Nutrient Deficiencies and Toxicities in Wheat

A Guide for Field Identification

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On the cover: Head sterility of wheat (indicated by translucence of the spike lets) in Thailand most likely attributable to boron deficiency in the soil. (Photo by Gene Hettel).

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Preface

The use of visual symptoms to identify nutrient deficiencies and toxicities in plants can be improved by both their careful observation and description. This guide attempts to accurately describe symptoms of nutrient deficiencies and toxicities in wheat *(Triticum* spp.). An effort has also been made to develop criteria for distinguishing one nutrient deficiency or toxicity from another using these visual symptoms.

Expression of visual symptoms of a nutrient deficiency or toxicity may change with the variety. Although many of the 47 photos in this publication depict a single variety subjected to various nutrient deficiencies and toxicities, it is felt that the descriptions of symptoms presented will be of considerable value for diagnosing nutrient deficiencies and toxicities in other varieties of wheat.

This booklet is designed as a quick guide for identifying these toxicities and deficiencies in the field. It is intended primarily for agricultural researchers, technicians, and farmers in developing countries, but also will be of value to others. The text comprises a brief description of the major nutrient deficiencies and toxicities in wheat. Color photographs, a diagnostic key for identifying deficiencies in the center of the guide, and a set of appendices complement the text as an aid to identification. Except where indicated, the photographs are provided courtesy of the authors.

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Introduction

Symptoms of nutrient deficiencies and toxicities result from impaired metabolism within the plant. Many symptoms are sufficiently characteristic to permit identification of the deficiency or toxicity that is impairing metabolism and decreasing growth. Other symptoms are less characteristic and their presence could indicate one of several possible stresses. For example, a general paleness of shoots with reddening and premature senescence of old leaves could indicate nitrogen, sulfur, or molybdenum deficiencies. In this guide, we consider symptoms of nutrient stresses in relation to function and mobility of nutrients within the plants.

Symptoms in relation to the functions of the nutrients

Essential nutrients have several functions in plants. An element may:

- Play a role in a physiological process.
- Activate an enzyme or regulate the rate of an enzyme-mediated process.
- Be an integral constituent of an essential metabolite, complex, or macro-molecular assembly.

Our knowledge of nutrient function varies for the essential nutrients. Essential elements may have nonspecific roles in plant growth, which may be additional to the specific functions listed In Appendix 1. For example, many ions are important for the establishment of osmotic potentials within plants and for the maintenance of electrical neutrality.

It is clear that one nutrient may have several functions within the plant. Symptoms that are most characteristic for a particular nutrient are those in which one specific function has a much greater requirement than other functions. For example, the impairment of auxin metabolism in zinc-deficient plants leads to characteristic symptoms of leaf distortion and Internodes shortening. Confusion can occur when several elements all play a role in the formation of a key component in a physiological process. For example, nitrogen and magnesium are constituents of chlorophyll. Deficiencies of sulfur, iron, and manganese all lead to decreased chlorophyll concentrations within the plant. Confusion can also occur when one nutrient is involved in the assimilation or metabolism of another nutrient. For example, molybdenum deficiency in wheat can lead to symptoms of nitrate toxicity because molybdenum is a constituent of the enzyme that reduces nitrate within the plant.

Symptoms in relation to the mobility of the nutrients

The location of symptoms of nutrient deficiencies within plants will depend on the extent and rate of retranslocation of the nutrients from old leaves to new growth. Nutrients differ markedly in their mobility within the plant (Appendix 2). Nutrients such as nitrogen, phosphorus and potassium are readily translocated from old leaves to new growth. Hence, symptoms of these deficiencies occur initially in the older leaves. Nutrients such as calcium and boron do not appear to be retranslocated from old leaves to new growth under any circumstances. Hence, for these nutrients, deficiency symptoms occur generally in young growing areas of the plant.

For many nutrients, the extent of retranslocation is variable, depending upon the degree of deficiency, the plant species, and the nitrogen status of the plant. For example, there is little or no movement of copper, zinc, or molybdenum out of old leaves of deficient plants. For these nutrients, symptoms will occur mainly in young tissues. For nutrients where nitrogen supply affects the movement of other nutrients from old leaves to new growth, the location of symptoms may vary with fluctuation in the nitrogen supply. An example of this is the effect of nitrogen supply on the location of sulfur deficiency. In plants with an abundant supply of nitrogen, symptoms of sulfur deficiency occur Initially on young leaves. However, in plants with a marginal supply of nitrogen, sulfur-deficient plants are generally pale and symptoms occur initially in the older leaves.

Methods for Identifying Nutrient Deficiencies and Toxicities

Visual symptoms, strip plots, and soil and plant tissue analyses are methods of identifying nutrient deficiencies and toxicities. There are advantages and disadvantages for each method.

Visual symptoms

Many nutrient deficiencies produce characteristic visual symptoms in cereals. Visual symptoms may be the first clue that the nutrient supply is limiting plant growth. These symptoms in wheat are far more nebulous than in some other species. Symptoms on other species may also give an Indication. However, different species have diverse nutrient requirements. Nutrient availability also varies among species, so a deficiency in another crop does not necessarily mean the nutrient is deficient in wheat. For some nutrients, visual symptoms (e.g., those of copper deficiency in wheat during vegetative growth) are so characteristic that deficiencies of nutrients can be confidently identified on the basis of symptoms alone. For other nutrients, deficiencies or toxicities may produce foliar symptoms similar to those of other stresses. For example, copper deficiency during reproductive growth may produce a head tipping similar to that produced by either frost or drought at anthesis. To distinguish between such stresses, further experimentation and/or plant and soil analyses are required. Analysis of an appropriate tissue will confirm for many nutrients whether the diagnosis of a nutrient deficiency or toxicity using visual symptoms was correct (Appendix 3).

Strip plots

Strip comparisons between fertilized and nonfertilized areas may be a simple way to confirm the presence of a deficiency. In these comparisons, the nutrient can be applied either to the soil or on the foliage to overcome the deficiency. Soil application is best for macronutrients, whereas either soil or foliar applications are appropriate for the micronutrients (Appendix 4). The exception to this is for iron deficiency on calcareous soils where soil application of iron may not correct the deficiency.

In many instances, the foliar sprays must be neutralized to prevent foliar burn. For example, additions of calcium hydroxide or sodium carbonate are used to neutralize the acidity and to decrease the risk of foliar scorch at high concentrations of manganese sulfate. It is best to add nutrients singly because of possible effects of one nutrient upon the uptake of another. Where multiple deficiencies occur, correction of one deficiency would be expected to change symptom expression and successive diagnosis and elimination of nutrient deficiencies may be possible.

Analysis of soil and plant tissues

For most nutrient deficiencies, growth may be limited considerably without any symptoms. Hence it is essential that reliable procedures for soil and plant tissue analyses should also be used to monitor nutrient status and diagnose nutrient deficiencies.

