Centro Internacional de Agricultura Tropical

Nutritional disorders of the cassava plant

STUDY GUIDE

To be used as a supplement to the audiotutorial unit in the same topic.

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Nutritional disorders of the cassava plant

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Contents

Objectives

The fundamental objective of this audiotutorial unit is to train the student to identify symptoms caused by nutritional disorders of the cassava plant.

This objective will have been accomplished if the student is able to:

1. Classify the elements according to their mobility (mobile, of intermediate mobility, and immobile) through the phloem of the cassava plant, and specify, from this classification, in which part of the cassava plant these symptoms can be expected to appear.
2. Describe the symptomatology in cassava caused by deficiencies of the macronutrients, N, P, and K; and secondary nutrients, S, Ca, and Mg, and cite the differences in the symptoms.
3. Describe the symptomatology in cassava caused by deficiencies of the micronutrients, B, Cu, Fe, Mn, and Zn, and state the differences in symptoms.
4. Describe the symptomatology in cassava caused by toxicities of Al, B, and Mn and give the differences in symptoms.
5. Indicate for each of the essential nutrients in what type of soils and/or under what conditions deficiencies of these nutrients are expected to be present in cassava.
6. Indicate in what type of soils and/or under what conditions toxicities of Al, B, and Mn can be expected to be present in cassava.
7. Describe the symptoms caused by nutritional problems due to salinity and alkalinity.
8. Classify cassava as tolerant, moderately susceptible, or susceptible, according to the degree of susceptibility the plant shows to deficiencies of the essential elements, N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, and Zn; to toxicity of Al, B, and Mn; and to disorders caused by soil salinity and alkalinity.

Introduction

Cassava is a crop that, although adapted to poor soil conditions, requires high rates of fertilizers to produce maximum yields and, at the same time, conserve soil fertility.

Figure 1 shows the main cassava-producing countries and the elements that most limit production of this crop in each country, according to the literature. In general, deficiency of phosphorus is most common in Latin American cassava-producing areas, while deficiencies of nitrogen and potassium are most limiting in Africa and Asia.

Plant symptoms provide the means for visually diagnosing nutrient deficiencies and mineral toxicities in the field; this method has the advantage that it does not depend directly on expensive equipment or laboratory services. Nevertheless, as different nutritional disorders can sometimes produce very similar symptoms, it is advisable to confirm any diagnosis by analyzing the plant tissue, the soil, or both.

Symptoms of clearly recognizable nutritional disorders in cassava are generally associated with severe conditions. In less critical cases, and particularly when major elements such as N, P, and K are deficient, there are no specific symptoms but only crop vigor and yield may be reduced. Again in this case, analyses of the soil and plant are a great help in making correct diagnoses of nutrient disorders.

The principal objective of this audiotutorial unit is to describe symptoms caused by nutrient deficiencies and mineral toxicities in cassava, so these symptoms can be used to diagnose nutritional problems.

