chelated trace elements

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Contents

The need for trace elements

As every farmer knows, besides the major elements (nitrogen, phosphorus and potassium) plants *must* receive adequate amounts of trace elements such as iron, boron, cobalt, copper, magnesium, manganese, molybdenum, and zinc—although magnesium is really a major element, along with calcium.

Trace elements are often referred to as micronutrients or "minor elements", but this term refers only to the quantities needed. It does not mean that the minor elements are any less important to plant life. *In fact, if only one of these minor elements is withheld from a crop, the effect will be just as disastrous as if there were no nitrogen, or phosphates, or potash.*

A shortage of one or more of these trace elements, *even when it is too small to give rise to visual symptoms,* can cause a marked reduction in crop yield and quality. When symptoms begin to appear, the deficiency disease has then made considerable advances *and if immediate corrective action is not taken, the effect on the crop can be very severe.*

Plants also require other elements such as chlorine, sulphur and some others, but in the UK, in Europe and in other industrialised countries these are present in rainfall, or as impurities in NPK fertilisers, etc., in amounts that are sufficient to maintain natural levels in the soil. In some soils therefore, it can actually be harmful to apply additional chlorine or sulphur compounds. Additional sodium is usually beneficial only to root crops, or to some species having special photosynthetic metabolisms.

In some respects, the role of trace elements in crop feeding is similar to that of vitamins in human and animal nutrition. For example, vitamins and trace elements are both needed in extremely small quantities; and shortages, in either case, soon have an increasingly adverse effect on the growth and health of the subject, finally leading to recognisable deficiency diseases.

Why the problem is growing

Trace element deficiency diseases have become more widespread during the past twenty or thirty years, and deficiencies are on the increase. There are a number of reasons for this:

1. The almost universal use of concentrated NPK fertilisers

instead of farmyard manure or other bulky organic manures, which used to put trace elements back into the land via the livestock.

2. More intensive cropping methods have produced much higher yields which take more nutrients out of the land. *The farmer has been replacing the lost N, P and K, but not the trace elements.*

3. Most agricultural land has now been raised to a high degree of fertility. Paradoxically, this can give rise to trace element problems, simply because where the soil has a high nitrogen or phosphorus content, this in itself will tend to depress trace element uptake.

4. New varieties and improved methods of husbandry have increased crop yields and therefore the *rate* of removal of available elements from the soil.

5. In years gone by, many of the impurities in NPK fertilisers consisted of beneficial trace elements. Today, fertiliser manufacturers are using concentrated substances which are much more refined. These contain few, if any, trace elements as impurities.

6. On some farms, overliming, or even routine liming, has *induced* trace element deficiencies.

7. Reclaimed land often suffers from trace element deficiencies, especially after it has been cropped for some time.

There is now a growing awareness of the need for trace elements, both in the UK and throughout the world. As a result, these essential nutrients are now being used on an ever-increasing scale, not only in areas where there are known deficiencies, but also for the maintenance of existing trace element levels.

To correct these deficiencies, it has been customary to use well known inorganic chemicals such as manganese sulphate, copper sulphate, and so on.

But simple chemicals of this kind have a number of disadvantages. To be really effective, trace elements should be used in *chelate* form.

INORGANIC SALTS AND THEIR DISADVANTAGES

The biggest disadvantage in simple mineral salts (manganese sulphate for instance) is that all such inorganic elements react very easily with other soil substances, making the element insoluble, that is, "locked up" and not available to the crop.

For instance, in the case of a crop growing in an alkaline soil and therefore suffering from iron deficiency, it is quite useless to try to correct matters by applying iron in any inorganic form, such as ferrous sulphate. The same applies to the use of inorganic magnesium, manganese, copper, and many other trace elements in calcareous soils.

Similar reactions take place between inorganic trace elements and phosphates, whether the phosphates are in the soil *or even in NPK fertilisers.* The phosphates make the trace elements insoluble and unavailable to plants, *locking up a corresponding amount of the phosphate content as well, so that this also is unavailable.*

However, when trace elements are in chelate form, they remain soluble in the soil and fully effective.

WHAT ARE CHELATES?

"Chelate"* is a word used in chemistry for over a hundred years. It is derived from the Greek word *chela* (a claw) and is used to describe a special kind of organic chemical compound in which the metal (nutrient) part of the molecule is held so tightly that it cannot be "stolen" by contact with other substances which would convert it to an insoluble form. The chemical process is sometimes called *sequestration,* and chelates are sometimes referred to as *sequestered* compounds.

Here are some of the advantages of using chelated trace elements:

1. As practically all the chelated element remains available to the crop, much lower quantities are needed, compared with inorganic elements. On a weight for weight basis, chelates are more expensive, but per hectare,their cost is little greater,if at all, and they are much more effective.

2. Due to their organic structure, chelates are more readily absorbed by plant roots or leaves, and after that, they are more easily assimilated (digested) within the plant system.

3. Also, chelates are more readily *translocated* within the plant. That is, their action is partly systemic.

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* *Pronounced 'Keylate', with the accent on the first syllable.*

4. As every farmer knows, inorganic chemicals such as sulphates or chlorides have a certain amount of caustic action, so that one has to be very careful to avoid over-dosing. In contrast, as chelates are organic substances, they have a "mild" effect on plant tissues, so that there is much less risk of root damage or leaf scorch. And if chelates are over-applied by mistake, there is much less likelihood of causing harm.

5. The chelate form of iron is the *only* way of feeding this element, via the soil, to a crop growing in alkaline conditions. This can also apply to other elements, e.g., manganese, copper, and zinc.

6. As everyone knows, liming the soil can give rise to certain deficiency problems which can persist for as long as the benefits derived from the liming. In the past, where lime has been needed, the farmer has had to put up with this for the sake of the gains from the liming. Now however, land can be limed if necessary, and the resulting trace element deficiencies can be corrected with the use of chelates. In such cases, chelates are the *only* way of doing this effectively.

7. Because chelates are much less reactive with other substances, *they are compatible with a much wider range of pesticides,* compared with inorganic trace elements.

8. In certain cases, chelated elements can be used to correct soil *toxicity* due to an excess of other trace elements in the soil, whether this occurs naturally or whether it has been caused by previous soil treatments. This is due to the ability of certain chelates to beneficially depress a toxic excess of another element.

9. Although chelated trace elements are readily soluble in water, they are not easily leached from the soil. This is due to a phenomenon called *ad*sorption—an attraction to the surface of soil particles. Inorganic elements, on the other hand, are more easily leached from sandy soils, or from most soils after long spells of heavy rainfall. *This ability of chelates to "latch on" to soil particles, while still remaining available to plants, is an especially valuable feature of most chelate compounds.*

10. When inorganic trace elements, such as sulphates, are added to NPK liquid feeds, either for soil irrigation or foliar spraying, the inorganics react with the soluble phosphates and other substances in the NPK mixture, converting the trace elements into an insoluble form—and "locking up" some of the phosphates as well. Not only does this deprive the farmer of some of the phosphates and trace elements he has paid for, but

it also produces an insoluble precipitate which can build up as sludge, blocking spray lines and nozzles. However, when the trace elements are in chelate form this does not happen. The trace elements and the phosphates *both remain soluble, and fully available to the crop.*

11. It has been shown that chelated nutrients are much more effective than inorganic salts in their ability to feed the many beneficial micro-organisms which live in the soil.

12. Experiments have shown that in chelated compounds, the organic sequestering portion of the structure can act as a plant growth stimulator in its own right. That is, *in addition to the nutritional value which is derived from the trace element itself. This growth stimulator effect is entirely beneficial to plant life* and has been shown to be just one of the reasons for the better crop responses that are produced by trace elements applied in chelate form.

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Librel chelates

'Librel' chelated trace elements are produced in the form of dry powders, which dissolve quickly and completely in cold water. They are also available as liquid concentrates, for mixing with water before use.

There is a complete range of 'Librel' chelates, from cobalt to zinc—a chelate for every purpose— for using alone, or for mixing with dry or liquid fertilisers, or for applying in combination with insecticides, fungicides or herbicides, whether for soil or foliar application.

'Librel' chelated trace elements are the products of Interlates Limited, an all-British company run by people who have had over 30 years' experience in crop feeding — people who have also been *specialising,* for most of this time, in the micronutrient field.

All this wealth of experience is now freely available to all 'Librel' users.

'Librel' chelates are used by farmers and growers not only in the UK, but in many countries throught the world. What is more, since 1968 an associated company, Bilton Hutchinson Limited, has been supplying chelates on a worldwide scale to many of the largest fertiliser manufacturers, for incorporating into their own NPK compounds.