Soil analysis is not generally useful for either micronutrients or nitrogen. For micronutrients it has proved difficult to find an extractant that estimates accurately that small fraction of the total amount of the nutrient in the soil that is available for uptake by plants, particularly across a range of soils. For nitrogen soil analysis is of limited value because of the strong influence of soil temperature and soil moisture on nitrogen transformations within the soil.

Some generalizations can be made regarding the availability of nutrients to plants in relation to soil pH. As shown in Appendix 5, deficiencies of zinc, manganese, and iron are more common on alkaline soils while deficiencies of molybdenum, calcium, and magnesium occur more commonly on acid soils. For other nutrients such as potassium and sulfur, there is little association between soil pH and availability to plants. Toxicities of aluminum and manganese occur almost exclusively on acid soils.

There are many effects of one nutrient upon the uptake of another nutrient (Appendix 6; see review by Robson and Pitman, 1982). As well as these interactions, any condition that decreases root growth (e.g., aluminum toxicity, calcium deficiency, boron deficiency, and toxicity of hydrogen ions per se) will decrease nutrient uptake.

Where samples are taken for analysis of plant tissues, it is essential to record growth stage, agronomic practices used (including past fertilizer applications), and other site details (soil type, growing conditions). It is also important to avoid contamination (e.g., galvanized iron and brass In collection instruments could be sources of zinc and copper, respectively) and to take a representative sample.

To diagnose deficiencies using tissue analysis in paints showing symptoms, it is essential to clearly describe the symptoms and to collect plant samples from affected and unaffected areas within the crop. To avoid secondary effects, take plant samples when symptoms of the disorder are first observed.

When collecting plants from small, uniformly affected areas of a crop, choose the sample size by the amount of material required for chemical determinations. Usually 30-50 shoots or plant parts are collected systematically and combined. When sampling, exclude diseased or insect-damaged plants when possible. In addition, do not take samples when plants are under drought stress. Avoid contamination by trace elements by using clean plastic shovels, stainless steel cutting implements, and distilled or deionized water. Wrap samples in tissue paper and place them in open paper bags before drying at approximately 65ºC.

In addition to comparing the concentrations in affected and unaffected plants, also compare the concentrations in plants of similar age with critical concentrations established for the same tissue and species (for a very complete compilation of critical concentrations, see Reuter and Robinson, 1986). Tissue analysis is based upon the relationship between nutrient concentrations within the plant and its growth stage. The most important factor affecting this relationship is the extent to which nutrients are remobilized from old tissues to new growth and grain. For nutrients such as nitrogen, phosphorus, and potassium, which move readily from old leaves in ail situations, analysis of whole shoots gives a reasonable indication of nutrient status with critical concentrations decreasing with plant age. For nutrients that are immobile or variably mobile (Appendix 2), concentrations in whole shoots will be poor indicators of nutrient status because they reflect the previous supply rather than the current status. Nutrient concentrations in young leaves have proven to be reliable indicators of current nutrient status. An additional advantage is that critical concentrations in tissues of the same physiological age (e.g., the youngest fully emerged leaf) tend to decrease less with plant age than do critical concentrations in whole shoots.

The critical concentrations established for wheat listed in Appendix 3 represent the available world data. It is clear that further work is required to establish critical concentrations for a wider range of plant ages. Critical concentrations do not generally vary in varieties within a species. Tissue analysis can only be used to separate plants with an adequate supply from those with a deficient supply. It cannot be used to indicate degree of deficiency or amount of nutrient required to eliminate the deficiency.

Diagnostic key for identifying nutrient deficiencies

A diagnostic key using symptoms to identity nutrient deficiencies in wheat is presented in the centerfold of this guide (pages 36-37). Major separations have been made based on:

- The location of symptoms.
- The color of whole shoots.

Minor separations are made on the basis of the characteristics of the specific symptom.

Nutrient Deficiency Symptoms in Wheat

Many of the symptoms described and depicted in the following photographs were developed with adequate, but not toxic, supplies of other nutrients. Deficiencies of nitrogen, phosphorus, potassium, sulfur, copper, zinc, and molybdenum on wheat were produced in plants growing on a sandy virgin soil. The remaining deficiencies were produced in plants growing in water culture. In every case, control plants were grown alongside the deficient plants and often are shown in the photos for comparison. Where possible, photographs of field symptoms in wheat under natural conditions have been included for comparison. Often, certain symptoms are common to a number of nutrient deficiencies. To help keep track of these similarities, Appendix 7 provides a cross reference of similar symptoms on various plant parts.

Nitrogen

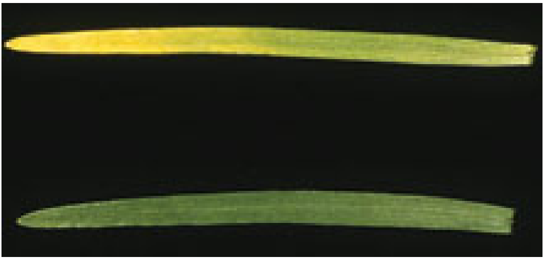
N deficiency is the most common and widespread nutrient deficiency in small grains. Plants suffering from N deficiency are pale In comparison to healthy plants due to the breakdown in chlorophyll production.

Specific symptoms of N deficiency first appear (as with P and K deficiencies) on the oldest leaves with the new leaves remaining relatively green. The older leaves become paler than newer leaves with chlorosis (marked yellowing) beginning at the tip and gradually merging into light green further down the leaf (**1,2**). As the chlorosis spreads to other leaves the oldest leaves become totally chlorotic, changing from yellow to almost white in color. However, necrosis (death of leaves or parts thereof) may not set in for some time in contrast to P and K deficiencies. N-deficient plants will reach anthesis and maturity before plants with an adequate N supply.

In the field, symptoms almost always start as pale green or yellow patches, which may spread rapidly so that, in a fairly short time, the whole field may appear yellowish (**3**).

1) Old leaf symptoms (above): yellow merging into green.
2) Growth depression (right) due to N deficiency.
3) N deficiency in wheat showing a genera/ paling.

1



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M. Mason

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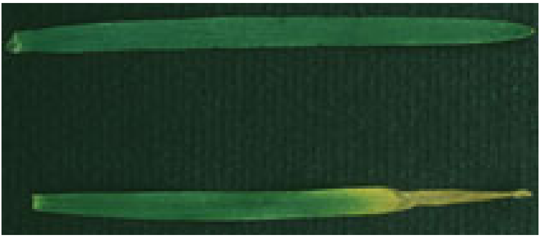

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6

P. C. Wall

Phosphorus

During the early stages of vegetative development, the most noticeable feature of P deficiency in wheat is the reduced growth and vigor of the plant. The color of all leaves of P-deficient plants becomes a dull dark green with slight mottling of the oldest leaf (**4**). Leaves appear coiled to a greater degree than normal; old leaves sometimes encase younger leaves. New growth can appear spindly and may remain folded for some time.