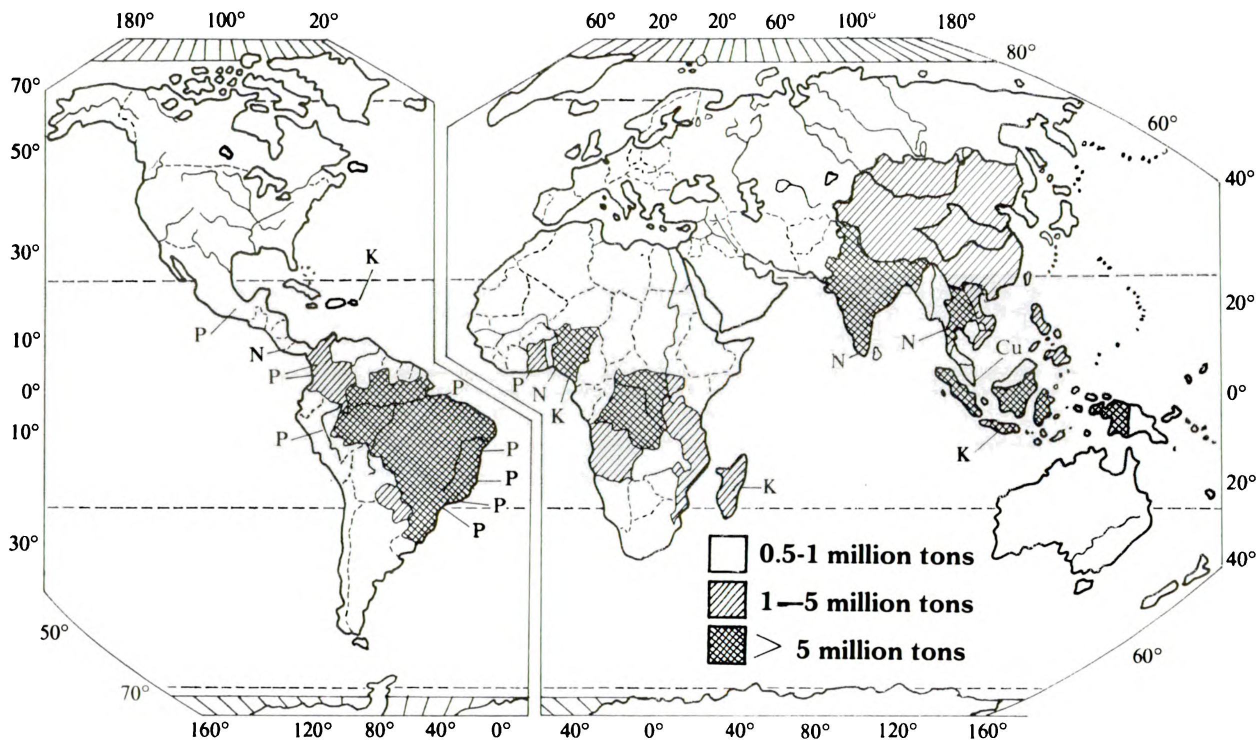

Figure 1. Major cassava growing areas and most-limiting nutrients.

Importance of the leaf position in visual diagnosis

Normal patterns of distribution and redistribution of mineral nutrients within the plant cause symptoms of nutritional disorders to occur in specific parts of the plant.

Consequently, in addition to observing how affected leaves appear on sick plants, it is necessary to look at the location of these same leaves.

Under deficiency conditions, most plants tend to remove elements such as nitrogen, phosphorus, potassium, magnesium, sodium, and chlorine that are found in older leaves and redistribute them among the younger, actively growing plant organs. Since these elements are redistributed through the phloem, they are known as "phloem-mobile" elements. Deficiency symptoms for any of these elements can be expected to show up in older leaves (the lower ones). This is the development pattern for symptoms that normally are observed in cassava, although the phloem mobility of nitrogen and also sulfur seems to be less in cassava than in other crops.

Calcium and boron are redistributed very little when they are deficient and, therefore, are known as "phloem-immobile" elements. Symptoms of their deficiencies appear on younger parts of the plant, such as shoots and root tips.

The other essential elements (Cu, Fe, Mn, Zn, and S) are considered to have intermediate mobility through the phloem, and their deficiency symptoms generally appear on the younger plant parts. However, when the supply of one of these elements has been insufficient during some growth period, deficiency symptoms may be found on leaves formed during that period and in between healthy leaves. As for sulfur, it seems that in some crops, including cassava, it is less mobile than are other elements, and it thus has been classified as having intermediate mobility.

When the soil solution contains an element in a concentration above the optimum, the excess that the plant takes up tends to accumulate in the leaves. Older leaves have higher concentrations of the nutrient because the accumulation has taken place in them for a longer period. Therefore, toxicity symptoms can be expected to appear first and be most prominent in older leaves. This is what happens normally, but when the excess of an element prevents the absorption of a second element or interferes with its utilization within the plant, the main observable symptoms may be those of a deficiency of the second element. In this case, the location of the symptoms will characterize the deficiency of the second element; that is, symptoms may or may not be present on older leaves.

