DIAGNOSIS AND CORRECTION OF NUTRITIONAL DISORDERS IN GINGER

(Zingiber officinale)

by

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1975

Contents

Preface

The ginger research programme of the University of Queensland is relatively recent, the first studies having commenced in 1969. As little was known about the mineral nutrition of the crop at that time, it was decided to concentrate initially on the description of visible symptoms of various nutritional disorders so that these could be recognized in the field and appropriate corrective action taken. This booklet describes for the benefit of growers the main results obtained from those early studies.

Although in this booklet we have suggested ways in which particular nutritional disorders may be corrected, little reliable information is available in this area for ginger and we have had to rely heavily on both local and overseas experience with other crops. In addition, the best way of correcting a particular nutritional disorder will often by strongly influenced by the soil type, pH, and previous cropping history of the paddock. Hence the same treatment will not always be equally effective when applied in different situations. Consequently, growers are strongly urged to discuss their crop nutrition problems with an officer of the Queensland Department of Primary Industries before departing from their usual programme of fertiliser application.*

The studies described in this booklet and the publication of the booklet itself were made possible by the generous financial support of the University of Queensland, the Buderim Ginger Growers Cooperative Association Ltd, the Commonwealth Development Bank of Australia, and the Australian and New Zealand Banking Group Limited. In addition, much valuable advice and assistance were received from many people associated in one way or another with the industry. In this connection the authors are particularly grateful to Mr G. S. Shrapnel and Mr H. C. Ham of the Buderim Ginger Growers Cooperative Association and to Mr W. V. Mungomery and Mr A. W. Whiley of the Horticulture Branch of the Queensland Department of Primary Industries.

Special thanks are due also to Mr J. Barry of Beerwah for the use of his land and for help in the running of field experiments in the 1970–71 and 1971–72 growing seasons, and to the many other ginger growers throughout the Industry who have assisted by permitting us to locate test plots on their properties and to remove soil and plant material needed for experimental purposes. The authors are indebted also to Professor E. J. Britten of the Department of Agriculture, University of Queensland for his advice, encouragement and continuing support of the project since the time of its inception.

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* Attention of growers is drawn also to information prepared by officers of the Queensland Department of Primary Industries in the October 1972 and November 1974 issues of the Queensland Agricultural Journal.

Introduction

For ginger crops to make vigorous, healthy growth and produce high rhizome yields, the plants must be able to obtain adequate amounts of the following mineral elements: nitrogen, potassium, calcium, magnesium, phosphorus, sulphur, chlorine, iron, boron, manganese, zinc, copper and molybdenum. The first six of these elements are needed in relatively large amounts and are therefore referred to as major elements or macronutrients. The remaining elements are needed in much smaller amounts and are known as trace elements or micronutrients. Correction of major element deficiencies usually accounts for the major fertilizer cost because of the large amounts of these elements required. However, from the point of view of possible yield reductions due to nutrient deficiencies, the trace elements are just as important as the major elements and deserve equal attention.

Many of the above elements are toxic to plants when supplied in amounts far in excess of the crop requirement. Hence, when applying fertilizers it should be our aim to supply the smallest amount of each element that, together with what is already available from the soil, will just satisfy the needs of the crop. Since soils differ greatly both in nutrient content and in their capacity to react with and render fertilizer materials unavailable to plants, the amounts of particular nutrient elements which need to be added for best results often vary substantially from soil to soil. Hence only general guidelines for fertilizer application can be given here.

When crop growth is being reduced by a deficiency or a toxic excess of a mineral nutrient, a characteristic set of leaf symptoms is often produced, and these can be valuable in identifying the cause of the trouble. The main purpose of this booklet is to help growers to recognize such deficiency and toxicity symptoms when these occur in their crops. However, a word of caution is necessary here, since diagnosis based solely on leaf symptoms can sometimes be in error, particularly where the problem involves more than one mineral element. Consequently, it is always wise to seek professional advice when a nutritional problem is encountered, and if possible to have the original diagnosis checked by plant analysis. Unfortunately, accurate critical concentrations for most mineral elements (the lowest concentrations in the plant tissue that will lead to maximum or near-maximum yields) are not yet available for ginger, but enough information is available in many cases for plant analysis to be a useful aid to diagnosis.

In most crops, symptoms can be classified conveniently into those which occur mainly on the upper (younger) leaves and those which occur mainly on the lower (older) leaves. The former are usually due to deficiencies of elements such as calcium, boron and iron which are not very mobile in the plant tissues and hence cannot move from the older to the younger parts of the plant under deficiency conditions. Symptoms on the older leaves are usually due to either deficiencies of mobile elements such as nitrogen, potassium or magnesium which move out of the older leaves under deficiency conditions, or to toxicities.

While this method of classifying symptoms is useful for ginger also, the pattern of symptom development is less clear cut than for many other crops. In this regard the behaviour of nitrogen is most unusual, the symptoms quite commonly occurring on the younger growth. Since nitrogen is an extremely important element in commercial ginger production, and its pattern of symptom development appears more variable than that of the other essential elements, this element will be dealt with first.

Disorders producing symptoms on leaves of any age

NITROGEN DEFICIENCY

(a) Symptoms

Nitrogen deficient ginger plants are a paler green than normal and may be quite yellow in the case of severe deficiency. When nitrogen deficiency develops gradually, the redistribution of nitrogen from older to younger tissues will cause the leaf yellowing (chlorosis) to be most pronounced on the lower leaves. However, when the onset of the deficiency is rapid (for example when heavy rains leach out most of the plant-available nitrogen from the soil at a time when the crop is growing rapidly) the redistribution of nitrogen may not be rapid enough to keep the young actively growing tissues healthy, so that the uppermost leaves show severe deficiency symptoms.