The 'Librel' range includes various chelates of each of these elements:

Calcium
Cobalt
Copper
Iron
Magnesium
Manganese
Zinc

In addition, there are 'Librel' mixtures for specific purposes. Some of these are special compounds that are made exclusively for individual fertiliser companies, but a product which is widely used for general purposes, and as a preventative, is 'Librel BMX', which contains iron, manganese, copper, zinc, boron, and molybdenum.

Soil and tissue analysis

Where the farmer or commercial grower is concerned, it is vital of course to be able to obtain prompt and reliable information about nutrient levels in soils and in plant tissues, as well as advice on the treatment of any deficiencies or excesses which have thus been brought to light.

So far, the most accurate diagnostic methods have proved to be soil analysis and plant tissue analysis. A chemical test of the soil, despite its limitations, can generally reveal what is available and what is missing, and tissue analysis can tell the farmer or grower what the plant itself is actually short of, or what it has plenty of. And while no diagnostic method can be completely reliable in every situation, such tests can reveal very much more than was known beforehand. These procedures, accompanied by modern methods of *interpretation,* and advice on what the laboratory figures mean, can usually make a tremendous difference to the health and yield of the crop.

GOVERNMENT SERVICES

In the UK, and in most overseas countries, the Government's Agricultural Advisory Service is of course able to carry out such tests for farmers and commercial growers.

Interlates is also able to offer a prompt service on similar lines, giving the farmer and the grower quick and accurate results. This is not intended to compete with the Government services, but to augment them. To encourage customers to obtain as much information as possible, this is a non-profitmaking service — the fee is not only modest, but it is well below the actual cost to Interlates Limited.

The use of the Interlates Analytical Service does not necessarily involve using more Interlates products! This is a completely ethical service. If trace element treatment is not needed, the recommendations make it very clear.

KNOWING AND PREVENTING

There are two ways in which a good soil and plant laboratory can help in successful crop management:

1. *Diagnostic* — that is, helping to identify a suspected problem, or

2. *Preventative* — to ensure, before a crop is sown or planted, that nutrient levels are satisfactory, and to discover *incipient* deficiencies, if any. These are hidden deficiencies which are just beginning to develop, so that they often have an effect on crop yields *long before any visible symptoms appear.*

BUT IT SHOULD BE A FULL ANALYSIS

In the case of *preventative* tests, Interlates carries out a comprehensive analysis, covering the major elements and all the trace elements, together with soil pH, lime requirement, and soil organic matter. The results, together with skilled advice on the basis of previous field history, the crop to be grown, and so on, usually provides a reliable guide to the treatment to be applied, if any. In most cases however, it is very important that soil analyses should be *complete,* that is, they should cover all possible factors: it is seldom sufficient to test soils for the presence or absence of only one or two nutrients. As there is a complex inter-relationship between the various nutrients, associated with other factors such as pH and OMC (organic matter content) unless a complete analysis is carried out, the results can be misleading. And when symptoms appear in a growing crop, tissue analysis can be invaluable. Where tissue tests are appropriate, it can however be useful to analyse for specific elements only. When results indicate that no treatment is needed, it is still vital to know that all's well.

SAMPLING

For the laboratory work to be effective, it is absolutely essential that great care is exercised to ensure that each field is sampled in the prescribed manner. It must be as true a representation as possible of the whole area of land that is to be tested, or in the case of tissue analysis, of the whole crop. After all, the chemist can only report on what is given to him. Errors arising from faulty sampling can be many times greater than the small "acceptable" variations that can arise in the laboratory. If the sample is not truly representative, then the resulting advice cannot be accurate.

As part of Interlates' service therefore, the taking of soil and tissue samples is carried out through certain local distributors only, whose field representatives have been properly trained in sampling procedure.

Trace element functions

Boron

Chemical symbol: B

Unlike most other micronutrients needed by plants, boron is not a metal. It is not possible, chemically, to produce it as a chelate. For crop feeding therefore, this element is usually applied in the form of borax (sodium borate) or boric acid.

Function in the Plant

The apical growing points of plants need boron for their continued development. It also plays an essential part in cell division, and in the health and development of all plant cells. Boron is needed for the proper translocation of sugars within the plant; this is particularly important in broad-leaved plants and especially in sugar beet. But in cereals and grasses, the need for boron is less than in broad-leaved species such as vegetables, fruit, and root crops. (The relatively larger amounts needed for sugar beet could in fact be toxic to cereals or to leguminous fodder crops.)

Boron is essential for pollen tube growth and fertilisation. In apples and pears, even moderate shortages can lead to reductions in fruit set. But the range of crops that are susceptible to boron deficiency is much smaller than for some of the other trace elements. Cereals and grasses do not appear to be much affected, while only slight deficiencies can be very damaging to sugar beet, red beet, mangolds, swedes, turnips, carrots, and other root crops. Celery, cauliflower, broccoli and kale can also be severely affected. Lucerne is a susceptible crop. Among horticultural crops, tomatoes, carnations and chrysanthemums are all affected by boron deficiency.

Boron deficiency symptoms

There is a wide variation in the amount of boron required by different plants, but for any particular species, requirements are restricted to a very narrow range. Visual symptoms of boron deficiency can differ from one kind of plant to another.

Yellowing caused by boron deficiency can usually be distinguished from yellowing due to other causes (for example, potassium or nitrogen deficiency) by the fact that it is confined to the upper leaves. It is therefore easy to confuse this with iron deficiency symptoms, which also appear in the younger leaves. However it may be possible to determine the cause by taking into account such factors as field history, type of crop being grown, weather conditions, and other symptoms, if any. Usually however, the precise cause can best be determined by plant tissue analysis.

Generally, the effects of boron deficiency only become apparent later on in the growing season, when boron requirements are high. One of the most common symptoms is death of the growing point of the main stem, causing the plant to become stunted and distorted. Some common symptoms are as follows:

Crop affected	**Symptoms**
Apples	Poor flower set. Leaves small, thickened and brittle. Cracking of fruit, which is often small and misshapen. Internal cracking. Dieback of shoots.
Barley	Short heads. Reduction in seed set, resulting in empty ears.
Beet	
Sugar beet	Reduction in size of leaves. Leaves turn yellow and die. Heart rot ("brown heart", "raan", or "water core"). Rotting of crown. Often there is cracking of leaf midrib.
Fodder beet	As for *Sugar Beet*. In fodder beet, blackening often spreads down the side of the root ("girdling").
Red beet	As for *Sugar Beet*, with black spot and canker. Often there is also some "girdling" (see *Fodder Beet*).
Cabbage	Leaves distorted and wilted. Internal breakdown of stem.
Cauliflower, broccoli	Deformed foliage, brown curd, "hollow stem" disease.
Celery	Mottling of leaves, "cracked stem" disease.
Citrus	Dieback of young shoots. Small, hard misshapen fruit, low juice and sugar content. Gum formation in albido and pith.
Cotton	Short internodes. Discoloration. Dieback of growing points. Many of the buds die off, or bolls fall.
Fodder beet	See *Beet*.
Lettuce	Leaves brittle and cup-shaped.
Maize	Short bent cobs. Barren ears. Poor kernel development. Growing points die.

Mangolds	As for *Sugar Beet.*
Olives	Leaves show apical browning. Terminal shoots and leaves die back. Fruits drop when immature, and those that develop are pitted and shrivelled ("monkey face" fruits).
Peaches	Dieback of shoots. Cracked fruit.
Peanuts	"Hollow heart" disease (a dark hollow area in the centre of the nut).
Pears	Dieback of shoots. Dwarf terminal leaves- "Blossom blast" disease. Poor fruit set. Fruits that develop are deformed
Potatoes	Short internodes. Plant is bushy in appearance. Rusty necrosis in tubers. Tubers discolour rapidly when cut. Note: symptoms of some potato virus diseases are very similar to those caused by boron deficiency.
Radish	Deformed, brittle and chlorotic leaves. Roots may be water soaked and show brown flecks.
Swedes, turnips	As for *Sugar Beet.*
Tobacco	Deformation and reduction in size of young leaves. Terminal leaves light green. Plant becomes bushy in appearance.
Tomatoes	Malformation of young leaves. Death of growing points. Sometimes chlorosis of terminal lobe of leaves, due to breaking of brittle midrib. Foliage becomes orange-yellow. Plants become stunted.
Vines	Dieback of shoots. Shortened internodes. Poor fruit set. "Hen and chickens" disease, or "shot berries" (different size grapes on the same bunch).