Specific symptoms are, however, on the old leaves. Chlorosis begins at the tip of the old leaf and moves down the front of the leaf. The base of the leaf, like the remainder of the plant, stays dark green (**5**). Unlike N deficiency, necrosis of these chlorotic areas is fairly rapid with the tip becoming orange to dark brown and shrivelling and the remainder turning yellow. When this occurs, the second oldest leaf has generally taken on the early symptoms of P deficiency. Other common symptoms of P deficiency are delayed and irregular plant maturity and small heads.

P deficiency is usually more general across a field than N deficiency and usually results in stunted plants with fewer shoots if the deficiency is mild (**6**). The whole field is affected to a greater or lesser degree unless the deficiency is due to faulty fertilizer or lime application.

4) Growth depression due to P deficiency. Control plants on left.

5) Old leaf symptoms of P deficiency. Control above.

6) Test plots in P-deficient soil. The effects of applied P at right.

Specific K deficiency symptoms always appear in the oldest leaves of wheat, although growth of the whole plant can be affected prior to symptoms with all leaves having an unthrifty and spindly appearance. Under severe K deficiency, necrosis in the oldest leaves begins as a necrotic speckling along the length of the leaf, spreading quickly to the tip and the margins (**7**). As a result of this spread of necrotic tissue, an arrow of green tissue from the base upwards towards the center can remain (**8**).

Chlorotic tissues, generally seen as a mottling, turn necrotic rapidly with K deficiency in contrast to N deficiency. Complete death of old leaves is common and plants in the field may appear to have dried prematurely due to drought stress. Mg and K deficiencies in wheat also result in plants appearing unthrifty and drought stressed and in reduced 1000-grain weight. K deficiency may occur within specific areas in a field associated with deep leaching sands, livestock feedlots, and the removal of hay and other above-ground plant material. Crops severely affected appear drought stressed with large numbers of prematurely dead, old leaves and spindly growth.

7) Degrees of K deficiency on old leaves of wheat showing chlorotic mottling, necrotic tipping, and green arrow. Control leaf on left.

8) Close-up of green arrow effect on an old leaf.

7

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9

10

Sulfur

S in plants is a constituent of certain amino acids. Since S is also involved in chlorophyll production, deficiency symptoms in wheat are similar to N chlorosis (i.e., a general chlorosis of the leaf). However, S deficiency does differ from N deficiency in that the whole plant is pale with a greater degree of chlorosis in the young leaves (**9,10**). The pattern of chlorosis of the new leaves may show gradation in intensity from tip to base, but they quickly become totally chlorotic and take on a light yellow color.

Under severe deficiency and as the plant ages, other symptoms besides paling can appear on old leaves.

9) Growth depression due to S deficiency. Control plants on left.

10) S deficiency in the three youngest leaves (right). Note the general chlorosis with some graduation on these leaves without any necrosis. Three control leaves on left

Notes:

Leaf tip necrosis can occur, but this may be indicative of nitrate accumulation rather than a direct effect of S deficiency. Extreme S deficiency can result in a lack of head formation (**11**). Symptoms of S deficiency in the field resemble N deficiency with a light yellowing of the leaves (**12**). However, unlike N deficiency these symptoms are predominantly on the younger leaves. S deficiency is most marked with the use of mono-ammonium phosphate and diammonium phosphate, which contain no S and high levels of N. When ordinary superphosphate, which contains approximately 12% S, is applied, S deficiency is uncommon except late in the season on very sandy soils in high rainfall areas.

11) Extreme S deficiency shows lack of head formation (right). Control plants on left.
12) S deficiency in the field shows a light yellowing of the leaves.

Notes:

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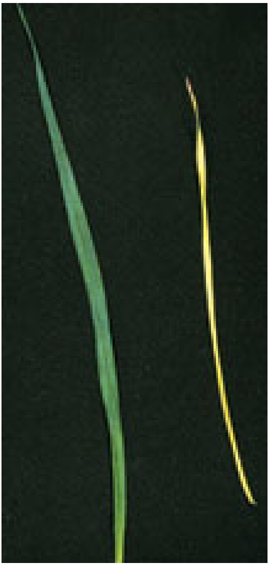
J. Yeates

13



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Magnesium

The symptoms of Mg deficiency resemble those of K and Fe deficiencies in a number of respects. However, there is a major difference in the location of the initial symptoms in the case of K. Unlike K deficiency, the new leaves of Mg-deficient wheat plants are pale in contrast to the old leaves (**13**). This, however, is similar to Fe deficiency. The new leaves soon become chlorotic and remain unopened, resulting in a twisted appearance that gives the plant an unthrifty look reminiscent of drought stress.

If Mg deficiency is severe enough, the entire length of the leaf will remain folded or rolled (**14**). After some time, several leaves including the new shoot may be folded or rolled. Over time, the chlorosis of the new

13) Plant on right shows reduced growth with folded new leaves and contrast in color between old and new leaves. Control plant on left.

14) Leaf on right shows marked chlorosis and rolling of leaf blade. Control leaf on left.

Notes:

Magnesium (continued)

leaves referred to earlier becomes mottled and finally necrotic, although the leaves remain erect. Even the oldest leaves develop a mottled chlorosis and in some cases a reddish coloration along the leaf margins.

In the field, Mg deficiency of wheat is not common, however, It can occur where Mg has become unavailable or on sandy acid soils in high rainfall areas. Symptoms of Mg deficiency in the field appear as patchy yellowing and stunting of the crop (**15**). Examination below ground would reveal a poorly developed root system.

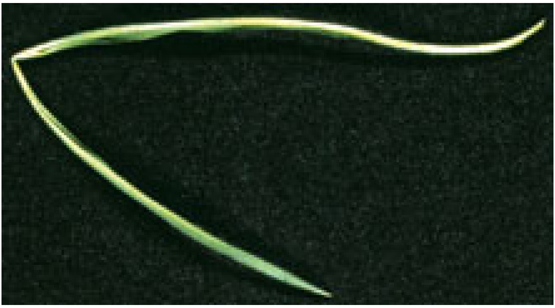
15) Mg deficiency in the field.

Notes:

15

R. Weir

16



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18

Calcium

Ca Is Immobile in the phloem of plants and, since it plays an important role in the growth of meristematic tissue, symptoms of Ca deficiency always appear in new growth. Plant roots are generally the first tissues to show Ca deficiency. As with B deficiency, the main roots become shortened with a proliferation of stunted laterals (**16**). Wheat leaves do not become chlorotic with Ca deficiency; old leaves, particularly, retain their dark green color.

The first definite symptom is a necrotic spotting about the middle of the leaf on the newest growth. This area quickly expands and the leaf collapses midway before unrolling (**17,18**). Severe Cu deficiency can produce similar symptoms in the new growth. However, for Cu, unlike Ca, there are generally older leaves showing "wither tip" as well as the new growth. Additionally, in Ca deficiency, the section above the central collapse remains green for some time, whereas in Cu deficiency, the section above the collapse withers and quickly becomes necrotic. The general greenness and erect growth habit of Ca-deficient plants is another feature that contrasts Cu deficiency where plants are pale and appear wilted. Calcium deficiency in wheat in the field is very uncommon and the authors have not observed it.

16) Ca-deficient roots of wheat (above) show stunted laterals. Control roots below.