Plate 1a shows a young nitrogen-deficient ginger plant in which the most severe leaf yellowing is on the youngest leaf. Unlike many other nutritional disorders, with nitrogen deficiency, the whole leaf including the veins tends to be the same colour (however, see also Sulphur Deficiency on page 17). Plate 1b shows the effects of varying degrees of nitrogen deficiency on the appearance of ginger plots at Beerwah in mid-February 1972.

Based on observations in the 1971–72 season, it appears that nitrogen deficiency is a common problem on commercial ginger properties, particularly in the latter part of the growing season when the rhizomes are increasing rapidly in weight. Thus on a sample of twelve properties, late harvest (early May) yields were increased significantly on seven properties by the application of an extra 112 kg nitrogen/ha in mid-February. In addition, yield increases were obtained on a similar number of properties with a "shotgun" mixture of other mineral nutrients, suggesting that increased attention should be paid to the nutrient requirements of the crop during the latter part of the season.

(b) Tissue Analysis

Several parts of the plant can be used for diagnostic nitrogen analysis. In most of our work we have used leaf samples because these can be taken quickly and easily, with a minimum of damage to the plant and hence with a minimum risk of subsequent attack by disease organisms. However the results obtained so far indicate that the period during which leaf samples can be used successfully for diagnosis of nitrogen deficiency is shorter than for some of the other tissues. Results obtained in the 1970–71 season are summarized in the following table.

Sampling date	Approx. concentration of total nitrogen needed for near-maximum yield of rhizomes (%)			
	Rhizomes	Whole shoots (pseudostem plus leaves)	3rd leaf from top of plant*	
			From Primary shoots only**	From shoots of any age
November 15th	2.8	3.1	—	—
December 1st	2.6	3.0	—	—
15th	2.4	2.8	—	—
January 1st	2.2	2.7	—	—
15th	2.1	2.5	—	—
February 1st	1.9	2.4	—	—
15th	1.8	2.2	—	3.7
March 1st	1.6	2.1	3.3	3.5
15th	1.5	2.0	3.0	3.3

* Excluding the cone of tightly rolled leaves at the very top *i.e.* counting the first full-opened leaf from the top of the plant as leaf 1.

** These values tested on commercial properties in the 1971–72 season and found to be satisfactory.

Notes on Nitrogen Fertilization

The various combinations of organic and inorganic fertilizers previously recommended provide widely differing amounts of nitrogen for the crop (125 to approx. 830 kg nitrogen/ha). Our calculations indicate that if all the nitrogen applied was taken up by the plants, for a heavy crop we would need about 250 to 350 kg nitrogen/ha. However, some losses of applied nitrogen are inevitable due to leaching, volatilization (especially with urea), and microbial incorporation into the soil organic matter (especially when low-nitrogen organic material such as sawdust has been incorporated into the soil). Leaching losses can be reduced substantially by dividing the total nitrogen to be applied into a number of dressings spread throughout the season. When this is done it should be possible to produce a heavy crop with 350 to 400 kg nitrogen/ha on light sandy soils and perhaps less on heavier soils on which the leaching problem tends to be less severe.

More research is needed on nitrogen fertilization, but in the meantime, we are suggesting the following approach:

At or slightly before planting, apply about 100 kg of plant-available nitrogen/ha in the form of an organic fertilizer such as poultry manure (10 tonnes/ha) or mill mud (20 x 6¼-tonne loads/ha*). This should provide sufficient nitrogen for the crop during the first 8 to 10 weeks from planting when growth is slow and the requirement for nitrogen (and other mineral nutrients) relatively small.

Ten to 12 weeks from planting, apply an inorganic nitrogen fertilizer at 40 to 50 kg nitrogen/ha (i.e. approx. 90–110 kg urea, *or* 110–140 kg "nitram" *or* 190–240 kg sulphate of ammonia), repeat in 3 weeks time and thereafter every 2 or 3 weeks depending on the condition of the crop, until about 24 or 25 weeks after planting.

As the colour of the crop is quite a good indicator of its nitrogen status, the timing of the nitrogen applications can be varied at the grower's discretion to maintain a healthy green colour. Sometimes, when very heavy rain occurs shortly after an application of nitrogen much of that application may be lost by leaching, and the crop will start to look yellow even though nitrogen was applied recently. In these circumstances a further nitrogen application may be made. However, care should be taken not to fertilize excessively with nitrogen as leaf burning and reduced yields may result (see following section on Physiological Leaf Scorch). Our experiments suggest no difference in the effectiveness of urea, "nitram" or sulphate of ammonia as nitrogen sources when applied as sidedressings and watered in. However, since sulphate of ammonia is substantially more expensive per unit of nitrogen than the other two fertilizers, and it causes more acidification of the soil, we suggest that sulphate of ammonia should not be used unless a grower wishes to lower the soil pH or to supply extra sulphur to his crop (see "Sulphur Deficiency", page 17).

A considerable saving in labour can be obtained by applying soluble nitrogen fertilizers to the crop by way of the irrigation water. Both home-made and commercially produced devices have been used successfully for this purpose. When using such devices, it is desirable to continue

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* This amount of mill mud contains much more than 100 kg nitrogen/ha but much of this nitrogen is not readily available for use by the crop.

irrigating for a short while after the nitrogen has been applied to each block to wash most of the fertilizer off the leaves, and to flush the fertilizer out of irrigation equipment.