Deficiency-prone soils

A considerable portion of the soil's boron content is held in its organic matter, from which it is gradually released by soil micro-organisms. So boron deficiency is likely to be found in sands, in very light soils, loamy sands and other open-type soils in which leaching is severe in wet weather. Similar deficiencies occur in soils that have been limed just prior to the growing of a susceptible crop, and in other soils where the pH is above about 6.5.

In some countries, the natural water supply has a high boron content. In this case, toxicity effects can sometimes be prevented by liberal applications of nitrogenous fertilisers, or by moderate liming. Failing this, the only remedy may be to grow crops tolerant to boron.

Inter-relationships with other substances

Boron deficiency is aggravated by liming, and by heavy applications of nitrogenous fertilisers.

Seasonal and weather influences

Boron shortages occur frequently in humid regions, and especially in areas which have wet periods followed by long dry periods. The problem is more prevalent in dry summers, especially after a wet winter or spring. It can also occur when a long dry spell follows good growing conditions in early summer.

Where the deficiency is slight, the symptoms may disappear after the end of the moisture stress period, but the appearance of symptoms in such cases clearly indicates a low boron content in the soil.

General remarks

Different crops differ widely in their need for boron, and for any particular species, the amount needed is more critical than in the case of other trace elements. The quantity required by some plants would, in fact, give rise to deficiency symptoms in others, while certain plants need quantities so relatively large as to be toxic to other plants.

In the soil, borax is a satisfactory source of boron but as it is only sparingly soluble, it is not suitable for use in irrigation water, or in foliar sprays. For these purposes it is advisable to use one of the soluble forms of boron that are on the market.

Boron compounds can be mixed with NPK fertilisers, but if these are drilled fairly close to the seed, some suppression of germination may occur.

While 'bitter pit' in apples is known to be associated with calcium deficiency, experiments have shown that boron is also involved, probably due to its ability to enhance utilisation of calcium and to aid the translocation of Ca within the plant.

BORON

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Cobalt

Chemical symbol: Co

Function in the plant

Cobalt is essential for the growth of algae and for nodule bacteria in legumes. It does not appear to be required by higher plants, although there are reports that applications of Co have led to increased growth and yield.

In leguminous crops, Co plays a part in the symbiotic fixation of atmospheric nitrogen. In New Zealand for instance, it is necessary to provide cobalt for the clovers that are grown in order to fix the nitrogen needs in grassland.

Function in animals

Cobalt is a constituent of vitamin B_{12} (cobalamine), an essential part of the diet of all animal life.

In livestock, particularly ruminants, a shortage of cobalt causes loss of appetite, retarded growth, anaemia, and poor reproduction. The effect is known in different countries as *vinquish, daising, salt sickness, bush sickness, pining, coast disease, Morton Mains disease, or enzootic marasmus.*

Non-ruminant animals, including humans, require Co but only in the form of vitamin B_{12}. Humans require about 1 microgram of cobalt per day for the safe prevention of *pernicious anaemia.* Ruminant animals require a few micrograms of Co per day in order to supply the micro-organisms in the rumen which produce vitamin B_{12}.

Cobalt deficiency also makes affected animals more susceptible to worms and other parasitic infestations.

It has been established by many experiments during the past 40 years that animals begin to suffer from Co deficiency diseases when they are fed on pasture on soils containing less than 3 ppm of cobalt. Where the soil content has been between 0.3 and 2 ppm there have been severe deficiency symptoms.

The critical level of cobalt in herbage for ruminants appears to be around 0.08 ppm (dry matter).

Good pasture soils have been found to contain between 5 and 30 ppm of cobalt, although animals grazed on soils containing 2-3 times these amounts have not shown any ill effects.

Where pregnant ewes are wintered on crops, the usual method is to apply the cobalt to pastures for their lambs during the following spring or early summer, which is just the time when additional Co for lambs may be needed. The pasture should be sprayed with a solution of cobalt chelate ('Librel Co') at the rate of 250g (dry weight) per hectare (4 oz per acre).

Co deficiency in animals can be corrected by adding it to salt licks and mineral supplements, but experience in many countries has shown that the most effective method of feeding cobalt to grazing animals is through topdressing the pasture, where it is also essential for the growth of legumes such as clover and lucerne, and for leguminous crops grown for stock feeding, such as field beans.

Salt licks are generally suitable in dry climates, but their disadvantage is that it is impossible to ensure that individual animals receive the correct dosage. Taste for salt varies from one sheep to another, and it has been shown that when fed with micronutrients via salt licks, some animals receive too much cobalt and others not enough.

In New Zealand, applications of 125-250g/hectare (2-4oz/acre) of 'Librel Co' in the autumn of each year will usually increase the cobalt content of pastures above deficiency levels for a period of 12-18 months.

Where livestock are fed via grains or other concentrates, Co chelate can be included in the mineral supplement of feed mixtures.

Deficiency symptoms

Insufficient cobalt causes stunting of plant growth, accompanied by chlorosis, which, in legumes and other symbiotic nitrogen fixing species, can easily be mistaken for symptoms of iron deficiency, but is caused by failure of nodule formation and nitrogen fixing capacity, resulting in severe nitrogen deficiency.

Deficiency-prone soils

Soils likely to be deficient are acid sands, soils derived from granites, and alkaline soils, especially shell-sands. Availability of cobalt may also be reduced in peat soils. Forage crops grown on high organic soils can be low in cobalt content.

In some parts of the world (for instance in Australia, in parts of Scotland, and in some regions of North America) there is often a shortage of Co in easily leached soils such as granite sands. In New Zealand, cobalt is seriously deficient in many of the pumice soils in the North Island and in the granite sands in the South Island. Until the cause was known to be Co deficiency, it was impossible up to 40 years ago to farm sheep and cattle on such land. In Australia the coastal sandy soils, rich in calcareous shell, used to be markedly deficient.

In some soils high manganese can immobilise cobalt. This is common in Australian soils which have been treated with excessive amounts of manganese salts.

Inter-relationships with other substances

Uptake of cobalt is reduced by liming or by the application of alkaline fertilisers such as basic slag. Availability is reduced in soils with a high phosphorus content. Excess applications of phosphates can cause Co deficiency.

Crops treated with cobalt may absorb additional amounts of molybdenum. So if the molybdenum content of the soil is already high, molybdenum toxicity problems may be aggravated. As *teart* disease occurs on soils of pH 7 and above, it is advisable to avoid applying cobalt with lime or mixed with fertilisers which have an alkaline reaction, such as basic slag.

Seasonal and weather influences

There is an increase in the cobalt content of herbage in winter. The level declines during the summer months.

Effects of excess

Cobalt toxicity problems are not known to occur naturally, either in plants or animals. There also appears to be a wide range of tolerance which makes it unlikely that treatments can cause toxicity. For instance, plants as diverse as pasture grasses and citrus have been grown in soil treated with cobalt at up to 100 times the normal application rate, without any detectable harm. It has also been shown that no ill effects resulted from feeding rats with 25 times their normal Co requirement.

COBALT

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Copper

Chemical symbol: Cu

Function in the Plant

Copper is necessary for the functioning of ascorbic acid enzymes. It also influences many other metabolic reactions within the plant. It is essential for the plant's production of iron compounds, needed to synthesize chlorophyll.

Copper deficiency symptoms

In cereals, the symptoms are usually seen only when the plants are well developed in April to mid-May. Wet weather delays the appearance of the symptoms. On fen soils and peats the leaf margins of the cereal plants become pale yellow and whitening of the tips of the youngest leaves may occur. The young leaves may twist in spirals and bend over at right angles to the stems. Growth may be severely checked and ear emergence delayed. The ears may develop few grains and by harvest, appear white. In wet seasons and in mild deficiencies these symptoms may not appear until June or early July.

The above symptoms do not always appear, especially in slight to moderate deficiencies. The crop may appear vigorous and healthy until the grain is being formed, but no grain develops in the tips of the ears and yields may be up to one-third less than expected.

On chalk soils the symptoms are quite different, the plants looking normal until early July. Deficient plants show a "blackening" symptom and become dark olive green in colour. The appearance of the blackening starts below the ear and progressively moves down the plant. There is usually a drastic reduction in amount and quality of grain and there may be production of "rat tailed" ears. At harvest, affected plants may turn darker in colour and die. The straw is weakened and the plants may curve over and collapse.