In summary, depending on the elements' mobilities through the phloem, it is expected that in the cassava plant early deficiency symptoms appear on:

- Older leaves (lower ones)—for mobile elements
- Younger parts of the plant and expanded leaves—for elements of intermediate mobility
- Growing points, including root tips—for immobile elements

The essential elements are classified according to their mobility through the phloem in Table 1.

Table 1. Classification of essential elements according to their mobility through the phloem of the cassava plant.

Mobile	Intermediate mobility	Immobile
N	Cu	Ca
P	Fe	B
K	Mn	
Mg	Zn	
Na	S	
Cl		

Deficiencies of macronutrients and secondary nutrients

Table 2 summarizes the functions, characteristic deficiency symptoms, types of soils where the deficiency may be expected, and the reaction of cassava to a deficiency of each of the macronutrients and secondary nutrients involved in cassava nutrition.

Nitrogen (N) deficiency

Nitrogen is a basic component of proteins, chlorophyll, enzymes, hormones, and vitamins. It also is a constituent element of the cyanogenic glucosides linamarin and lotaustralina, which produce hydrogen cyanide (HCN).

Under severe nitrogen deficiency conditions, cassava plants become dwarfed, with low vigor and chlorotic lower leaves. Chlorosis does not advance inward from the apices and leaf edges, as happens with many other nutritional disorders, but, rather, the entire leaf becomes chlorotic at almost the same time. Close observation shows that the veins retain some of their green color, giving the leaves a slightly greenish coloring. The upper leaves on the plant are generally much paler than normal (Figure 2, center pages). Symptoms of moderate nitrogen deficiency in cassava are not always clearly recognizable, except for a decreased growth rate; however, the absence of specific symptoms does not necessarily mean that the plant has an adequate supply of nitrogen.

Cassava seems to tolerate nitrogen deficiency better than most crops, although differences have been found among cultivars.

Nitrogen deficiency is most common in sandy or very acid soils (Oxisols and Ultisols), where a low pH or toxic levels of Al and Mn may decrease the microbial decomposition of organic matter. It is also common on soils derived from volcanic ash; although these soils normally possess a considerable

Tabla 2. Summary of macronutrients and secondary nutrients in cassava.

Element	Function	Characteristic symptoms of the deficiency	Types of soils where the deficiency is expected	Reaction of cassava to the deficiency
N	Basic component of proteins, chlorophyll, enzymes, hormones, vitamins, cyanogenic glucosides (linamarin and lotaustralina)	Reduced plant growth; uniform chlorosis of the plant, which begins on lower leaves and extends over the whole plant. The entire leaf becomes chlorotic and veins retain little of their green color	Sandy and acid soils (Oxisols, Ultisols and those derived from volcanic ash)	Moderately tolerant
P	Basic component of nucleo-proteins, nucleic acids, phospholipids, and some enzymes; essential for phosphorylation, photosynthesis, respiration, and metabolism of carbohydrates, proteins, and lipids	Reduced plant growth-small leaves and thin stems; under acute conditions: uniform chlorosis of lower leaves, including the veins; upper leaves tend to retain their normal color. In some cultivars affected, leaves take on a purple and not yellow color. Affected leaves become flaccid and hang from the petioles, drying up and falling with time	Acid soils (Oxisols, Ultisols, Inceptisols)	Moderately susceptible, depending on the effectiveness of the mycorrhizal association
K	Essential for synthesis of proteins and lipids and transport of carbohydrates	Reduced plant growth, small leaves, excessive branching; under severe conditions: purple spots on older leaves; yellowing and necrosis of lower leaf tips and margins; fine cracks on upper stems and premature lignification of these same stems	Sandy and acid soils (Oxisols and Ultisols)	Susceptible, especially when cassava is grown continuously on the same plot