PHYSIOLOGICAL LEAF SCORCH

In glasshouse experiments with ginger we have consistently observed scorching of the tips and margins of leaves of plants grown under full sunlight and with a high nitrogen supply. The cause of this condition, which we call "physiological leaf scorch", is not properly understood at present but out experiments indicate that its severity can be reduced by shading the plants, raising the humidity either by misting or by other means, and by lowering the nitrogen supply. The beneficial effects of shading and raising the humidity suggest that the problem may be related to the "sunburn" problem sometimes encountered under field conditions. If this proves correct, extra care not to overfertilize with nitrogen during periods of high sunburn risk may be advisable. While it is not certain that a high nitrogen supply does increase the risk of sunburn injury, it is known that application of fertilizer nitrogen to crops already high in nitrogen can lead to leaf burning (Plate 2) and in some cases to reduced yields. Hence, when deciding how much nitrogen to apply, the aim should be to provide sufficient to keep the crop growing vigorously and to maintain a healthy green colour in the leaves, but care should be taken not to add more nitrogen fertilizer than is necessary for these purposes.

Plate 1. Nitrogen deficiency. (a) Nitrogen deficient plant with chlorosis of youngest leaf. (b) Field plots in nitrogen fertilizer experiment at Beerwah. Paler coloured plots have received insufficient nitrogen for health growth.

Plate 2. Leaf scorch caused by applying 112 kg nitrogen/ha to a commercial crop that was already well supplied with nitrogen (Palmwoods, 1971-72 season).

Plate 3. Potassium deficiency. (a) Portion of plant suffering from severe potassium deficiency (note reddish-brown colours in older leaves, yellow mottling on leaf at upper right) (b) Close-up of healthy (left) and potassium deficient (right) ginger leaves.

Plate 4. Phosphorus deficiency. Note gradation of symptoms from old to young leaves.

Plate 5. Phosphorus toxicity. (a) Close-up of lower leaves of affected plant showing characteristic pattern of chlorosis (b) Shoot at left shows phosphorus toxicity. The two younger shoots (centre and right) show phosphorus-induced copper deficiency (see Plate 15 for simple copper deficiency).

1a

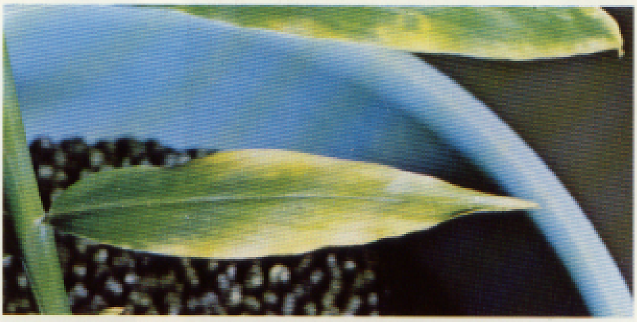
1b

2

3a

3b

5a



4

5b

6a

6b

7

8

9a

9b

Disorders producing their main symptoms on the older (lower) leaves

POTASSIUM DEFICIENCY

(a) Symptoms

In the early stages, the plants tend to be smaller and darker green than usual. As the deficiency becomes more severe the tips and margins of the lower leaves develop a yellowish-brown mottling and later die, the areas of dead tissue being irregular in shape (Plate 3b) and often showing patches of reddish-brown colour. Leaf surfaces are often crinkled and the leaf tips twisted (Plates 3a, 3b). Leaf margins may be turned either upwards or downwards. As the deficiency progresses, successively younger leaves become affected (Plate 3a). Sometimes when the plants are well grown before the deficiency first appears, the bottom one or two leaves may remain free of symptoms but apart from this the pattern of symptom development is unchanged.

(b) Tissue Analysis

No accurate critical value is available but in our experiments potassium deficient leaves have usually contained less than 1 per cent potassium while leaves from healthy plants have contained 3.8 per cent or more. Tentatively, it is suggested that a concentration of 3.0 to 3.5 per cent potassium in the younger leaves should be adequate.

Plate 6. Magnesium deficiency. (a) Young plant showing gradation of symptoms from old to young leaves. Note brown colour of dead leaf tip at lower left. (b) Close-up of older leaves. Note water-soaked patches on leaf nearest bottom of photograph.

Plate 7. Boron toxicity. Note chlorosis of margins of older leaves.

Plate 8. Manganese toxicity. Note brown tinges on chlorotic lower leaves, and retention of green colour each side of the midvein on leaves in the mid-section of the plant.

Plate 9. Calcium deficiency. (a) Chlorosis of an upper leaf of a calcium deficient plant. Note dead youngest leaf at far right (b) Group of calcium deficient plants in which young leaves have died while still rolled up inside the pseudostem *N.B.* Chlorosis of lower leaves in this picture is due to physiological leaf scorch (see page 8), not to calcium deficiency.

Notes on Potassium Fertilization

As with other "root" crops, ginger can be expected to remove large amounts of potassium from the soil (up to 500 kg/ha for a heavy crop). Earlier fertilizer recommendations provided for an annual addition of only 90–160 kg potassium/ha. These quantities are probably adequate for some of the potassium-rich red soils in the ginger growing area but not for the poorer sandy soils which have limited reserves of soil potassium.

Poultry manure and mill mud both contain substantial amounts of potassium (but blood and bone does not). Hence the amount of potassium fertilizer that has to be applied can be reduced somewhat if poultry manure or mill mud is applied at the beginning of the season (see also comments under "Nitrogen Deficiency," page 5).