Copper deficiency also causes *reclamation disease (yellow tip)* in legumes, beet, and in oats and other cereals, and *exanthema (die-back)* in citrus crops, apples, pears, and Japanese plums. In South Africa *exanthema* affects peach and apricot trees as well. *Falling disease* of cattle (in Australia), *stringy wool* of sheep, and *coast disease* are all caused by Cu deficiency associated with a shortage of cobalt.

Deficiency-prone soils

Peat land, also some sand and gravel soils. In south eastern and central southern England, copper deficiency is found in black "puffy" soils of 10% or more organic matter content, overlaying chalk, and usually shows up a few years after cultivation.

In chalk and other alkaline soils a shortage of copper is usually worse after growing kale, turnips or rape.

Inter-relationships with other substances

Copper deficiency is made worse by excess nitrogen, phosphorus, or heavy liming. There is a "see-saw" effect between copper and molybdenum: excess of one prevents or reduces the uptake of the other. Therefore molybdenum *toxicity*, induced by liming, can often be treated by applying copper. But where both are deficient, both should be applied.

An increased need for copper often arises when growth of cereals has been stimulated by nitrogen and phosphates.

Excess copper can induce iron deficiency.

Symptoms of copper deficiency can be complicated by manganese deficiency, which appears earlier than copper deficiency on fen peats of pH 6.0 and over. Unless the shortage of manganese is corrected by spraying, recognition of the copper deficiency may be very difficult.

Liming the soil, by raising its pH, tends to reduce uptake of copper. In alkaline soils, iron and manganese may also be deficient, with no response to copper applications unless iron and manganese are applied as well.

Seasonal and weather influences

In dry seasons, Cu deficiency may develop in soils which have a high organic content. Draining fen peats and lowering the water table may induce copper deficiency.

General remarks

Cattle and other livestock are especially susceptible to copper deficiency. If a shortage of copper has been found in cereals it is prudent to treat pastures to prevent livestock suffering from a deficiency. This is best done by applying a foliar spray containing 'Librel Cu' at ½ lb/acre (½ kg/ha) mixed with 'Libspray' at the rate of 3-4 lbs/acre (3-4 kg/ha).

(Also see 'General Remarks' under *Manganese*.)

Caution: Livestock should be kept out of sprayed pasture for 14 days.

COPPER

The following references may be helpful to readers who wish to study the subject in greater depth.

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Iron

Chemical symbol: Fe

Function in the plant

Iron is essential to all plants and animals, and a continuous supply is needed. Plants require iron in order to produce chlorophyll, the green colouring matter which is necessary for photosynthesis. Iron also plays an important part in the formation and activity of a series of respiratory enzymes. This element is relatively immobile in plants and tends to remain in older tissues, while new growth can remain starved.

Iron deficiency symptoms

Characteristic symptoms are chlorosis of young growth, especially interveinal, or pale leaf colour, sometimes with scorching of leaf margins and tips, and eventually die-back of shoots. Growth is retarded, and in severe cases results in death of the plant. (Note however that a pale leaf colour can also be caused by nitrogen deficiency, which would also tend to retard growth.)

The most common sufferers are horticultural crops, especially top fruit and soft fruit. The effects often become worse with increasing age of the tree. Some varieties are affected more than others. Damage to roots can lead to iron deficiency. Some ornamental crops and flowers also suffer from iron deficiency. Shortage of iron is particularly harmful to raspberries, strawberries, and other soft fruit. This shows as chlorosis on young growth, with reduction in fruiting.

Citrus crops are particularly susceptible to iron deficiency, which is worse if copper fungicides have been in regular use. In citrus there is a failure to mature all the fruit that sets, and many of the fruits fall early. Those that remain are pale in colour.

In grasses and cereals, common symptoms are alternate stripes of green veins and yellow interveinal areas.

In brassicas, there is often a chlorotic marbling effect on leaves (note however that this is similar to symptoms of manganese deficiency).

In sugar beet, chlorotic mottling of younger leaves, the older leaves remaining green at first.

In potatoes, chlorosis of leaf tips.

In tomatoes, chlorotic mottling, beginning first at the top of the plants, especially near the midrib and towards the bases of leaflets.

Even in cases where there is not the slightest sign of iron deficiency, an application can often produce a marked improvement. For instance, iron in chelate form deepens the colour of many of the blue-green conifers. The more healthy the plants are, the better the effect. Iron chelates are also used to produce a richer green in various kinds of nursery stock.

Note: Chlorosis due to iron deficiency can often be confused with damage from excess *residual* weedkiller application or its spray drift from adjoining land.

Deficiency-prone soils

Iron is made unavailable by lime or chalk, so is deficient in conditions of high pH, ie., in alkaline soils. Therefore liming can induce Fe deficiency.

Often, iron is also deficient in acid sands — due to leaching — and is oxidised and made less available in most freely-drained soils.

Iron deficiency is induced by (a) bicarbonate ions in soil solution or irrigation water, (b) low organic matter content in acid soils, (c) heavy manuring of alkaline soils, (d) poor aeration (excess carbon dioxide), (e) poor drainage, or (f) high phosphate content.

Grassing-down of orchards helps to alleviate iron deficiency. Note however that iron is usually abundant in lateritic soils and is made soluble — even to excess — by anaerobic conditions caused by flooding, etc.

Inter-relationships with other substances

Iron deficiency can be induced or aggravated by an *excess* of cobalt, copper, manganese, phosphorus, sodium, or zinc, or by a *shortage* of potassium.

Where it is caused by a low level of potash, a shortage of iron tends to be particularly harmful to apple, maize, and potato crops, especially when associated with high phosphorus levels.

Iron deficiency is often associated with established or incipient manganese and/or magnesium deficiencies. Thus applications of iron may increase the severity of these deficiencies. It is usually advisable therefore to apply a mixture or iron, manganese and magnesium.

On the other hand deficiencies of manganese and/or magnesium may often mask an iron deficiency, causing symptoms which are not characteristic of iron deficiency alone. For instance, as chlorosis due to manganese or magnesium deficiency tends to show on older leaves, and as iron deficiency shows up first on new leaf growth, there may be an overall chlorosis which may not be readily identifiable. The same masking effect can also be caused by zinc deficiency.

Too much molybdenum may also accentuate Fe deficiency, especially in certain areas where there is an excess of cadmium, cobalt, copper, manganese, or zinc.

Seasonal and weather influences

Iron deficiency is worse in hot dry summers; in conditions of high light intensity; in periods of drought; and where there are extremes of temperature and moisture.

General remarks

In the case of top fruit and other deep-rooting crops, iron is probably the least effective of all the trace elements when added to the soil in the form of inorganic salts, such as ferrous sulphate. As a foliar spray, inorganic iron also tends to be ineffective because it so easily damages leaf tissue.

Chelated iron, however, although more expensive, is many times more effective than any other form of this element. Therefore much less is needed, and the chelate is effective in conditions where inorganics are not available to the crop.

The 'Librel' range includes three different kinds of iron chelate: Librel Fe-Hi, containing FeEDDHA, for *soil* application in the case of crops growing in particularly high pH soils; Librel Fe-Lo (FeEDTA) for lower-pH soils and for foliar spraying, and Librel-DP (FeDTPA) for soil use where the pH is fairly high but not to the extent that would necessitate using the more expensive FeEDDHA chelate.

In obtaining results from iron applications, method and timing are of great importance. Wherever possible, treatment should begin in the early stages of plant growth. Iron chelate must get down to the root zone. On tree crops in the UK this usually means applying in late winter to allow the rains to wash the chelate in. In arid countries, it should be applied with the irrigation water. As root absorption of iron is greatest early in the season, the chelate ought to be in the root zone before seasonal growth growth begins. The full results of a soil application may not be apparent in the first year, but may last for 2-4 years after application, depending on soil type, rainfall, and crop. Once the deficiency has been corrected, applications of smaller amounts of iron chelate, up to a quarter of the initial amount, will usually prevent the deficiency recurring.

Foliar spraying costs less than soil applications, and it produces a more rapid response. However, repeat applications are needed, although in some cases there may be disturbance of a growing crop. Two or three sprayings are usually required, each at 2-3 week intervals, beginning as soon as there is sufficient leaf area to absorb the spray. With all iron sprays, there is little movement from the point of application and therefore young growth must be sprayed as it develops. If the deficiency symptoms are well advanced, chlorotic foliage may not recover during the year in which it is treated.

IRON

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Magnesium

Chemical symbol: Mg

Function in the plant

Magnesium forms a part of the chlorophyll molecule, and therefore any deficiency can have a direct effect on photosynthesis.