17) Unrolled sections of youngest leaf above and below collapsed point.

18) Ca-deficient plant on right showing collapsed new growth

Iron

Fe deficiency, like Mg deficiency, is involved in the failure of plants to produce sufficient chlorophyll with the result that Fe and Mg symptoms can be similar for many plants. In both deficiencies, new leaves are affected first and become chlorotic, but with Fe deficiency, the contrast between the green of the old leaves and the chlorosis of the new growth (**19**) is more marked than for any other relatively Immobile element. The nature of the chlorosis in the case of Fe deficiency is characteristic for cereals. Wheat leaves show a longitudinal interveinal chlorosis (**20**), resulting in a pattern of alternate green and yellow striping, and this pattern Is more regular for Fe deficiency than for Mg or Mn deficiencies. Under severe Fe deficiency, the new growth may appear completely devoid of chlorophyll and turn white. These new leaves remain chlorotic for some time, unlike other deficiencies where necrosis can set in even though a portion of the leaf remains green.

19) Note contrast between old and new leaves of the Fe-deficient plant at right. Control plant on left.
20) Interveinal chlorosis. Control leaf on left.

Notes:

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P. C. Wall

21

Iron (continued)

In the field, Fe deficiency is seen most on calcareous soils or after heavy applications of lime. Mn deficiency can also be induced under these conditions, but symptoms differ as stated above. Moreover Fe-deficient plants remain relatively erect, while Mn-deficlent plants are generally floppy. Plant growth in compacted areas (i.e., wheel tracks) may be normal (**21**). Without compacted areas, there is usually general yellowing over the field, unless there are limestone outcrops to which Fe deficiency is restricted.

21) Fe deficiency in the field. Note healthy plants growing in soil compacted by implement wheels.

Notes:

Manganese

Chloroplasts In plants are most sensitive to Mn deficiency, which results in pale plants and is, to some degree, similar to Fe and Mg deficiencies. However, symptoms of Mn deficiency can be quite characteristic.

In wheat, symptoms appear first in new leaves, which become pale and limp in contrast to the old leaves (**22**). Light grey flecking and striping then appear at the base of the youngest fully opened leaf. Under severe deficiency, the new growth may emerge with this flecking and striping over the entire length of the leaf. Although the striping is Interveinal, It differs from Fe deficiency in its irregularity and in the flecking associated with it. In time these new leaves lose more chlorophyll, particularly in the lower half of the leaf (**23,24**) where necrosis sets in and they collapse. By this symptom stage, they have become middle leaves.

Severe deficiency in the field reflects the above symptoms with some additional withering of new shoots. In the field, as with Fe deficiency, Mn deficiency can be induced on calcareous soils or after heavy applications of lime. Mn deficiency shows up as patches of pale, floppy wheat in an otherwise green healthy crop; symptoms may be worse in compacted areas, such as wheel tracks.

22) Note symptoms on new and middle-aged leaves. Control plant on left.

23) Note green upper end and intensity of symptoms in the lower half.

24) Degrees of Mn deficiency.

22

23

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26

Copper

The first visual symptom of Cu deficiency in wheat is a general wilting of the whole plant occurring at early tillering, even though the soil may be at field capacity. If the deficiency is severe enough, an effect on the development of tillering itself can be measured. Although there is initially a decrease in tillering as in other deficiencies, there may be a proliferation of tillers in severely Cu-deficient plants that occurs when Cu-adequate plants are experiencing stem elongation. Plants also appear lighter in color where Cu is deficient. These symptoms are generally only noticeable when comparisons are made with Cu-adequate plants.

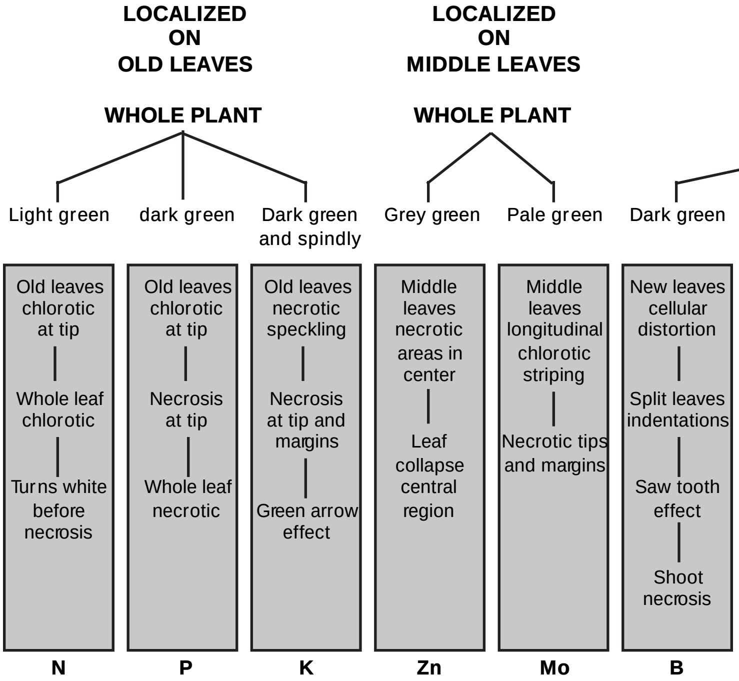
Withertip, the first characteristic symptom of Cu deficiency, appears on young leaves. It shows as a sudden dying and withering (curling) of the tip end of the leaf blade, sometimes up to half the length of the blade (**25**). The base end of the leaf, however, can remain green until normal senescence occurs. Under severe deficiency, as with Ca deficiency, the new growth can wither before unfolding and few heads will emerge. With less severe deficiency, heads may emerge but grains may not form in the spikelets at the tip of the head (**26**). The whole head takes on the appearance of a 'rat tall' with full grain in the base of the head, shrivelled grains in the middle of the head, and a withered necrotic tip. This rat

(continued on page 38)

25) Note withering (curling) of the tips and the normal healthy base end of the blades.

26) Failure of grain formation in head tip.

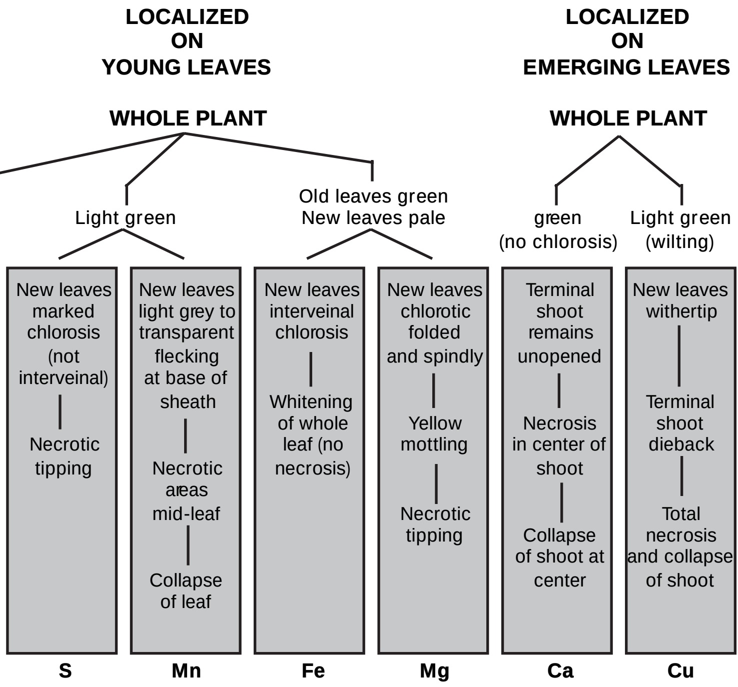
DIAGNOSTIC KEY FOR IDENTIFYING



Major separations have been made on the basis of the location o
The color of the whole plant is then used to further separate the

Descriptions within the boxes refer specifically to symptoms wh
down the column. Comments made at the top of the boxes refer
bottom refer to a later period in the plant's growth.