The compound inorganic fertilizers currently recommended all contain some potassium. Where potassium deficiency is a problem it may be wise to change to a fertilizer with a higher potassium content. Alternatively, additional potassium can be applied as muriate of potash (potassium chloride). Since this fertilizer is readily soluble in water it can be surface-applied and watered in or applied in the irrigation water if so desired. As potassium is readily lost by leaching on sandy soils, it may be advantageous to split the total potassium application into a number of dressings throughout the season rather than apply it all at planting. Excess potassium does not appear to be toxic but trouble may be encountered with chloride injury if muriate of potash is applied at very high rates.

PHOSPHORUS DEFICIENCY

(a) Symptoms

As with potassium deficiency, the affected plants tend to be smaller and darker green in colour than healthy plants, and as the deficiency becomes more severe the tips and margins of the lower leaves become chlorotic and eventually die (Plate 4). However, the chlorotic areas are generally paler than with potassium deficiency, the boundaries of the chlorotic tissue are smooth rather than irregular, and leaf crinkling is less apparent. Boundaries of affected leaf areas tend to be fairly distinct.

(b) Tissue Analysis

No accurate critical value is available but in our experiments leaves of deficient plants have contained less than 0.15 per cent phosphorus while those of healthy plants have contained 0.2 to 0.4 per cent. Hence a concentration of about 0.2 per cent phosphorus appears adequate.

PHOSPHORUS TOXICITY

Excess phosphorus may adversely affect the growth of ginger either directly (phosphorus toxicity) or by immobilizing in the tissues elements such as copper, zinc or iron that form insoluble phosphates (phosphorus-induced deficiencies).

(a) Symptoms

As with most other toxicities, phosphorus toxicity tends to appear first on the lower leaves, the tips and margins of these leaves becoming chlorotic and eventually dying. The chlorotic areas often contain bright yellow spots or patches and have a rather diffuse edge (Plate 5a).

With phosphorus-induced trace element deficiencies we would expect to find symptoms similar to the usual deficiency symptoms for the particular trace element involved. So far, the only such deficiency we have observed is phosphorus-induced copper deficiency (Plate 5b), but other phosphorus-induced deficiencies may occur also.

(b) Tissue Analysis

In our experiments leaves containing more than 1 per cent phosphorus have usually showed symptoms of phosphorus toxicity. For safety, leaf values should be kept below 0.8 per cent phosphorus. In the case of phosphorus-induced deficiencies, phosphorus levels can be expected to be high but the concentration of the deficient element may not be low, since the element may be precipitated in the tissues in the form of insoluble phosphate compounds.

Notes on Phosphorus Fertilization

Soils differ greatly in the extent to which they "fix" applied phosphorus in forms unavailable or only slowly available to plants. Consequently, the amounts of phosphorus fertilizer needed will vary greatly from soil to soil. Earlier recommendations corresponded to an annual application of from 240 to 250 kg phosphorus/ha, whereas a heavy crop is likely to remove only 35 to 50 kg phosphorus/ha. On soils of high phosphorus fixing capacity (e.g. some red soils), high rates of phosphorus application may be necessary, particularly if the soils have not previously received large amounts of phosphatic fertilizer. However, on the lighter textured soils, some of which have very little capacity to fix phosphate, and perhaps also on some of the older ginger soils which have already received large amounts of phosphate, the present high rates of phosphorus fertilizer application appear unnecessary and could in some cases be detrimental to crop growth. Until data are available from fertilizer trials on each soil type, no firm recommendations can be made, but we believe that growers on the lighter soils could safely reduce their rates of phosphorus application to 50 per cent or less of the previously recommended levels. The use of poultry manure as an organic nitrogen source in preference to blood and bone will lead to substantial reductions in the amount of phosphorus applied on many properties since poultry manure is relatively low in phosphorus. On the lighter soils, use of compound fertilizers lower in phosphorus and higher in potassium than those previously recommended could be an advantage also (see earlier comments under "Potassium Deficiency" page 11).

MAGNESIUM DEFICIENCY

(a) Symptoms

The most striking symptom of magnesium deficiency is a bright yellow to white chlorosis of the leaves, the lower leaves being affected first and showing the most severe symptoms (Plate 6a). The symptoms commence at the leaf tip and work back towards the leaf base, the edge of the chlorotic area being even less distinct than for phosphorus toxicity (Plate 6b). Severely affected leaves may develop irregular watersoaked areas which later die (Plate 6b). Dead tissues are usually brown in colour (Plate 6a).

(b) Tissue Analysis

No reliable critical values are available. However, we have found concentrations of less than 0.1 per cent magnesium in leaves of affected plants and concentrations of 0.5 to 0.8 per cent magnesium in healthy plants. The magnesium content of upper leaves tends to be higher than that of lower leaves.

Notes on Magnesium Fertilization

As far as we are aware, magnesium deficiency has not been observed in ginger crops in Queensland, although magnesium deficiencies of other species have been reported from various parts of the Queensland coast, including the Beerwah area. Where dolomite is used as a liming material, magnesium deficiency would appear unlikely. If a deficiency should occur, we suggest the application of magnesium sulphate (heptahydrate) at 200 to 400 kg/ha. As this material is readily soluble in water, it may be applied as a side dressing and watered in if desired.

BORON TOXICITY

(a) Symptoms

Boron toxicity causes chlorosis and eventual death of the margins and tips of the lower leaves. The chlorotic area is usually a light colour and patches of it are often pure white (Plate 7). However, after death the tissue may turn brown.