S	Component of some amino acids; essential for protein synthesis	Uniform chlorosis of both the lower and upper leaves; chlorosis is similar to that caused by nitrogen deficiency	Oxisols and Ultisols and on soils distant from industrial areas	Susceptible
Ca	Regulation of water in the plant	Reduced growth of the root system; necrosis and decomposition of the roots; curling of leaf tips and deformation of younger leaves.	Sandy and acid soils (Oxisols and Ultisols) with low base contents and high contents of exchangeable aluminum	Moderately tolerant
Mg	Component of chlorophyll; essential for photosynthesis	Certain reduction in plant height; interveinal chlorosis of lower leaves; under severe conditions: chlorotic areas that necrose	Sandy and acid soils (Oxisols, Ultisols and Inceptisols) with high levels of potassium and low magnesium	Susceptible

amount of organic matter, decomposition is slow and does not contribute much to the nitrogen supply.

Although little work has been done on the effects of crop rotation on cassava nutrition, observation in the field suggest that nitrogen deficiency is more probable when cassava is planted after a maize crop than when it is planted following a legume, such as beans. Consequently, costs for nitrogeneous fertilizers can be decreased substantially if legumes are included in the rotation system.

The normal content of nitrogen in the upper leaves of 3 to 5 month-old plants is between 5 and 6%, with a critical concentration of 5.7%. Petioles normally contain between 1 an 2% nitrogen, while stems and roots contain only between 0.25 and 1%.

Phosphorus (P) deficiency

Phosphorus is a basic component of the nucleoproteins, the nucleic acids, and the phospholipids, as well as the enzymes involved in transporting energy. Phosphorus is essential for certain physiological processes such as phosphorylation, photosynthesis, respiration, and synthesis of carbohydrates, proteins, and lipids.

A deficiency of phosphorus can substantially decrease cassava growth without any clearly visible symptoms. Thus, light and moderate deficiencies can be diagnosed only by foliar analysis, soil analysis, or field experiments. The most notable symptom of acute phosphorus deficiency that is easily recognized in the field is the uniform chlorosis that develops on lower leaves. These leaves cannot maintain their turgor and so hang from the petioles (Figure 3, center pages). Plants with a severe deficiency of phosphorus frequently have thinner stems, shorter petioles, narrower foliar lobes, and fewer lobes per leaf, than do normal ones.

Symptoms of phosphorus and nitrogen deficiencies resemble each other. Unlike with symptoms of nitrogen deficiency, in phosphorus-deficient plants the secondary and often the main veins of the lower leaves tend to have the same yellow color as the interveinal tissue. Interveinal areas adjacent to the petiole attachment point frequently retain some of their greenish color and the main veins can remain green for some time. Sometimes, the foliar edges of the lower chlorotic leaves curl upward before they completely lose their turgor and hang down from the petioles. Affected leaves of some cultivars turn a purple color instead of yellow and dry up and fall with time. The upper leaves of phosphorus-deficient plants appear healthy and retain their green or greenish-purple color and only a few lower leaves become yellow, unlike symptoms of nitrogen deficiency.

Normal concentrations of phosphorus in upper, fully expanded leaves vary between 0.3 and 0.5%, and the critical concentration has been determined as 0.44%. Petioles of upper leaves normally contain from 0.12 to 0.20% P, while contents of only 0.08 to 0.12% P are found in roots.

Cassava has not been observed to develop phosphorus deficiency symptoms unless this element is found in the soil in concentrations very much lower than that tolerated by other species. This is considered a clear indication of cassava's adaptation to soils with low phosphorus contents. Recent investigations indicate that in infertile soils, cassava depends to a great degree on mycorrhiza for absorption of phosphorus, and also possibly zinc. If the mycorrhiza are eliminated through sterilization, cassava becomes highly susceptible to phosphorus deficiency, and even though fertilized with this element, there may be no crop response.

Phosphorus deficiency is very common in acid soils, especially in those that have high levels of iron and aluminum, such as the Oxisols, Ultisols, and Inceptisols (Andepts).

Potassium (K) deficiency

Potassium is not a basic component of proteins, carbohydrates, and lipids, but it plays a role in their metabolism. It is also essential for translocation of carbohydrates.

