297
Lactuca sativa 420
Lathyrus sylvestris 297
Lens culinaris 151
Leptospermum spp. 497
Lespedeza cuneata, stipulacea, striata 297
Leucadendron spp. 484
Leucaena leucocephala 298, 543
Linum usitatissimum 152
Litchi chinensis 365
Lolium multiflorum 298
Lolium perenne 299
Lolium rigidum 302
Lophostemon confertus 544
Lotononis bainesii 303
Lotus corniculatus 303
Lotus pedunculatus 303
Lupinus albus 152
Lupinus angustifolius 152
Lupinus cosentinii 159
Lycopersicon esculentum 449
Macadamia integrifolia 365
Macadamia tetraphylla 365
Macroptilium atropurpureum 303
Macroptilium lathyroides 304
Adiantum raddianum cv. *Elegans* 485
Malus domestica 350
Mangifera indica 366
Manihot esculenta 105
Medicago minima 305
Medicago murex 305
Medicago polymorpha (*denticulata*) 306
Medicago sativa 307
Medicago truncatula 311
Melinis minutiflora 312
Mentha arvensis 149
Musa spp. 354
Neonotonia wightii 312
Nephrolepis exaltata 471
Nicotiana tabacum 231
Olea europea 368
Olearia phlogopappa 174
Ornithopus compressus 313
Oryza sativa 185
Panicum maximum 314
Paspalum dilatatum 314
Paspalum notatum 315
Paspalum plicatulum 315
Passiflora spp. 369
Pelargonium zonale 478
Pennisetum clandestinum 315
Pennisetum glaucum 181
Pennisetum purpureum 315
Persea americana 353
Petunia hybrida 488
Phalaenopsis sp. 488
Phalaris aquatica *316*
Phaseolus vulgaris 164, 389
Phleum pratense 317
Pinus brutia (see *Pinus halepensis*) 545

Pinus canariensis 545
Pinus caribaea var. *Hordurensis* 545
Pinus contorta 546
Pinus elliottii var. *elliottii* 546
Pinus halepensis 547
Pinus insularis (*see Pinus kesiya*) 548
Pinus kesiya 548
Pinus nigra 548
Pinus palustris 549
Pinus pinaster 550
Pinus radiata 550
Pinus taeda 554
Pistacia vera 374
Pisum sativum 140
Pisum sativum 428
Poa pratensis 318
Poinsettia (*Euphorbia pulcherrima*) 489
Populus deltoides 555
Populus misc 555
Populus tremuloides 556
Protea spp. 490
Prunus amygdalus 350
Prunus armeniaca 325
Prunus avium 356
Prunus persica 370
Prunus spp. 375
Pseudotsuga menziesii 556
Psidium guajava 363
Psophocaryus tetragonolobus 253
Puccinellia ciliata 319
Pueraria phaseoloides 319
Pyrus communis 371
Rhododendron indicum 469
Ribes nigrum 354
Rosa spp. 494
Rosa floribunda 493
Rubus idaeus 376
Saccharum spp. 218
Schefflera actinophylla 497
Secale cereale 107
Sesamum indicum 193
Setaria sphacelata 319
Solanum tuberosum 430
Sorghum almum 319
Sorghum bicolor 193
Sorghum bicolor x *S. sudanense* 320
Sorghum halepense 320
Sorghum vulgare 193
Spinacia oleracea 442
Stylosanthes capitata 320
Stylosanthes guianensis 320
Stylosanthes hamata 321
Stylosanthes humilis 321
Stylosanthes macrocephala 322
Stylosanthes scabra 322
Stylosanthes viscosa 322
Swietenia macrophylla 558
Tanacetum cinerariifolium 184
Tectona grandis 558
Telopea speciossissima 498
Thinopyrum ponticum (*Elytrigia pontica*) 323
Thyridolepis mitchelliana 323
Toona ciliata 560
Trifolium alexandrinum 323
Trifolium ambiguum 323
Trifolium balansae 324
Trifolium dubium 325
Trifolium fragiferum 325
Trifolium glomeratum 326
Trifolium hirtum 326
Trifolium hybridum 326
Trifolium michelianum 324
Trifolium pratense 326
Trifolium repens 327
Trifolium resupinatum 330
Trifolium semipilosum 330
Trifolium subterraneum 331
Triticale (*X Triticosecale*) 236
Triticum aestivum and Triticum durum 236
Urochloa mosambicensis 337
Urochloa oligotricha 337
Vaccinium corymbosum 355
Vicia faba 137
Vigna angularis 84
Vigna luteola 337
Vigna mungo 94
Vigna radiata 146
Vigna unguiculata 133
Vigna vexillata 337
Vitis vinifera 361
Zea mays 110
Zea mays var. *rugosa* 443
Zingiber officinale 145
Zinnia elegans 500