(b) Tissue analysis

In healthy plants we have found concentrations of 80–110 ppm boron in the upper leaves and 150 to 200 ppm in lower leaves. In affected plants upper leaves having no symptoms contained 270 to 350 ppm boron while lower leaves with well developed symptoms contained 600 to 930 ppm.
N.B. As far as we know there are no naturally occurring boron-toxic soils in Australia. Hence, any problems of boron toxicity that do occur are likely to be man-made (see also "Boron Deficiency," page 23).

MANGANESE TOXICITY

An excessive supply of manganese can adversely affect the growth of ginger either directly (manganese toxicity) or by interfering with the iron nutrition of the plant (manganese-induced iron deficiency). The latter condition is discussed under "Iron Deficiency" on page 18.

(a) Symptoms

The older leaves become chlorotic at the tips and along the margins, and the affected tissue eventually dies. The dead tissue is usually brown and the chlorotic tissue may have streaks and patches of brown colour also. Usually, the midvein and a narrow strip of tissue each side of it remains green for some time after the remainder of the leaf has become chlorotic (Plate 8).

(b) Tissue Analysis

Ginger plants often contain higher concentrations of manganese than would be considered normal for other plants, and very high concentrations are associated with manganese toxicity. Thus in apparently healthy plants we have measured concentrations of 125 to 250 ppm manganese in upper leaves and up to 820 ppm in lower leaves, while in plants suffering from severe toxicity affected leaves have had concentrations as high as 9500 to 9900 ppm. Whenever leaf samples contain 1000 ppm or more of the element, manganese toxicity should be suspected.

Control of Manganese Toxicity

The chemistry of soil manganese is very complex, but the two main factors controlling availability to plants are drainage and soil pH. Under waterlogging conditions, normally-insoluble higher oxides of manganese are converted to a solube form and toxic levels may be reached in the soil solution. Hence good drainage is important in preventing manganese toxicity on soils of high manganese content.

Most, but not all manganese toxic soils, are strongly acidic, the availability of the element being much higher under acid conditions than in the region of neutrality (pH 6 to 7). Hence manganese toxicity can often be corrected by liming. However, since liming also reduces the availability of iron, copper and zinc, excessive use of lime can cause deficiencies of these other trace elements. Hence the aim should be to use the smallest amount of lime that will just bring the problem under control.

Disorders producing their main symptoms on the younger (upper) leaves

CALCIUM DEFICIENCY

(a) Symptoms

The first sign of calcium deficiency is usually the appearance of numerous small, irregular·chlorotic spots towards the tips and margins of the upper leaves. These spots coincide with depressions in the upper surface of the leaf. The tissue in the spots eventually dies and the spots may join together into larger areas of affected tissue (Plate 9a). Sometimes the shape of affected leaves becomes irregular. As the deficiency develops, young emerging leaves become more and more seriously affected and in extreme cases may shrivel and die before emerging from the pseudostem (Plates 9a, b). Roots of affected plants tend to be stunted and brownish in colour.

(b) Tissue Analysis

Since calcium is not readily remobilized to other tissues once it has been deposited in a tissue, it is possible to have large differences in calcium concentration between young and old leaves of the same plant. As the young tissues give the most up-to-date picture of the plant's calcium status it is these that should be analysed for diagnostic purposes.

In our experiments, upper leaves of calcium deficient plants have contained 0.05 to 0.07 per cent calcium while corresponding leaves of healthy plants have contained 1.1 to 1.3 per cent.

Notes on Calcium Fertilization

Calcium deficiency of ginger is extremely unlikely to occur as a field problem in Queensland because of the relatively large amounts of calcium added to the soil in agricultural lime, superphosphate, compound inorganic fertilizers based on superphosphate, and organic fertilizers.

SULPHUR DEFICIENCY

(a) Symptoms

Sulphur deficiency leads to chlorosis of the upper leaves. As with nitrogen deficiency, there is a simultaneous loss of green colour from both the veins and the areas between the veins (Plate 10). The disorder is easily confused with nitrogen deficiency when the latter occurs on the younger leaves. However, with sulphur deficiency the affected leaves are usually paler in colour than nitrogen deficient leaves and may be almost white in the case of a severe deficiency.

(b) Tissue Analysis

No critical values are available but in our experiments chlorotic upper leaves have contained 0.09 to 0.11 per cent sulphur while the corresponding leaves on healthy plants have contained 0.35 to 0.40 per cent. Plants with 0.2 per cent sulphur or more in the leaves are probably adequately supplied.

Notes on Sulphur Fertilization

The amounts of sulphur needed by the crop are roughly the same as the amounts of phosphorus i.e. about 20 to 40 kg/ha. Existing fertilizer recommendations appear to provide considerably more sulphur than the crop would require even allowing for the fact that sulphur is much more easily lost from the soil by leaching than is phosphorus. However, sulphur deficiency of ginger could become a problem in the future as a result of the general trend towards the use of fertilizers of lower sulphur content (e.g. from ammonium sulphate to "nitram" or urea which contain no sulphur, and from mixed fertilizers based on superphosphate to high analysis fertilizers which often contain very little sulphur).

Many different sulphur-containing fertilizers can be used effectively to supply additional sulphur to the crop should this be required. Consequently, the selection of a sulphur source will depend mainly on price per unit of sulphur and convenience to the grower. The cheapest source of sulphur at present is dump gypsum. However, the physical condition of this material necessitates the use of special spreading equipment. The next cheapest source is sulphur fortified superphosphate. Ordinary superphosphate is a relatively expensive source of additional sulphur.