NUTRIENT DEFICIENCIES IN WHEAT



of the symptoms on the plant. The block headings refer to these. mineral deficiencies.

ich have become localized and generally follow a time scale r to plant parts at an early growth stage while comments at the

tail appearance is sometimes confused with frost damage (**27**). Marginal Cu deficiency may decrease grain yield by producing shrivelled grain and a bending over of the stem and head. Cu is required for the lignification of cell walls and hence a deficiency decreases stem strength.

Cu deficiency can, along with some other factors, be responsible for the formation of the pigment melanin, resulting In a purpling of the stem, nodes, and even the spikelet glumes in some crops . Symptoms of Cu deficiency in the field may be many and varied. Symptoms on vegetative growth range from a paleness and floppiness of leaves to withertip (**25**). In many cases, effects do not show up until heading or even later with a discoloration (melanin) of the stubble during and following harvest (**28**). Whole fields may be affected evenly when Cu Is inherently low, but patches may also be seen (**29**).

27) Frost damage of the head is sometimes confused with Cu-deficiency.

28) Cu-deficiency in the field showing discoloration in the stubble.

29) Patches of Cu-deficiency in the field.

27

S. Fuentes

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Zinc

Generally, the first symptoms of Zn deficiency in wheat appear on the middle-aged leaves (**30**), but considerable variation exists between individual plants; some plants produce symptoms in both old and middle-aged leaves simultaneously. These initial symptoms show a change in color from a healthy green to a muddy grey-green, generally in the central regions of the leaf (**30,31**). These leaf regions appear drought-stressed and necrotic areas, beginning with a small necrotic spot soon develop (**31**), gradually extending to the margins. As the deficiency becomes more severe, many leaves take on an oily

30) Symptoms of Zn deficiency: whitish-brown patches become necrotic lesions in wheat leaves middle-aged and older.

31) As severity intensifies, necrotic lesions spread, and leaf blades take on a "scorched" appearance.

Notes:

appearance; the necrotic patches become larger and are surrounded by mottled yellow-green areas (**32**). At this stage, Zn-deficient leaves tend to collapse in the middle regions and even the youngest leaves produce symptoms.

Zn deficiency in wheat can occur in soils inherently low in Zn, in soils where Zn is unavailable to plants, and in soils where plant-available Zn has declined. Severe Zn deficiency in the field can result in stunted chlorotic plants with many collapsed leaves due to necrosis in the center of the leaves. Whole fields may be affected but, more generally, there are chlorotic patches within the crop. Ordinary superphosphate may contain considerable Zn as a contaminant and dramatic effects of Zn deficiency can be seen on sandy soils when superphosphate is replaced by phosphatic fertilizers low in Zn.

Tolerance of cereals to zinc-deficient soils declines in the following order: rye (immune), triticale (mostly immune), bread wheat (highly variable), barley (highly variable), oats, durum wheat (sensitive). When soils are suspected of being severely zinc deficient, durum wheat may be used as an indicator.

32) Close-up of Zn-deficient leaf showing mottling and necrotic lesions.

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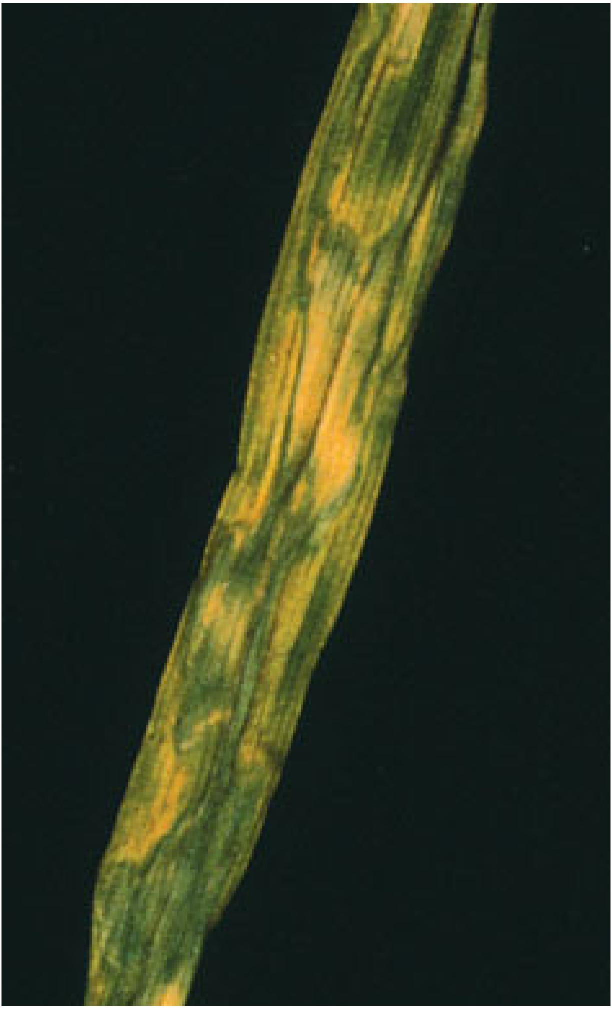

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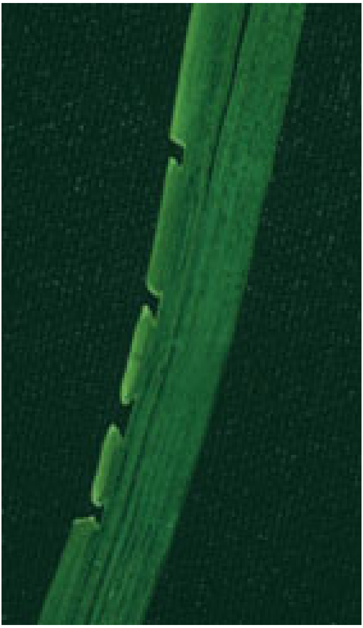

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Boron

Due to the passive nature of B uptake and the nonmobility of B in the plant, expression of symptoms under marginal deficiency conditions is extremely variable, influenced largely by the weather prevailing at particular plant growth stages. The first characteristic sign of B deficiency is a splitting of the newer leaves close to the midrib (**33**). This is accompanied by some unusual indentations, also along the length of the leaf, but on the opposite side of the midrib to the splitting. Some new leaves show a loss of chlorophyll in a very narrow strip along the full length of the leaf.