Potassium deficiency, like that of phosphorus, is mainly characterized by a marked reduction in plant height; petioles are short and the leaves small. Only in severe cases of deficiency are specific symptoms observed. Initially, small purple or brown spots appear on old leaves, which curl upward from the foliar margins and, in some cases, downward from the tips. As the deficiency intensifies, chlorotic areas develop on the tips and edges of lower leaves and finally join and give way to a marginal necrosis. These leaves and their petioles grow old prematurely and fall (Figure 4, center pages). Excessive branching resulting in prostrate growth is another symptom.

In some cultivars with potassium deficiency, the development of fine cracks on the upper stem internodes and later the premature lignification of the upper part of the stem have been observed; the internodes are also very short, giving the upper stems a zig-zag appearance.

Normal cassava plants have a potassium concentration of 1.2 to 2.0% in the youngest, fully expanded leaves, from 1.5 to 3.0% in the petioles, and from 0.5 to 1.0% in the roots. Potassium contents vary much more in the petioles than in leaf blades, and, consequently, the former seems to be a better indicator of the plant's potassium level than are the blades. As with phosphorus and nitrogen contents, potassium decreases considerably from the upper to the lower leaves. High levels of calcium and/or magnesium decrease potassium absorption. It should be noted, however, that excessive applications of potassium can cause deficiencies of magnesium and/or calcium, due to the decreased absorption of these elements.

Cassava extracts large quantities of potassium from the soil. Each ton of fresh roots harvested contains approximately 3 kg of potassium; with a production of 30 tons of roots per hectare, about 90 kg of potassium is extracted from the soil. Therefore, continuous cassava production without adequate potassium fertilization can rapidly deplete soil reserves of this nutrient.

Because a cassava harvest extracts more potassium than any other element from the soil, potassium deficiency in cassava can show up in soils where other crops do not respond to fertilization with this element. Potassium deficiency has been found in sandy soils and in Oxisols and Ultisols with low levels of bases.

Sulfur (S) deficiency

Sulfur is a basic component of various amino acids and therefore is necessary for protein synthesis. Under sulf-deficiency conditions, plants accumulate excessive quantities of inorganic nitrogen, amino acids, and amides in the leaves without forming proteins.

Sulfur is usually classified as a phloem-mobile element. However, in many crops, symptoms of sulfur deficiency are not as restricted to lower leaves as are deficiency symptoms of other phloem-mobile elements. This suggests that sulfur is relatively immobile.

Leaves deficient in sulfur are uniformly pale green to yellow, similar to nitrogen deficient leaves (Figure 5, center pages). Symptoms normally appear first on upper leaves, but later extend over the whole plant.

Plants grown in the field generally have sulfur concentrations from 0.3 to 0.4% in the upper, fully expanded leaf blades; a critical concentration of 0.32% has been determined in work at CIAT. Petioles have lower sulfur concentrations (0.13 to 0.15%) than the leaves, while roots contain from 0.05 to 0.06% sulfur.

Cassava appears to be more susceptible than other crop to sulfur deficiency. Sulfur deficiency has been recorded on many Oxisols and Ultisols of Tropical America and also in Australia; it is more frequent in zones away from industrial areas where the atmosphere does not contain much of this element.

Calcium (Ca) deficiency

Calcium has an important function in regulating water in the plant.

Calcium has little phloem mobility, so the development of calcium-deficiency symptoms in actively growing tissues is a consequence of the slight redistribution of absorbed calcium in the plant. The plant does not develop a healthy root system, and roots become necrotic and decompose. Calcium deficiency causes curling of the tips and deformation of the youngest leaves, although this has not been observed in all cultivars (Figure 6, center pages). Calcium-deficiency symptoms are seldom seen in the field; however, on acid soils a response to application of low levels of lime has been obtained due to correction of calcium deficiency.

Normal levels of calcium in upper, fully expanded leaves vary between 0.6 and 1.5%, while levels in the corresponding leaf petioles are from 1.5 to 3.0%. As would be expected from an element having little mobility, calcium levels tend to be greater in the lower leaves than in higher ones.