IRON DEFICIENCY

Most soils contain large amounts of iron relative to crop needs. Hence iron deficiency usually arises from either low availability of the soil iron (simple iron deficiency), or from the presence of an excess of another element such as manganese or phosphorus which interferes with iron nutrition (induced iron deficiency). So far the only induced iron deficiency we have observed in ginger is manganese-induced iron deficiency.

(a) Symptoms

The first symptoms are a paling of the tissue between the veins of the upper leaves giving these leaves a distinctive striped appearance (Plate 11a). As the disorder becomes more severe, the areas between the veins lose their green colour, the veins remaining green for a time but eventually becoming chlorotic also. With severely affected plants the upper leaves may be almost white (Plate 11b) and may resemble those of sulphur deficient plants.

Plate 10. Sulphur deficiency. Note general chlorosis of upper leaves.

Plate 11. Iron deficiency. (a) Mildly deficient plant with charactertistic striped appearance of leaves due to retention of green colour along the veins (b) Severe iron deficiency. Note almost complete loss of colour from upper leaves.

Plate 12. Manganese deficiency. Note retention of green colour towards the tips of the affected leaves.

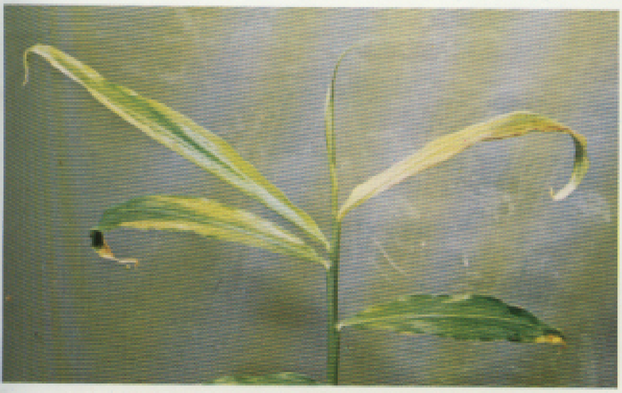
Plate 13. Boron deficiency. (a) Boron deficient plant showing reduced distance between leaves towards the top of the pseudostems (b) Young boron deficient plant showing characteristic transparent spots on the top leaf.

10

11a

11b

12



13a

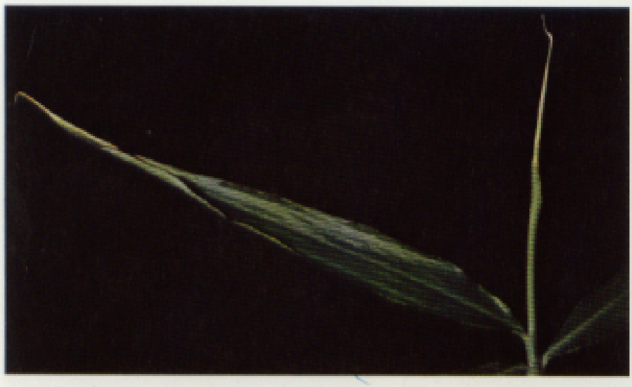
13b

14a

14b

15b

15a



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15c

(b) Tissue Analysis

Diagnosis of iron deficiency by plant analysis tends to be rather unreliable particularly if the iron supply has varied a good deal during the growing season. However in glasshouse experiments we have found 13 to 36 ppm iron in the upper leaves of iron deficient plants compared with 100 to 160 ppm in the corresponding leaves of healthy plants.

In the case of plants suffering from manganese-induced iron deficiency however, the chlorotic leaves may contain iron concentrations similar to those in healthy plants (110 to 140 ppm in glasshouse experiments) suggesting that excess manganese interferes with iron utilization in the tissues. The manganese content of the same leaves was 9500 ppm (see also "Manganese Toxicity", page 15).

Notes on Iron Fertilization

The availability of soil iron decreases with increasing soil pH, the most common cause of simple iron deficiency being high pH either from natural causes or from the excessive use of lime. Where this is the case, iron deficiency may be corrected either by applying sulphur to lower the soil pH or by spraying an iron salt on to the leaves.

Soils high in manganese pose some special problems because the use of lime to raise the soil pH will lower the availability of iron as well as manganese. Hence while liming alone may be effective in correcting a case of simple manganese toxicity (see page 15), where a manganese-induced iron deficiency is involved, a combination of liming and spraying with iron may be needed to control the problem. Experience so far indicates that spraying alone is not an effective cure for manganese-induced iron deficiency.

While 3 per cent ferrous sulphate solutions have been found to be safe and effective in controlling iron deficiency in some crops, we suggest that

Plate 14. Zinc deficiency. (a) Isolated bed of ginger at Imbil showing severe zinc deficiency (b) Close-up of affected plants showing bunching of leaves at the top of the plant and characteristic pattern of leaf striping (vertical leaves near centre and on right) *N.B.* Leaf spotting is thought to have been caused by insect attack.

Plate 15. Copper deficiency. (a) Withering and drying of leaf tips and failure to unrol fully. (b and c) Trapping of young leaves in the still-rolled tips of older leaves to produce a tangled leaf arrangement. The plant top shown in (c) was taken from a commercial crop at Buderim.

Plate 16. Suspected molybdenum deficiency. Note bleaching of leaf tips and margins, and the presence of narrow chlorotic lines on affected leaves.

until more experience has been accumulated with the foliar applications of trace elements on ginger, the concentration should not exceed 1 per cent (1 kg ferrous sulphate heptahydrate in 100 litres water). In addition, a test strip should be sprayed and checked for signs of injury (2 or 3 days later) before large areas of crop are treated.