Although not always present, another characteristic symptom of B deficiency is the development of a sawtooth effect on young leaves (**33**), reflecting abnormal cellular development. As the deficiency becomes more severe, an increase in tillering occurs, new shoots have a water-soaked appearance (**34**) and are paler than the older parts of the plant. Considerable distortion occurs along the margins of these leaves. Finally, new growth becomes necrotic and shoots wither, not unlike extreme Cu and Ca deficiencies.

33) Saw-tooth effect and splitting near the midrib attributed to B deficiency.
34) New growth with water-soaked appearance.

Head sterility is also a characteristic symptom of B deficiency (**cover, 35**). In some cases, the entire spike is sterile; the anthers do not open and the ovary does not develop. In some years, leaf symptoms described above may be apparent, but no sterility occurs. In other years, severe sterility can be observed without the characteristic leaf symptoms. Reduced 1OOO-grain weight and grain shrivelling can also result from B deficiency.

35) Head sterility of B-deficient plants (right). Normal heads on the left.

Notes:

35

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Molybdenum

Deficiency symptoms of Mo depend to some degree on the N status of the plant. At low levels of applied N, the initial limp leaf symptoms in Mo-deficient plants contrast with the upright stature of Mo-adequate plants (**36**). Differences in color are not evident. However with high levels of applied N, Mo-deficient wheat plants are much paler green than those adequately supplied with Mo (**36**). When very high N-rates are applied to Mo-deficient plants, tip scorching of old leaves may occur. This is because Mo is a constituent of the enzyme nitrate reductase and nitrate may accumulate to toxic concentrations within the old leaves.

A characteristic symptom of Mo deficiency is a longitudinal yellow striping mostly on the middle leaves (**37**). Plants become very pale green and limp when compared to Mo-adequate plants. The old leaves remain greener than the remainder of the plant, although with time some plants develop necrosis of the tips and margins of the old and middle-aged leaves. New growth remains normal,

36) Wheat without (left) and with Mo grown on an acidic sandy soil with moderate supply of N.

37) Longitudinal yellow striping is a characteristic of Mo deficiency. Control leaf on the left.

but under severe deficiency delayed maturity will occur and very deficient plants can produce empty heads (**38**). In the field, Mo deficiency can decrease yields by 30% before symptoms become apparent. It is difficult to diagnose mild deficiency, but there is a general paling of all but the oldest leaves and a limp appearance of most leaves as if in the early stages of drought stress. Delayed maturity and white and empty heads may be apparent (**38**).

38) Mo deficiency (left) shows delayed maturity and white heads.

Notes:

38

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Nutrient Toxicity Symptoms in Wheat

Toxicities of phosphorus and boron were produced by growing plants in a sandy brown soil. Aluminum toxicity was produced on an acid sandy loam. Manganese toxicity was not produced even though an application rate equivalent to 30 times the commercial fertilizer rate was applied. Control plants were grown at rates of phosphorus and boron that gave maximum growth. In the case of aluminum, control plants were produced by the application of lime since the acidity of the untreated soil was sufficient to produce aluminum toxicity.

It is difficult to distinguish between the toxicity symptoms of phosphorus, boron, and aluminum. All three toxicity symptoms appear on the oldest leaf and begin at the apex (**39)**. However, differences do occur in the degrees of chlorosis and necrosis and their development.

39) From left, comparison of P, B, and Al toxicities in old wheat leaves.

Notes:

The first signs of P toxicity occur as a mottled chlorosis just behind the tip of the oldest leaf and along the margin of the leaf (**40**). The tip itself rapidly becomes necrotic. Within a few days, the progression of symptoms leads to the chlorosis turning a bright yellow along the margins leaving a green arrow effect and increased necrosis of the tip. The base of the leaf remains green and healthy.

In the case of severe P toxicity, a similar series of symptoms appear on the second oldest leaf and will progress to all leaves in time with subsequent death of the plant. In many cases in the field, plants may initially show toxicity symptoms due to high levels of P near the germinating seed, but will grow out of the toxicity with no apparent detrimental effect on yield.

40) Symptoms of P toxicity on old wheat leaf.

Notes:

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Boron

At the very early stages of growth, symptoms of B toxicity are indistinguishable from P toxicity. In time the chlorosis associated with B toxicity is less yellow. The mottled appearance of the chlorosis and necrotic tipping of the oldest leaf are similar for both toxicities; however, in the case of B toxicity, these mottled chlorotic areas have a dehydrated appearance and the necrosis of the tip leads down the margins in a fine necrotic edging (**41**). As these symptoms increase in severity, Individual chlorotic spots appear in from the margins and well down the leaf (**42**). Necrotic areas soon form within the chlorotic spots and finally join together giving much of the leaf a shrivelled and dead appearance. Wheat appears to be more tolerant to B toxicity than barley. Symptoms of B toxicity can sometimes be confused with fungal infections.

41) Degrees of B toxicity symptoms. Control leaf on left.
42) Note individual chlorotic spots on an old wheat leaf.

Notes:

Aluminum

Genetic variability exists among wheats for tolerance to Al toxicity. Although retarded root growth in susceptible wheat varieties is the most characteristic symptom of Al toxicity (**43**), beware that this symptom can be confused with nematode infestations and root diseases. The first above-ground sign of Al toxicity is a reduction in growth (**44**) with plants appearing unthrifty with thinner than normal leaves (**45**). This could be due to the early effect on root growth.

The first specific foliar symptom of Al toxicity (as with B and P) is a yellowing along the margin near the tip of the oldest leaf. Within a few days brown lesions form in these chlorotic regions and work in from the margins resulting in the formation of indentations. The progress of these toxicity symptoms is rapid. Old leaves become drought stressed and withered and at times collapse in the center.

43) Retarded root growth in a wheat variety susceptible to Al toxicity (right) compared to a tolerant variety.

44) Growth reduction of wheat plants susceptible to Al toxicity (right) compared to tolerant plants that are growing normally.

45) Degrees of Al toxicity on leaves. Control leaf below.