SPECIES IN TABLES

B. Common names

Adzuki bean 84
Aleppo pine 547
Alfalfa 307
Almond 350
Alpine ash 517
Alsike clover 326
Annual medic 306
Annual ryegrass 302
Apple 350
Apricot 325
Arm grass 288
Asparagus 386
Atro 303
Australian red cedar 560
Australian rose gum 524
Australian wax flower 468
Avocado 353
Azalea 469
Bahia grass 315
Balansa clover 324
Banana 354
Banksia 470
Barley 84
Barley grass 296
Barrel medic 311
Bean:
  french, green, snap, dwarf, bush 389
  navy bean and other beans 164
Beefwood 512
Beetroot 392
Benguet pine 548
Bermudagrass 291
Berseem clover 323
Birdsfoot trefoil 303
Black bunched speargrass 296
Black gram 94
Black pine 548
Black walnut 543
Blackbutt 532
Blackcurrant 354
Blackwood 508
Blueberry 355
Bluegrass 288
Boronia 471
Boston fern 471
Broccoli 394
Brown barrel 519
Brown salwood 508
Brush box 544
Brussels sprouts 395
Buckwheat 97
Buffalograss 289
Buffel grass 289
Bunched speargrass 296
Burr medic 306
Cabbage 397
Canary Island pine 545
Canola 97
Capica stylo 320
Capsicum:
  bell, cherry, cone, cluster, chilli, sweet 402
Caribbean pine 545
Caribbean stylo 321
Carnation 472
Carrot 405
Cashew 350
Cassava 105
Cattleya 486
Caucasian Clover 323
Cauliflower 408
Celery 410
Centro 290
Cereal Rye 107
Cherry 356
Chestnut 357
Chickpea 108
Chicory 110
Chloris 290
Chrysanthemum 475
Citronella Java 110
Citrus spp. 358
Cluster clover 326
Coachwood 514
Cocksfoot 292
Coconut 359
Coffee 359
Columbus grass 319
Common lespedeza 297
Corn, maize 110
Corsican pine 548
Cotton 125
Cottonwood 555
Cowpea 133
Creeping indigo 297