Mg is essential for carbohydrate metabolism, and for cell respiration. In oil producing crops, such as oilseed rape, it also plays a part in the plant's synthesis of oils and fats.

Magnesium deficiency symptoms

Symptoms generally appear first on older leaves, usually in the latter part of the growing season, and may progressively affect the younger leaves.

Usually there is a fading of the healthy green colour between the leaf veins, followed by chlorosis, sometimes turning into brilliant colours. Chlorosis may begin at the leaf margins or tips and spread inward between the veins. Eventually there is complete destruction of the tissue between the veins or along margins or tips of leaves, accompanied by premature defoliation, with reduced growth and yield.

Deficiency-prone soils

Magnesium deficiencies occur most commonly in peat soils, acid sandy soils, and in imperfectly-drained clays, especially in areas of moderate to high rainfall.

Inter-relationships with other substances

It is well known that there is a "see-saw" effect between magnesium and potassium, especially in alkaline soils. Often the addition of potash to the soil will induce or aggravate Mg deficiency. Experiments have shown that most crops grow best when there is a ratio of about 2 of K to 1 of Mg on many soils in the UK.

Magnesium deficiency is often associated with shortages of iron and/or manganese, as explained on page 23. Also it is sometimes associated with zinc deficiency, especially in citrus crops.

When correcting a shortage of magnesium, it is worth noting that a high level of nitrogen tends to reduce the severity of the Mg deficiency.

Seasonal and weather influences

Magnesium deficiencies usually occur in areas of high rainfall, or in wet seasons anywhere. It is worst in light, acid soils.

General remarks

Magnesium is now regarded as one of the major elements. Where a severe deficiency is known to exist, especially when low-value crops are being grown, kieserite at 4 cwt/acre (450 kg/ha) should be applied to the soil annually until the deficiency is remedied. If lime is required on a magnesium deficient soil, magnesian limestone should be used.

On high-value horticultural crops however, soil applications of magnesium chelate, such as 'Librel Mg' at 6 lbs/acre (6 kg/ha) are often economically worthwhile.

Tomatoes and other crops which are intensively grown under glass often benefit from frequent applications of magnesium.

For foliar spraying, Librel Mg at 0.1% is more effective than inorganic magnesium, such as magnesium sulphate. The absorption of magnesium can be further improved by the addition of 0.2% urea.

Chelated magnesium, such as Librel Mg, is much less likely to cause precipitation problems in concentrated liquid fertilisers, compared with inorganic magnesium salts. For instance, if magnesium sulphate is used to correct Mg deficiency in crops grown in peat modules, it is often necessary to omit the phosphate portion of the NPK feed in order to avoid the chemical antagonism which tends to inactivate both magnesium and phosphorus. Naturally this soon leads to an insufficiency of phosphorus. But if the Mg is applied in chelate form, this problem does not arise: the magnesium chelate and the phosphorus can be applied together and both of them remain fully available.

MAGNESIUM

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Manganese

Chemical symbol: Mn

Function in the plant

Manganese is involved in the metabolic processes of plants, where it influences the uptake and assimilation of other nutrients such as nitrogen. It also activates a number of enzymes connected with the production of oxygen, via the process of photosynthesis.

Manganese deficiency symptoms

Symptoms are usually: interveinal chlorosis or yellowing, followed by whitening and sometimes speckling of older leaves. In cereals the leaves may show a striping effect.

Typical manganese deficiency diseases are *grey speck* of oats and other cereals, *pahala blight* of sugar cane, *speckled yellows* in sugar beet, and *marsh spot* of peas.

Manganese deficiency also affects brassicas, red beet, fodder beet, mangolds, carrots, parsnips, beans, spinach, onions, leeks, lettuce, potatoes, and top fruit and soft fruit.

The yields of many crops are known to be limited by manganese deficiency without visual symptoms being apparent, for example on sugar beet and potatoes grown in organic soils, and in soils with a pH of 6.0 and over.

Excess manganese in soils in which wheat and barley is grown can cause browning of roots and the development of brown spots on the leaves.

Deficiency-prone soils

In the UK there are marked manganese deficiencies in many areas, especially in the Fens, Romney Marsh, and parts of Yorkshire, Somerset, Wiltshire, South West Lancashire and the West Midlands.

Manganese tends to be deficient in all alkaline soils from pH 6.0 and upwards. It is often associated with incipient or established shortages of iron, magnesium and/or copper.

In highly acid soils, soluble Mn may be present in excess, resulting in manganese toxicity.

Inter-relationships with other substances

Manganese deficiency is worse in alkaline conditions, so it tends to be aggravated by liming. Low potassium levels can also interfere with the uptake of Mn.

Deficiencies of manganese and copper often occur together, so that foliar applications of both elements (for example, a mixture of 'Librel Mn' and

'Librel Cu') can reduce or prevent lodging of cereals.

Excess of manganese tends to induce *iron* deficiency and vice versa, especially in beans, beet, cape gooseberries, and pineapple. Thus manganese and iron deficiencies often occur simultaneously in calcareous soils, or in limed acid sands. The ratio of copper plus manganese is of importance in relation to iron.

The effects of excess Mn at pH 4.0 to 5.5 can be alleviated by liming.

General remarks

Usually, manganese is best applied as a foliar spray. 'Librel Mn' at 2 lb/acre (2 kg/ha) is far less likely to cause scorch compared with manganese sulphate at 8 lbs/acre (8 kg/ha).

If manganese sulphate is applied to the soil prior to sowing, it may be made unavailable to the crop by the very conditions which caused the manganese deficiency. *Chelated* manganese, however, in the form of 'Librel Mn' at 4 lbs/acre (4 kg/ha) may be applied to the bare soil in late winter or early spring, where it remains available to the crop, avoiding the need for emergency spraying during the growing period. In many cases, generous applications of Librel Mn to the soil each spring for three or four years has completely corrected long-standing manganese deficiencies, especially where Librel Mn has been sprayed on before sowing or planting, and then harrowed in.

In the UK, significant increases in yields of broad beans, cabbage, lettuce, sprouts, and potatoes have been obtained in replicated plot trials on a Lias clay loam of pH 7.5, using Librel Mn at 3 lbs/acre (3 kg/ha). *These results were obtained in the absence of any deficiency symptoms in plants grown in untreated plots.*

Livestock: It has been shown that manganese can affect fertility. Manganese deficiency often occurs in conditions which also cause copper deficiency. This retards milk production and affects the growth of young animals. The most satisfactory treatment is to apply Librel Mn at 1 lb/acre (1 kg/ha) mixed with Librel Cu at ½ lb/acre (0.5 kg/ha) as a foliar spray to pasture, to fodder crops, or to cereals grown for feeding. *This is much better than feeding a deficient crop to livestock and trying to correct matters by adding manganese and copper to the feed.*

Caution: Livestock should be kept out of sprayed pasture for 14 days.

MANGANESE

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Molybdenum

Chemical symbol: Mo

Function in the plant

Molybdenum is needed for nitrogen assimilation within the plant. It is required by the root nodular bacteria in legumes (peas, beans and clover) for fixation of atmospheric nitrogen. Mo is therefore a key element in nitrogen metabolism.

Mo also plays a part in vitamin C synthesis within the plant. It makes iron available in the plant and it acts as a "buffer" against toxicity effects in the presence of excess copper, boron, cobalt, nickel, manganese or zinc. It also enhances the uptake of nitrogen, potassium, and calcium.

The amount of molybdenum that is required by plants varies widely with different plant species. But even at higher requirement levels, extremely small amounts of Mo are needed, compared with other micronutrients.

However, if plants do not get sufficient molybdenum, they become sickly and eventually die. In fact, the level of available Mo affects growth and yield more than any other micronutrient.

Molybdenum deficiency symptoms

Signs of Mo deficiency are yellow-green, yellow, or orange mottling of leaves, followed by marginal curling, wilting, and finally death of the tissue and withering away of the leaf. Symptoms usually appear first in the older leaves and then show up regularly in younger leaves until the growing point dies, and flowers wither or are suppressed. These conditions are more severe in plants which have been given ample supplies of nitrates, which are accumulated in the plant tissue. The tissue also has an abnormally low content of protein, total soluble nitrogen, and chlorophyll.

In brassicas such as cauliflower and broccoli, Mo deficiency is the cause of the well known "whiptail" disease. This starts as one or more small rounded, translucent areas between the largest veins near the midrib of one or two young leaves which then become yellow or totally chlorotic and then perforate. The perforations later become enlarged irregular holes.