MANGANESE DEFICIENCY

(a) Symptoms

Manganese deficiency is easily distinguished from other disorders which affect the upper leaves, by the distribution of chlorotic tissue over the leaf surface. Thus the main symptoms occur towards the base of the leaf, green colour persisting towards the leaf tip long after the tissues towards the base have become chlorotic (Plate 12). The chlorosis usually starts at the leaf margin about half way along the leaf then spreads towards the midrib and the leaf base forming a chlorotic V-shaped area with its apex towards the leaf base. Small necrotic spots usually develop along the veins within the chlorotic area.

(b) Tissue Analysis

Critical values have not been established but we have found 20 to 23 ppm manganese in the upper leaves of affected plants, compared with 125 to 250 ppm in apparently healthy plants.

Notes on Manganese Fertilization

As far as we are aware manganese deficiency is not a serious problem in the ginger growing area although some Wallum soils appear to be low in manganese. Since manganese availability is increased by waterlogging, the symptoms should be absent from wet patches in the paddock or at least milder than in the better drained areas. As liming reduces manganese availability (see also comments under "Manganese Toxicity", page 15), it is possible to cause a deficiency of the element by excessive use of lime on soils of low manganese status.

The problem can be controlled by lowering the soil pH, by spraying affected plants with a 1 per cent manganese sulphate solution, or where the soil pH is less than 6.0, by means of soil applications of manganese sulphate. In the latter case an application of 10 kg manganese sulphate/ha should be adequate in most cases.

BORON DEFICIENCY

(a) Symptoms

Affected plants show two main symptoms: (i) the spacing between the leaves is reduced towards the top of the pseudostem (Plate 13a), and (ii) the upper leaves develop small roughly circular whitish spots caused by local breakdown of the tissue inside the leaf. These spots appear transparent when affected leaves are viewed against the light (Plate 13b). In the early stages of the deficiency the plants are a darker green than usual and the leaves tend to be thickened and stiffer than usual. The latter characteristic is helpful in distinguishing boron deficiency from zinc deficiency which also reduces the spacing between leaves at the top of the pseudostem.

(b) Tissue Analysis

In our experiments upper leaves of affected plants have contained 14 to 20 ppm boron, while those of healthy plants have contained 80 to 112 ppm.

Notes on Boron Fertilization

Boron deficiency is not known to occur within the ginger growing area. Should it occur, a soil application of borax at 10 kg/ha is recommended. Note however, that excess boron is toxic to plants and the "safe" range between deficiency and toxicity is rather narrow. Hence boron should be applied only when there is good reason to suspect boron deficiency and then the aim should be to apply the smallest amount that will just correct the problem.

ZINC DEFICIENCY

(a) Symptoms

Zinc deficiency causes stunting of the plant, reduced spacing between the upper leaves, and the development of broad chlorotic stripes between the main veins of the leaves (Plate 14a, b). Zinc deficiency of ginger can easily be distinguished from boron deficiency which also causes a bunching of leaves at the top of the plant, by the absence of small circular spots on the upper leaves, absence of leaf stiffening when affected leaves are pulled through the fingers, and the presence of chlorotic stripes on the upper leaves. The chlorosis may be distinguished from that due to iron deficiency by the fact that in iron deficiency both major and minor veins tend to remain green (particularly in the early stages) whereas with zinc deficiency only the major veins remain green.

(b) Tissue Analysis

Zince deficiency should be suspected when the upper leaves contain 20 ppm zinc or less. Thus in the field we have measured values on deficient plants ranging from 10–15 ppm zinc and in pot experiments from 15 to 20 ppm. Upper leaves of plants not showing any signs of deficiency have ranged from 30 to 43 ppm zinc.

Notes on Zinc Fertilization

Our observations suggest that zinc deficiency may be a fairly common problem in Queensland ginger crops. Liming reduces the availability of the soil zinc to plants and it appears that excessive liming may be a factor leading to zinc deficiency on some properties. Thus in one case, plants on land that had received several annual applications of lime and had a pH of 7.5 were severely affected whereas plants on beds that had been extended on to newer ground with a pH of 6.1 showed only mild symptoms. Consequently lime should be used sparingly, particularly on sandy soils which often contain only limited amounts of total and available zinc.

Zinc deficiency may be controlled by soil applications of zinc sulphate or by spraying affected patches of crop with a dilute zinc sulphate solution neutralized with lime. For soil applications the rate needed can vary substantially from soil to soil but we would suggest applying zinc sulphate (heptahydrate) at 10 kg/ha at planting when the preceding crop has shown zinc deficiency symptoms. If this is not sufficent, further zinc may be applied either as a sidedressing or through the irrigation system.

Experience with other crops indicates that a 0.5 per cent solution of zinc sulphate to which 0.25 per cent hydrated lime has been added (i.e. 500 g zinc sulphate heptahydrate plus 250 g hydrated lime to 100 litres water) should be safe and effective as a foliar spray. When zinc sulphate is applied through the irrigation system, neutralization with lime should be unnecessary since most of the zinc sulphate will be washed off the leaves and into the soil.

As with most of the trace elements, excess zinc is toxic to plants, so the aim should be to apply the smallest amount that will just correct the deficiency.

However, until more experience has been obtained with the foliar application of trace elements to ginger, growers are advised to spray a test strip first, checking for signs of leaf injury 2 or 3 days later before going on to treat a larger area.

COPPER DEFICIENCY

(a) Symptoms

The most striking symptoms are the withering and drying of the leaf tips, failure of the leaves to unroll fully (Figure 15a, b) and the trapping of the tips of younger leaves in the still-rolled section of the older leaves, resulting in a tangled leaf arrangement (Figure 15b, c). Other symptoms include mottled chlorotic areas on the affected upper leaves and a closer spacing of the leaves on the upper part of the pseudostem.