Cucumber 414
Custard apple 360
Cyclamen 477
Cymbidium orchid 486
Dallis grass 314
Dalrymple vigna 337
Dieffenbachia 477
Douglas fir 556
Dunn's white gum 518
Elephant grass 315
English pea 140
Faba bean 137
Field bean 137
Field pea 140
Fig 360
Filbert 363
Flatpea 297
Flax 152
Flooded gum 524
Fodder beet 212
Freesia 478
Gamba grass 288
Garlic 419
Geranium 478
Ginger 145
Gladiolus 479
Glycine 312
Glycine pea 296
Golden-beard grass 291
Grapevine 361
Great brome grass 289
Greater lotus 303
Green couch 291
Green gram 146
Green panic grass 314
Greenleaf Desmodium 293
Grevillea 489
Guar 147
Guava 363
Guinea grass 314
Hazel-nut 363
Hibiscus 480
High bush 355
Holly 481
Hoop pine 509
Hops 149
Horsetail casuarina 511
Hydrangea 481
Impatiens 482
Impulse violet 482
Indian couch 288
Italian ryegrass 298
Ixodia daisy 483
Japanese mint 149
Jaragua grass 297
Johnsongrass 320
Karri 518
Kenaf 150
Kentucky bluegrass 318
Kenya White clover 330
Khasya pine 548
Kikuyu grass 315
Kiwi fruit 364
Korean lespedeza 297
Koronivia grass 288
Lablab bean 297
Lemon-scented gum 517
Lentil 151
Lettuce 420
Leucadendron, Silvan Red/Safari Sunset 484
Leucaena 298
Linola 152
Linseed 152
Loblolly pine 554
Lodgepole pine 546
Longleaf pine 549
Lotononis 303
Lucerne 307
Lupin 159
Lychee 365
Macadamia 365
Macrocephala stylo 322
Mahogany 558
Maidenhair fern cv. elegans 485
Maku 303
Mango 366
Maritime pine 550
Meadow fescue 296
Messmate 531
Mitchell grass 323
Molasses grass 312
Mountain ash 533
Mulgal grass 323
Murex medic 305
Mustard 163
Native pea 296
Navy bean and other beans 164
Needlewood 486
Norfolk Island Pine 510
Northern black wattle 507
Oats 169
Oil Palm 367
Olive 368
Onion 424
Orchard grass 292
Orchid 486
Orchid 488
Pangola 295
Papaw 368
Paspalum 314
Passionfruit 369
Pea 428
Peach 370
Peanut 174
Pear 371
Pearl millet 181

Pecan 372
Perennial ryegrass 299
Persian clover 330
Persimmon 372
Petunia 488
Phalaris 316
Phasey bean 304
Pigeon pea 182
Pineapple 373
Pistachio 374
Plicatulum 315
Plum 375
Poinsettia 489
Poplars (incl. hybrids) 555
Potato 430
Prairie gGrass 289
Puero 319
Pumpkin:
marrow, squash 439
Purple bean 303
Purple-top Rhodes 290
Pyrethrum daisy 184
Queen protea 490
Queensland maple 537
Radiata pine 550
Rapeseed 97
Raspberry, red 376
Red clover 326
Red gum 536
Rhodes grass 290
Rice 185
River red gum 515
River sheoak 510
Rockmelon:
musk, Persian, honeydew Casaba melons 441
Rose clover 326
Rose, floribunda 493
Rose, hybrid tea 494
Rubber 542
Ruzi grass 288
Rye 107
Sabi grass 337
Safflower 192
Saltmarsh grass 319
Sericea 297
Sesame 193
Setaria 319
Shaftal clover 330
Sheda grass 294
Shining gum 530
Shrubby stylo 322
Signal grass 288
Silky oak 541
Silky umbrella grass 294
Silver wattle 507
Silverleaf Desmodium 294
Siratro 303
Slash pine 546
Smooth brome grass 289
Smooth-stalked meadow grass 318
Sorghum 193
Sorghum-sudangrass 320
South African Pigeon Grass 319
Soybean 202
Spinach 442
Spotted Gum 529
Sticky Stylo 322
Strawberry 376
Strawberry Clover 325
Stylo 320
Subterranean Clover 331
Suckling Clover 325
Sugar beet 212
Sugar cane 218
Summer grass 294
Sunflower 226
Swamp sheoak 512
Swamp Yate 531
Swan River pea bush 496
Sweet corn 443
Sweet potato 448
Sydney blue gum 534
Tall (woolly) finger grass 295
Tall Fescue 295
Tall Wheat Grass 295, 323
Tallowwood 529
Tamarillo 377
Tasmanian blue gum 520
Tea 230
Tea-Tree 497
Teak 558
Timor Rose Gum 536
Timothy Grass 317
Tobacco 231
Tomato 449
Townsville Stylo 321
Trembling aspen 556
Triticale 236
Umbrella plant 497
Urochloa 337
Wallaby grass 293
Walnut 378
Waratah, New South Wales 498
Watermelon 456
Wattle 500
Wattle 507
West Indian cedar 513
Wheat 236
Whistling pine 511
White beech 538
White clover 327
Wild cowpea 337
Wimmera ryegrass 302
Winged bean 253
Wiregrass 288
Woolly burr medic 305
Yellow serradella 313
Zinnia 500