Lettuce are especially sensitive to lack of molybdenum.

In pasture, molybdenum deficiency produces weak, pale clover, often interspersed with healthy patches. If just sufficient Mo is applied to lead to a normal rate of symbiotic nitrogen fixation, the nitrogen content of the clover tissue rises sharply but the molybdenum concentration may still remain low. For this reason, a very low molybdenum content of white clover is only indicative of molybdenum deficiency if the nitrogen content is also below normal. (Deficiencies of nutrients other than molybdenum may however be the reason for a low nitrogen content in clover.)

Symptoms in peas and beans (which are very sensitive to molybdenum deficiency) are pale green leaves and reduced growth and yield. The symptoms can easily be mistaken for nitrogen deficiency, but spraying two or three plants with urea and others with ammonium or sodium molybdate will, after a week or so, usually serve to identify which of these elements is deficient.

In rape, kale, turnips and swedes, and in many other plants, symptoms are irregularly shaped leaves, upward curling of margins, with yellow mottling and pale colour. Mangolds and beet also show these symptoms, with stunting as well.

In alfalfa and other legumes, growth is retarded, the leaves turn bright green, and the older leaves eventually become scorched and drop off prematurely.

Cereals and grasses are not very sensitive to molybdenum deficiency. Where a deficiency exists however, wheat, oats, and rye often respond to molybdenum applications, although barley does not appear to be affected.

Carrots and parsnips are moderately sensitive to molybdenum deficiency. In deficient soils, these crops become yellow and very stunted. Tomatoes, spinach, lettuce, and citrus fruit are all similarly affected.

The common weed known as fat hen is particularly sensitive to Mo deficiency: it grows very pale green with yellow mottling, and is therefore a good "indicator plant".

Deficiency-prone soils

Molybdenum deficiencies occur frequently in podzols, acid soils, sandy soils, and soils with a high iron content.

In some acid soils where adequate molybdenum is present but unavailable to the crop, the beneficial effects derived from liming can be due to the effect of the lime in releasing Mo in a soluble form. However as excess liming locks up most of the other micronutrients, it is usually better in such cases to apply molybdenum rather than lime. What is more, liming cannot correct molybdenum deficiency in soils where there is an insufficiency of Mo. This can only be done by applying molybdenum.

Inter-relationships with other substances

Mo is gradually "locked up" by repeated applications of sulphate of ammonia or of compound fertilisers containing it. This is due not only to the well known acidifying actions of ammonium sulphate, but also to the presence of sulphate ions, which inhibit the plant's utilisation of molybdenum. On the other hand, applications of phosphates tend to enhance Mo uptake.

Molybdenum deficiency can also be caused by the presence, in relatively high amounts, of copper, magnesium, manganese, zinc, and nickel.

There is a well known "see-saw effect" between molybdenum and copper. An excess of molybdenum can induce copper deficiency, and vice versa.

Seasonal and weather influences

Molybdenum is often deficient in high rainfall areas or after periods of prolonged heavy rain, especially on alkaline sandy soils.

Effects on livestock

In animals, an excess of molybdenum is the cause of the well known "teart" disease in cattle and sheep, now known as *molybdenosis* (molybdenum toxicity). The animals most severely affected are milking cows and young calves, which suffer from extreme diarrhoea, loss in weight, and reduced milk yields. The condition is aggravated by liming the soil. The toxic effects of molybdenum in cattle and sheep can usually be prevented by applying copper to the pasture (preferably in chelate form) or in severe cases, by giving copper injections.

On the other hand, due to the molybdenum/copper relationship, animals grazing on pasture that is low in Mo may suffer from copper toxicity if the level of Cu is high, or even moderately plentiful.

If the diet of livestock contains a relatively large amount of sulphates, this will reduce the amount of molybdenum that is retained by the animal.

In humans and animals, molybdenum forms part of an enzyme which is concerned with the breakdown and elimination of the body's waste products. Mo is therefore essential to health, although only in extremely minute quantities. In sheep, it plays a part in the stimulation of micro-organisms in the rumen which is concerned with the breakdown of cellulose.

Dental caries has been shown to be caused, at least in part, by the regular eating of crops grown in regions where the soil has a low molybdenum content.

General remarks

As molybdenum is needed in such small quantities, particular care should of course be taken to ensure evenness of application. This is best done by applying it to the soil as a solution; for instance, spread over a given area, each gram of ammonium molybdate (54% Mo) mixed with a convenient volume of water will apply roughly half a gram, dry weight, of molybdenum calculated as the element, Mo. (However if sodium molybdate is used instead, it should be noted that this contains 39% Mo, so the application rate should be varied accordingly.)

MOLYBDENUM

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Nickel

Chemical symbol: Ni

Function in the plant:

Although nickel is present in most plants, it does not appear to act directly as a plant food. It does however play an important part in several metabolic processes. For instance, nickel is an essential component of the urease enzyme system, so that it can affect uptake and movement of nitrogen within the plant. It also seems to be required by leguminous crops, as an essential part of the nitrogen synthesis process. There are many other processes within the plant in which nickel appears to be involved, and this is now the subject of much research.

Effect on crops:

Whilst the fundamental processes are not yet fully understood, there have been many experiments which demonstrate that the rate of seed germination (for instance in peas, beans, wheat, castor beans, white lupins, rice, and soybeans) is stimulated by treatment with low concentrations of soluble nickel compounds. What is more, seedlings developing after nickel pre-treatment showed enhanced growth rates compared with untreated plants.

Significant increases in crop yields have been reported in the case of wheat, potato, and broad beans, following the application of foliar sprays containing nickel. Pre-treatment of potato tubers with very low concentrations of soluble nickel compounds has produced significant yield increases. Tomato yields have been increased by soil applications of nickel, and grape quality has been enhanced by nickel sprays. Increases in soybean yield have been noted following seed pre-treatment with nickel. Similarly, the yield of cotton and of upland rice has been enhanced by nickel treatment. In experiments with nickel pre-sowing treatment, a 13-27% increase in wheat yield has been reported, and a 26% increase in soybean yield, following nickel application to the soil at the rate of 25 g/ha.

Deficiency symptoms:

A deficiency of nickel will not show up as chlorosis in the same way as other trace element deficiencies. It will appear indirectly in the form of nitrogen deficiency and reduction in crop yield. Excess of nickel can result in symptoms similar to those caused by a deficiency of iron or manganese.

Deficiency-prone soils:

Acid conditions (below pH 5.6) favour nickel uptake by plants. The element is in an unavailable form in alkaline soils, or in most soils after liming. The remedy in such cases is to apply nickel in chelate form. Soil organic matter content affects nickel uptake: the greater the organic content, the less the proportion of available nickel in the soil. Applications of NPK fertilisers reduce the availability of nickel in the soil, but they enhance the mobility of any nickel contained within the plant. Thus, fertiliser applications can assist the movement of nickel from roots to stems and leaves.

Inter-relationship with other substances:

Nickel availability is reduced by liming, and by high levels of phosphate.

Effects of excess:

Nickel is required only in minute quantities. In excess, the element is highly phytotoxic.

NICKEL

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Zinc

Chemical symbol: Zn

Function in plants

Zinc acts as a catalyst in the processes of oxidation in plant cells, and is vital for the transformation of carbohydrates. It regulates the consumption of sugars, which provide energy for the production of chlorophyll. It plays a part in the formation of growth-promoting compounds within the plant, and it aids the absorption of adequate amounts of moisture. Zinc is a constituent of several enzymes, e.g., carbonic anhydrase, of importance for photosynthesis, as well as enzymes which transform organic acids.

Function in animals

Zinc is relatively non-toxic to animals. Without it, all animals — including humans — cannot live. As in plants, several enzymes contain zinc. These control the movement of carbon dioxide, and the breakdown of proteins.

A dairy cow weighing 1100 lbs and yielding about 3 gallons of milk needs about 50 ppm of zinc in its diet. Experiments have shown that this is most effective when the intake is from pastures or fodder crops.

Zn deficiency in animals usually shows up as retarded growth, bone and joint disorders, skin diseases, disorders in feathers and hair, delayed sexual maturity, sterility, and even death. The disease in pigs known as "parakeratosis" is due to zinc deficiency.

In calves, symptoms are inflammation of nose and mouth tissues, loss of weight, some swelling of hind feet, and hard, dry skin on the body and head.

Symptoms in chickens and turkeys include brittle feathers and bones, difficulty in walking, retarded growth, scaly skin, delayed maturity, poor egg hatchability, and lowered egg laying.