(b) Tissue Analysis

Upper leaves of affected plants have been found to contain 2 to 4 ppm copper while comparable leaves of healthy plants contained 8 to 10 ppm. However in the case of plants suffering from phosphorus-induced copper deficiency (see page 13) copper levels in the leaves appeared normal (6 to 12 ppm) indicating that the leaf copper was bound there in an inactive form.

Notes on Copper Fertilization

Copper deficiency has been reported on other plant species in the ginger growing area, and our observations indicate that copper deficiency is common in commercial ginger crops. As with iron, manganese and zinc, the availability of soil copper decreases as the soil pH increases. Hence copper deficiency can be brought on by excessive use of lime. As noted previously, excess phosphorus can also result in the development of copper deficiency.

Where copper deficiency symptoms have been observed in the previous season it is suggested that copper sulphate be applied at planting at 5 to 10 kg/ha. If necessary additional copper can be applied later in the season either as a sidedressing, through the irrigation system, or by spraying affected plants with a dilute copper sulphate solution neutralized with lime. Experience on other crops suggests that a 0.5 per cent copper sulphate solution containing 0.5 per cent hydrated lime (i.e. 500 g copper sulphate plus 500 g hydrated lime to 100 litres water) should be safe and effective. However, until more experience has been obtained with the foliar application of trace elements a test strip should be sprayed and checked 2 or 3 days later for signs of injury, before going on to treat a larger area.

Copper is not readily lost from the soil by leaching. Hence a single application of copper sulphate may serve to correct copper deficiency for several seasons. Since excess copper is toxic, copper should only be applied when there is good reason to suspect copper deficiency and then the aim should be to apply the smallest amount that will just correct the deficiency.

MOLYBDENUM DEFFICIENCY

(a) Symptoms

There is still some doubt about what molybdenum deficiency looks like on ginger, and the very small amounts of molybdenum required by plants make this deficiency rather difficult to produce in pot experiments. However in two experiments in which stringent precautions were taken to restrict the supply of molybdenum to the plants as far as possible, we observed bleaching of the tips and margins of the younger leaves, and the development of narrow chlorotic lines on these leaves (Plate 16). We believe these to be the symptoms of molybdenum deficiency but further research is needed to confirm this point.

(b) Tissue Analysis

Shoots of plants showing the symptoms described above contained 0.2 to 0.3 ppm molybdenum compared with 0.5 to 0.9 ppm in healthy plants.

Notes on Molybdenum Fertilization

Although molybdenized superphosphate is applied to pastures in parts of the ginger growing area, and molybdenum deficiency of horticultural crops occurs further south in the Ormiston-Redland Bay area, it is not known whether or not molybdenum deficiency of ginger occurs as a field problem in Queensland.

In contrast with iron, manganese, zinc, and copper in which availability decreases with increasing pH, with molybdenum, availability increases soil pH. Hence the widespread practice of liming ginger soils would tend to reduce the possibility of molybdenum deficiencies affecting crop growth.

Should molybdenum deficiency occur, molybdenized superphosphate could be substituted for ordinary superphosphate at planting, or molybdenum trioxide could be added to the fertilizer mixture at a rate equal to 100–150 g/ha.

Concluding Remarks

A great deal has been learned about the mineral nutrition of ginger during the past five years, but our knowledge is still far from complete and there is an urgent need to press on with research designed to fill the major gaps in our knowledge.

Reference has been made already to the lack of precise information on the amounts of various elements needed in the tissues of the ginger plant for healthy growth, and to the need for additional fertilizer experiments so that optimum rates and combinations of fertilizer can be worked out for each of the major soil types in use throughout the Industry. Again, attention has been drawn to the known effects of soil pH on the availability of various trace elements and the need to avoid excessive use of lime. It is hoped that research currently under way at the University of Queensland will lead to substantial improvements in our understanding of the effects of lime on various ginger soils, thus paving the way for firm recommendations regarding the liming of these soils.

Another major area of research which requires urgent attention is that of the effects of mineral nutrition on product quality. Up to the present most research on ginger has been aimed at increasing rhizome yields, very little attention having been given to possible effects of various agronomic factors on knob size, keeping quality, fibre content or oil content of the rhizomes. These quality factors are of great importance to the industry and we believe that there is an urgent need for research on nutritional and other factors likely to affect them.

Glossary of Terms

Chlorosis: Loss of green colour in the leaf. Affected areas are said to be chlorotic and may vary in colour from yellow to almost white depending on the disorder involved. Sometimes chlorotic areas may be tinged with other colours such as red or brown.

Critical Concentration: The lowest concentration of a mineral element in the plant tissues that will give maximum or almost maximum yield.

Deficiency: Disorder resulting from an insufficient supply of a mineral element that is essential for healthy growth.

Necrosis: Death of tissue. Usually follows chlorosis but tissues sometimes become necrotic without first becoming chlorotic.

ppm (parts per million): Unit of concentration used in trace element analysis. One ppm represents 1 g of the element per tonne of dry plant material.

Pseudostem: The true stem in ginger is a very small structure at the base of the shoot. The main above-ground portion is a pseudostem made up of tightly rolled leaf bases.

Shoot: Above-ground portion of the plant consisting of pseudostem plus leaves.

Toxicity: Disorder resulting from a poisonous excess of some substance in the plant's environment. Some elements that are essential for plant growth are capable of producing toxicities when supplied in excessive amounts.

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