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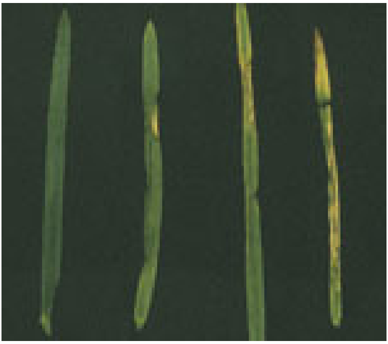

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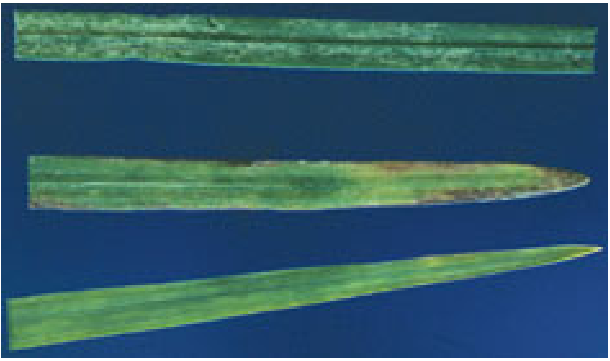

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Manganese

Symptoms of Mn toxicity appear first on the oldest leaf of a plant and progresses to the younger leaves. Symptoms can vary from variety to variety and include chlorosis with little necrosis, chlorosis progressing to necrosis, and in some cases reddening combined with necrosis and chlorosis (**46**). These symptoms begin to appear on the oldest leaf tips and progress along the leaf with the leaf margins being more affected. In some varieties, a brown blotch appears on the leaf while in others a "grey fleck" of necrotic tissue appears over the entire leaf usually accompanied by leaf tip chlorosis and/or necrosis.

46) Symptoms of Mn toxicity on old leaf sections. Note combination of necrosis and chlorosis.

Salinity

Salt concentrations within a field are rarely uniform; therefore, one of the first symptoms indicating a salt problem is variability in crop growth within the field. Barren spots are not uncommon (**47**). Plants suffering from salt toxicity are stunted and dark blue green in color with tip burn and firing on the leaf margins. A soil test can rapidly confirm whether salt levels are excessive.

47) Barren spots are common in fields with high levels of salt in the soil.

Glossary

Auxin: compound regulating the growth of plants.
Chlorophyll: green pigment in plants required for photosynthesis.
Chloroplast: plant structure where photosynthesis occurs.
Chlorosis: abnormal yellowing of leaves.
Enzyme: an organic compound catalyzing a specific reaction in the cell.
Meristem: tissue of rapidly dividing cells, generally at the apex of shoot and root.
Metabolite: compound undergoing chemical transformations within the plant.
Micronutrient: nutrient required in trace amounts (see Appendix 3).
Necrosis: abnormal death of leaves.
Phloem: specialized plant tissue mainly for conducting organic substances.
Reductase: an enzyme that catalyzes reduction.
Senescence: normal death of leaves.
Spikelet: plant structure bearing the grains in a cereal head.
Xylem: specialized plant tissue for conducting water and inorganic salts from roots to leaves.
Wlthertip: death of the leaf beginning at the tip, usually in young leaves.

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Appendix 1. Functions of essential elements in plants. (For more details see Epstein, 1972; Mengel and Kirkby, 1982; Marschner, 1986).

Element	Chemical Symbol	Physiological Process	Activators of Enzyme	Constituents of Metabolite
Nitrogen	N	Various		Amino acids, proteins, nucleotides, chlorophyll
Phosphorus	P	Energy transfer, membrane integrity		ATP, nucleotides, phospholipids
Potassium	K	Translocation, stomatal opening	Yes	
Sulfur	S	Protein synthesis and function, structure		Amino acids, co-enzymes, proteins
Calcium	Ca	Membrane maintenance	Yes	Calcium pectates
Magnesium	Mg	CO_2 assimilation	Yes	Chlorophyll

Chlorine	Cl	Maintenace, electrical neutrality, internal turgor		
Copper	Cu	Lignin synthesis		Ascorbic acid oxidase, phenolases, plastocyanin
Zinc	Zn	Auxin metabolism, nucleotide synthesis	Yes	Dehydrogenases
Manganese	Mn	Oxidation-reduction in electron transport	Yes	
Iron	Fe	Electron transport		Iron porphyrins (leaves), ferrodoxin
Boron	B	Nucleotide synthesis, assimilate translocation		
Molybdenum	Mo	Nitrogen fixation, nitrate reduction		Nitrogenase, nitrate reductase

Appendix 2. Mobility of nutrients within plants.

Mobile[a]	Variably Mobile[b]	Immobile[c]
Nitrogen	Copper	Calcium
Phosphorus	Zinc	Boron
Potassium	Sulfur	Manganese
Magnesium	Molybdenum	
Iron		

[a] *Retranslocated from old leaves to new growth under all conditions.*
[b] *Retranslocated from old /eaves to new growth only under some conditions.*
[c] *Not retranslocated from old /eaves to new growth under any conditions.*

Appendix 3. Concentrations of nutrients in whole shoots and young leaves that are deficient, critical, adequate, and toxic for the growth of wheat. Values are a guide only. For detailed information, see Reuter and Robinson (1986).

Nutrient	Age		Plant Part	Deficient	Critical	Adequate	Toxic
Macro (% dry wt)	FS	ZS[a]					
Nitrogen	5-6	30-31	WS[b]	<3.4	3.7 - 4.2	4.2 - 5.1	-
Phosphorus	4-6	31	WS	<0.2	0.3	0.3 - 0.5	>1.0
Potassium	10.1	57	WS	<1.3	1.5	>1.6	-
Sulfur	8	37	WS	<0.15	0.15	0.2 - 0.3	-
Calcium	5	30	WS	<0.15	0.2	0.2 - 0.3	-
Magnesium	3-5	20-30	WS	<0.10	0.15	0.15 - 0.3	-
Micro (µg/g dry wt)							
Copper	3-10	20-45	YL[c]	<1.3	1.3- 1.5	>2.0	>18
Zinc	3-5	20-30	YL	<12	14	15 - 70	>200
Manganese	4-6	31	YL	<10	1~13	20- 100	>400
Boron	Var.	Var.	YL	<3	-	3-25	>30
Molybdenum	1-10	10-45	YL	<0.05	0.075	>0.1	-
Iron	1-10	10 45	YL	-	-	25 – 100	-

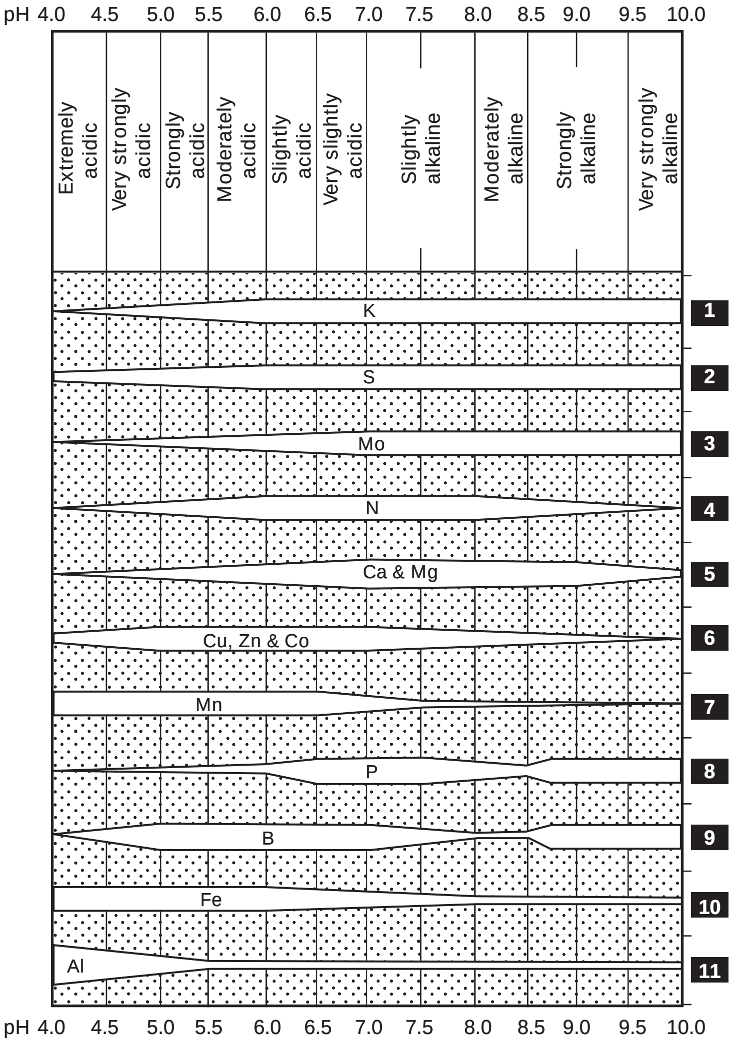
[a] FS = Feeke's scale; ZS = Zadoks' scale.
[b] WS = whole shoots.
[c] YL = young leaves.