Deficiency symptoms

Unlike many other nutrients, Zn does not move from old to new tissues, and therefore zinc chlorosis, dieback, and other deficiency symptoms tend to appear in *new growth*. The most common symptoms are yellowing or chlorosis of the leaves and leaf mottling, or change of leaf shape and much diminished size.

In cereals, especially maize, zinc deficiency generally shows up in the early stages of growth, when the plant is only a few inches high, appearing first as yellow streaks in the young leaves with a white to yellowish tip. White spots often appear in the leaves or along the edges, and a portion of the marginal area may die. Frequently the entire plant is stunted, due to shortening of the internodes.

In beans, the symptoms are similar to those in maize, and the lower older leaves and flower buds become brown and drop off. Often the plant dies prematurely.

In citrus, the leaves show irregular, yellowish areas between the veins, and as new foliage develops, it becomes progressively smaller (*"little leaf" disease*). Twigs die back and fruit quality and quantity is reduced.

In peaches, leaf symptoms are similar to those in citrus. In severe cases rosetting occurs, leaves die and drop off, young twigs die back for several inches, and the fruit is misshapen and reduced in quantity and quality.

In pecans a typical symptom is a brownish or bronze appearance in the tree when seen from a distance. The nuts are small and poorly filled, and the yield is reduced.

In tung trees, bronzing of the foliage is typical. There may also be chlorotic mottling of the leaves on affected branches and rosetting of the leaves at the shoot tips.

In cotton, the interveinal areas of the leaves become chlorotic at first. Later the leaves are bronzed and brittle, leaf margins turn upwards, and most of the affected leaves die. Growth and cropping are delayed.

The yield of many crops can be depressed by nutrient deficiencies without exhibiting any visual symptoms, and this applies especially in the case of zinc. In the absence of leaf analysis, a test application of *zinc chelate* to a few representative plants can often produce a beneficial response that is quite surprising.

Crops which are particularly susceptible to Zn deficiency are cereals, especially maize, and fruit trees, especially citrus and peaches. When there is insufficient zinc, all these crops usually show symptoms in soils where other crops appear to grow normally.

Sensitivity to zinc deficiency is also found in apples, cotton, sorghum, beans, onions, and tomatoes.

In citrus crops, first signs of zinc deficiency are some leaves showing typical symptoms of interveinal chlorosis known as *"mottle-leaf"* or *"frenching"*, long before further symptoms appear.

In fruit trees, leaves often show rosette terminal growth.

Terminal growth is affected in most plants, with reduction in stem length and rosetting or whorling of leaves.

In cereals, there is a white striping or banding on the lower half of the leaves.

Deficiency-prone soils

Zinc is present in nearly all soils in minute quantities, which theoretically, should be sufficient to satisfy the needs of most crops. However certain soil conditions reduce its availability as a plant nutrient.

This element may be unavailable in organic soils, e.g., peat soils, but it is seldom deficient in well-worked farm land where there has been adequate NPK fertiliser treatment, and a long history of crop rotations.

Zn is also leached from acid sands and from soils derived from granite, and can also be unavailable in clay soils with low silicon and magnesium. Zinc is often deficient in high phosphate soils and in alkaline conditions, especially in shell-sands.

Zinc does not move appreciably in the soil. This results in "positional unavailability". This is less of a disadvantage in *zinc chelate* than in other forms of zinc, but even the chelate should be ploughed or cultivated in, to place it as near as possible to the plant roots. For fruit trees, this can be done by soil injection.

Zn deficiency often occurs in parts of recently levelled land.

Inter-relationships with other substances

Zinc deficiency can be brought on by heavy liming or by heavy applications or prolonged use of phosphate fertilisers. However the effect of phosphates varies widely with different crops and different soils.

Where there is a tendency to Zn deficiency, moderate to heavy applications of nitrogenous fertilisers have been shown to increase the severity of zinc deficiency. On the other hand, if there is insufficient soil nitrogen, uptake of zinc can be reduced.

Uptake of Zn is *aided* by potassium, but only when there is a low concentration of phosphates.

Applications of zinc can cause iron deficiency, and phosphate applications can accentuate both iron and zinc deficiencies. The remedy is to apply iron at the same time, in the proportion of 4:1 of 'Librel Fe-Hi' and 'Librel Zn'

Excess Zn can exist in some acid peats, in land contaminated by zinc from mining operations, and in soils derived from rocks which contain zinc ore. In such cases the damage can range from unsuspected retardation of growth to severe damage or death of the plant. Zinc toxicity can be caused by using sewage sludge which is often high in zinc and copper.

Applying molybdenum may reduce Zn *toxicity*, but this should be done in moderation, to avoid risk of molybdenum toxicity. For this reason it may not therefore be of much practical value. Careful liming may be helpful, but can induce other minor element deficiencies.

Seasonal and weather influences

Uptake of zinc is reduced by prolonged cold periods, especially during the earlier stages of plant growth, hence uptake is lower in cold climates.

Marginal Zn deficiencies in acid sands and other easily-leached soils can be aggravated by prolonged periods of heavy rainfall. Hence zinc deficiency often occurs in such soils in heavy rainfall areas.

Effects of excess

Excess zinc can cause harm through interfering with the uptake of other essential nutrients, especially phosphorus, iron and copper.

Signs of moderate to severe *excess* of zinc is abnormally prolific growth of ragweed, with stunting of all other vegetation.

Excess Zn in soil can often be corrected by fairly heavy liming, but this may aggravate other deficiencies.

Of all the zinc compounds that are available on the market, the *chelate* form (e.g., 'Librel Zn') is the *safest,* especially in the case of an accidental overdose, when there is much less risk of leaf scorch or root damage. Zn chelate also gives the most effective control of zinc deficiency, and is more economic because of the relatively small amount required.

There is a "see-saw" effect between zinc and copper. Soil applications of Zn often induce or aggravate Cu deficiency and vise versa. Where this exists, the remedy is to apply both 'Librel Cu' and 'Librel Zn' in the proportion 2:1.

General remarks

In cases of mild or moderate deficiency, grassing down orchards with alfalfa appears to overcome the problem. As there is very little movement of zinc within the soil, it has been suggested that alfalfa roots might bring zinc to the soil surface, making it soluble and helping other plants to obtain it . The precise mechanism however is not understood.

ZINC

The following references may be helpful to readers who wish to study the subject in greater depth.

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For easy reference, much of the information in this booklet is summarised in tabular form in the following pages.

Table 1

SOIL TYPES AND THEIR EFFECTS

Key
D — deficiency
T — toxicity

	Fe	Mn	Cu	Zn	B	Mo	Co
CALCAREOUS SOILS. 1. Chalks especially lower chalk, poorly drained	DD	D			DD		
2. Calcareous sands (coastal and geological shell sands)	D	DD	DD	DD			D
3. Organic soils, peats, fens heavily manured		D	D			T	D
especially with fluctuating water table		DD	DD				
or overlying calcareous strata or pH above 6.5		DD	D	D			
4. Clays especially with alternate wetting and drying		D			DD		
5. Compacted or heavily phosphate dressed	D			D			
6. Magnesian limestones	D						
7. Calcareous like conditions produced by local or general overliming on acid peats		DD	D		D		
On marls, poorly drained clays, acid sands	DD	DD	DD	D	DD		
8. Recently broken up old pastures on chalk		DD					
9. Calcareous soils low in potassium	D						
10. Acidification on some alkaline soils					T		
BICARBONATE SOILS. Saline bicarbonate soils (certain areas)	D		T		D		
Saline — alkali soils					D		
SANDY SOILS Calcareous — see Calcareous Soils							
Inland, heavily leached and not subject to deposits of cyclic salt			D		D		
Acid leached sands ⋆ Mn can be deficient or in excess	D	D&T ⋆	D		D		D
GRANITES				D	D		D

VOLCANIC SOILS ★ B may be high in basaltic larvas and basic igneous rocks			T		T ★		
METALLIFEROUS SOILS Acid manganiferous soils (Hawaii, Puerto Rico)	DD	TTT					
Mine outcrops, residues, veins			TT	TT			
Serpentine soils Excess also of Cr, Ni, Mg		TT				D	
ACID SOILS Clays		TT				D	
Peats ★ Isolated instances of Zn excess in acid peats		TT	D	T ★	D		D
Sands and ironstone soils		TT	D	D	D	D	D
Some deficiencies may remain masked until soils are limed or fertilized.		D	D	D	D		
APPARENTLY NORMAL SOILS Excessive nitrogenous fertilizer			D		D		
Poorly drained	D						
Highly aerated		D					
Chronic fluctuating water table or frequent wetting and drying		D			D		
Heavily manured and limed land		DD	D				
Excessive phosphate manuring or old cattle corrals				D			
Magnesian limestones low in silica				D			
Acidified by ammonium sulphate or sulphur		T				D	
Use of leather wastes (Cr excess) or industrial sewage sludges (excess of Co, Ni, Zn, Cu, Cr, Cd, V etc.)			T	T			T

Table 2

INTERACTIONS BETWEEN ELEMENTS

● — Interaction exists

	Fe	Mn	Cu	Zn	B	Mo	Co
Excess Mn induces Fe deficiency especially in pineapple, beans, beet, cape gooseberries	●	●					
Manganese excess may accentuate Mo deficiency. Relative Mn excess Mo deficiency may reflect change in organic content		●				●	
Mo uptake may be stimulated by Co						●	●
Excess Cu induces Fe deficiency	●		●				
Excess Zn induces Fe deficiency but Fe content may be higher than normal	●			●			
Excess Co induces Fe deficiency; Cr, Ni, Cd, V also induce Fe deficiency	●						●
Mo may accentuate Fe deficiency induced by Cu, Mn, Zn, Co (also Ni. Cd, Cr)	●					●	
Sulphate antagonizes Mo uptake						●	
Phosphate assists Mo uptake						●	
Liming, which raises pH, assists Mo uptake						●	
Fe deficiency may be induced by low K (maize, apple, potato) especially with high PO_4	●						
Calcium in ionic form antagonizes Mn uptake		●					
Liming which raises pH decreases uptake of Fe, Mn, Zn, Cu, B, Co	●	●	●	●	●		●
Cu deficiency in animals is accentuated by Mo			●			●	
Cu deficiency may be accentuated by high N			●				
Zn deficiency may be accentuated by high P				●			
B deficiency may be accentuated by high N					●		
Mo deficiency may be masked by ammonium N						●	
Zn deficiency may be associated with Mg deficiency (citrus)				●			
Fe and Mn deficiencies may occur simultaneously in calcareous soils or limed acid sands	●	●					

Sulphur (elemental) accentuates Mn uptake as a result of acidification		●					
Co may antagonize or mask effects of Mn excess		●					●
Bicarbonate may antagonise Fe uptake or function	●						
Repeated applications of Fe to the soil of deficient trees may induce Mn deficiency	●	●					
Mn and Cu deficiencies may occur together, especially on organic soils overlying chalk.		●	●				

Table 3

CROP REQUIREMENTS

D — Sensitive to a deficiency
T — Sensitive to an excess
O — Relatively insensitive to a deficiency
● — Indicator plant
NB A blank space denotes a lack of information

	Fe	Mn	Cu	Zn	B	Mo	Co
CEREALS							
Barley		D ●	D	D/T	O	O	O
Maize	D ●	D	D/T	D ●	O		O
Oats	D ●	D ●	D ●	D/T	O		O
Wheat	D ●	D	D ●		O	O	O
GENERAL							
Broadbean		D/T	O/T	O	D	O	O
Broccoli, cabbage, cauliflower	D	D/T ●			D	D ●	O
Carrots	D	D	D		D		O
Celery	D	D	D		D ●		O
French beans, dwarf	D ●	D/T ●	O	O	D	O	O
Lettuce		D	D		D ●	D ●	O
Peas		D ●	D	D		O	O
Potato	D	D●/T		D	D/T		O
Radish					D	D	
Spinach	D	D	T		D	D ●	O
Swede, turnip	D	D/T			D ●	D	O
Sugar beet	D ●	D ●	D	T	D ●	D	O
Tomato	D ●	D ●	D	D	D/T	D ●	
FRUIT							
Apple	D ●	D ●	D ●	D ●	D ●	O	O

Apricot, peach	D	D	D	D ●	D/T		O
Avacado	D	D	D ●		D/T		
Citrus	D	D	D ●	D ●	D	D ●	O
Grape	D	D			D ●		O
Olive		D	D		D		
Pear	D	D ●	D		D ●	O	O
Pineapple	D	T					O
Plum	D ●	D	D			D	O
Raspberry	D	D			D		O
Redcurrant			D		D		
Strawberry	D ●	D			D		O
LEGUMES							
Nodulated herbage legumes	D	D	D	D	D/T	D	D
Herbage legumes generally	D	D ●	D ●	D ●	D●/T	D	O
MISCELLANEOUS							
Coffee				D	D		
Cotton		D		D	D		
Pecan				D ●			O
Sunflower			D		D ●		
Tea		D					O
Tung	D	D	D ●	D			O
Alfalfa (lucerne)		D	D/T	D	D ●	D	
Clover (■ red) (* white)		O■*	D■/T*		D■*	O■*	
Onion		D	D	D	D		O
Tobacco	D	D/T	D		D		

Conversion tables

WEIGHT	
To convert —	**Multiply by**
Ounces to grams	28.350
Grams to ounces	0.035
Pounds to kilograms	0.454
Kilograms to pounds	2.205
Cwts. to kilograms	50.802
Kilograms to cwts.	0.020
UK tons to metric tons (tonnes)	1.016
Metric tons (tonnes) to UK tons	0.984
VOLUME	
Cubic inches to cubic centimetres	16.387
Cubic centimetres to cubic inches	0.061
Cubic feet to cubic metres	0.028
Cubic metres to cubic feet	35.315
Cubic yards to cubic metres	0.765
Cubic metres to cubic yards	1.308
LIQUID MEASURE	
Pints to litres	0.568
Litres to pints	1.760
Imperial gallons to litres	4.546
Litres to imperial gallons	0.220
US gallons to litres	3.785
Litres to US gallons	0.264
Imperial gallons to US gallons	1.201
US gallons to Imperial gallons	0.833
LENGTH	
Inches to millimetres	25.400
Millimetres to inches	0.039
Inches to centimetres	2.540
Centimetres to inches	0.394
Feet to metres	0.305
Metres to feet	3.281

LENGTH (continued)

To convert —	Multiply by
Yards to metres	0.914
Metres to yards	1.094
Miles to kilometres	1.609
Kilometres to miles	0.622

AREA

Square inches to square centimetres	6.452
Square centimetres to square inches	0.155
Square feet to square metres	0.093
Square metres to square feet	10.764
Square yards to square metres	0.836
Square metres to square yards	1.196
Acres to hectares	0.405
Hectares to acres	2.471
Square miles to square kilometres	2.590
Square kilometres to square miles	0.386

PRESSURE

Pounds per sq. inch to kg per sq. cm.	0.070
Kg per sq. cm. to pounds per sq. inch	14.223

PROPORTIONS

Ounces per gallon to grams per litre	6.237
Grams per litre to ounces per gallon	0.160
Pounds per acre to kg per hectare	1.121
Kilograms per hectare to lbs per acre	0.892

(For day-to-day practical purposes, 1 lb per acre can be regarded as roughly equivalent to 1 kg per ha.)

Percentage (%) to parts per million (ppm)	10000.00
Parts per million (ppm) to percentage (%)	0.0001

(move decimal point 4 places)

Parts per million equals mg/L

TEMPERATURE

Fahrenheit to Celsius	Subtract 32 and multiply by 0.556
Celsius to Fahrenheit	Multiply by 1.8 and add 32

Quick mental conversion for domestic purposes, etc (not absolutely accurate except at 10°C (=50°F):—

Fahrenheit to Celsius	Subtract 30 and divide by 2
Celsius to Fahrenheit	Multiply by 2 and add 30

DENSITY

1 gallon of water weighs	10 lbs (at 20°C)
1 litre of water weighs	1 kg (at 20°C)

Statistical Definitions

To convert —	Multiply by
Phosphorus pentoxide (P_2O_5) to phosphorus (P)	0.436
Phosphorus (P) to phosphorus pentoxide (P_2O_5)	2.29
Potassium oxide (K_2O) to potassium (K)	0.83
Potassium (K) to potassium oxide (K_2O)	1.20
Magnesium oxide (MgO) to magnesium (Mg)	0.60
Magnesium (Mg) to magnesium oxide (MgO)	1.67

Weight/volume examples:

0.10% w/v = 1g/litre = 1 lb/100 gals.

Metric ton (tonne) = 1000 kg = 2204.6 lbs
Long ton (UK ton) = 20 cwts = 2240 lbs
Short ton (USA) = 2000 lbs