Appendix 4. Soil types most likely to suffer various nutrient deficiencies, fertilizers that can correct the problems, and rates of application.

	Rates of application of spray			
Nutrient	Soils where deficiency is most likely	Fertilizer likely to correct deficiency	Rate kg/ha (element)	Concentration for foliar application
N	Wide range of soils	Ammonium nitrate Urea Diammonium phosphate Ammonium sulfate	-	-
P	Wide range of soils	Superphosphate Diammonium phosphate	-	-
K	Coarse textured soils Low cation exchange capacity High rainfall with large product removal	Potassium chloride Potassium nitrate Potassium sulfate	-	-
S	Sandy soils where leaching occurs	Superphosphate Calcium sulfate	-	-
		Potassium sulfate	-	-

Mg	Acid soils with low cation exchange capacities	Calcium magnesium carbonate Magnesium sulfate		
Ca	Acid or serpentine soils	Calcium carbonate Calcium sulfate		
Cu	Solis with high organic matter Soils derived from laterite Soils derived from marine sediments	Copper sulfate Copper oxide	0.25	0.5%$CuSO_4.5H_2O$
Zn	Soils derived from laterite Calcareous soils	Zinc sulfate Zinc oxide	0.24	0.5%$ZnSO_4.7H_2O$
Fe	Calcareous high pH soils Calcareous soils with ph>7 (1:5 soil/water)	Ferrous sulfate Manganese oxide	1-2	1% $MnSO_4.H_2O$
Fe	Calcareous high pH soils Iron EDTA Iron EDDHA	Ferrous sulfate	0.2	0.5-1% $FeSO_4$
B	Acid sandy soils derived from igneous materials	Sodium borate Boric acid	0.6	0.3%$Na_2B_4O_7.5H_2O$+ $Na_2B_{10}O_{16}.10H_2O$
Mo	Acid soils with high iron	Molybdenum trioxide	0.1	0.05%$Na_2MoO_4.2H_2O$

Appendix 5. Effect of pH on availability of common elements in soils. Adapted from Truog (1948).



Notes to Appendix 5.

1. Deficiencies likely at low pH.
2. Some reduction at low pH, but S bacteria still active.
3. Similar to K.
4. Bacterial fixation curtailed below about pH 5.5.
5. May be deficient in acidic soils. Not available at very high pH.
6. May be toxic in acidic soils and deficient where pH > 7.0.
7. Similar to Cu, Zn, and Co.
8. Liable to be fixed by Fe, Al, Mn at low pH; insoluble forms at high pH, also Ca Inhibition.
9. Over-liming may cause deficiency. Toxicity dangers at very high pH.
10. Similar to Cu, Zn, and Co.
11. Liming to pH 5.5 recommended to avoid toxicity dangers at low pH.

Appendix 6. Effect of other nutrients and liming on uptake and transport of nutrients.

Nutrient	Uptake Decreased by	Uptake Increased by	Transport to growing point decreased by
Calcium	Ammonium-nitrogen Magnesium Potassium		
Potassium	Ammonium-nitrogen Magnesium Calcium		
Magnesium	Ammonium-nitrogen Calcium Potassium		
Sulfur			Nitrogen
Chloride	Bromides		
Molybdenum	Sulfate	Phosphate Liming	
Zinc	Copper Liming Calcium Magnesium		Nitrogen
Boron	Liming		
Copper	Zinc		Nitrogen
Manganese	Calcium Magnesium Iron Liming	Ammonium-nitrogen	
Iron	Manganese Calcium Magnesium Liming	Ammonium-nitrogen	Phosphate

Appendix 7. Cross references of similar nutrient deficiency symptoms on various plant parts.

Whole Shoot

Symptoms	Nutrient deficiency				
Light green	N	S	Mn	Cu	Mo
Grey green	Zn				
Green	Ca				
Dark green	P	B	K		
Old leaves green	Fe	Mg			
New leaves pale, spindly	K				

Old Leaves

Symptoms	Deficiencies with symptoms in old leaves		Deficiencies with similar symptoms in leaves other than old leaves				
Tip and margin necrosis	N	P	P				
Whole leaf chlorosis	N		S	Mg	Fe	Cu	Mo
Tip necrosis	P		Mg	S			
Whole leaf necrosis	P						
Tip and margin necrosis	K		Mo				
Necrotic speckling	K		Mn				
Green arrow effect	K						

Appendix 7 (continued)

Middle Leaves

Symptoms	Deficiencies with symptoms in middle leaves	Deficiencies with similar symptoms in leaves other than middle leaves
Chlorosis general	Mo	S Mg Fe Cu N
Tip and margin necrosis	Mo	K
Central necrosis	Zn	Mn
Leaf collapse (central region)	Zn	Mn
Longitudinal striping	Mo	
Watersoaked appearance	Zn	B

Appendix 7 (continued)

Young Leaves

Symptoms	Deficiencies with symptoms on young leaves	Deficiencies with similar symptoms in leaves other than young leaves
Chlorosis general	S Mg Fe	
Chlorosis interveinal	Fe	
Chlorosis mottled	Mg	
Necrotic tipping	Mg S	P
Necrotic midleaf	Mn	Zn
Leaf collapse	Mn	Zn
Flecking and striping	Mn	
Folding and spindly	Mg	K
Watersoaked appearance	B	Zn
Leaf distortion	B	

Appendix 7 (continued)

Emerging Leaves

Symptoms	Deficiencies with symptoms in emerging leaves	Deficiencies with similar symptoms in leaves other than emerging leaves
Chlorosis general	Cu	S Mg Fe Mo N
Remains unopened	Ca	
Necrosis in center of shoot	Ca	
Withertip	Cu	
Terminal dieback	Cu Ca B	
Shoot collapse	Cu Ca	

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