Cassava seems to tolerate low levels of calcium better than other crops. Calcium deficiency occurs most frequently in sandy soils, and in Oxisols and Ultisols with low base contents and high contents of exchangeable aluminum. Beneficial effects of low application rates (500-1000 kg/ha)of lime on some acid soils probably is due to correcting calcium deficiency and not to decreasing the levels of soluble aluminum in the soil. It should be noted, however, that excessive use of lime can induce deficiencies of zinc, potassium, magnesium, iron, manganese, or copper.

Magnesium (Mg) deficiency

Magnesium is a component of chlorophyll and thus is essential for photosynthesis in the plant.

The characteristic symptom of magnesium deficiency is interveinal chlorosis of the lower leaves, beginning on the tips and edges of the foliar lobes and extending inward between the central and secondary veins. The chlorotic tissue is generally yellow (Figure 7, center pages), and sometimes pale green. When deficiency of magnesium is severe, chlorotic areas can become necrotic and turn brown or whitish.

High concentrations of potassium have been shown to inhibit magnesium absorption, and magnesium deficiency can easily be induced by applying higher than optimum levels of potassium.

It has been determined at CIAT that the critical level for magnesium deficiency is 0.29% in the cassava variety CMC-40. Magnesium concentrations in deficient plants were generally greater in leaf blades that in the petioles. Nevertheless, in plants receiving adequate quantities of magnesium, concentrations in the blades and petioles were similar or sometimes greater in the petioles.

Cassava can be rather susceptible to magnesium deficiency, which is most frequent in sandy soils and in Ultisols and Oxisols with low base levels; deficiencies have also been observed on volcanic ash soils with a high level of potassium and a low level of magnesium.

Figure 2. N Deficiency

Figure 3. P Deficiency

Figure 4. K Deficiency

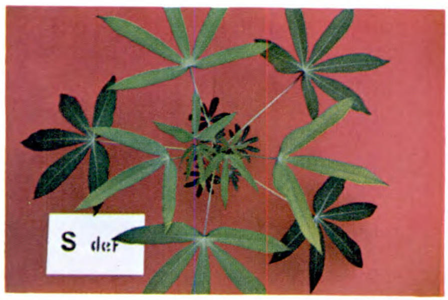

Figure 5. S Deficiency

Figure 6. Ca Deficiency

Figure 7. Mg Deficiency

Figure 8. B Deficiency

Figure 9. Cu Deficiency

Figure 10. Fe Deficiency

Figure 11. Mn Deficiency

Figure 12. Zn Deficiency

Figure 13. Al Toxicity

Figure 14. B Toxicity

Figure 15. Mn Toxicity

Figure 16. Symptoms caused by salinity-alcalinity

Evaluation

1. List the compounds in which nitrogen is a basic component.
2. List the compounds in which phosphorus is a basic component.
3. Which of the macronutrients and the secondary nutrients enter into the metabolism of proteins, carbohydrates, and lipids? Which are involved in photosynthesis?
4. Classify the macronutrients and secondary nutrients according to their mobility through the phloem. Where in the cassava plant can early symptoms of deficiencies of these nutrients be expected to appear?
5. Which of the macronutrients and secondary nutrients cause uniform chlorosis in cassava? Which ones cause interveinal chlorosis?
6. How are symptoms of deficiencies of nitrogen and sulfur differentiated?; symptoms of nitrogen and phosphorus deficiencies?
7. Describe the symptoms caused by calcium and magnesium deficiencies.
8. How does chlorosis from nitrogen deficiency differ from that of magnesium deficiency?
9. List the types of soils where deficiencies of macronutrients and secondary nutrients could be expected.
10. Classify cassava as tolerant, moderately susceptible, or susceptible, according to its reaction to a deficiency of each of the macronutrients and secondary nutrients.

Deficiency of micronutrients

Micronutrients have multiple functions in plants where they act as cofactors and enzymes in many metabolic processes.
Table 3 summarizes the deficiency characteristics, soil types where deficiencies can be expected, and the reaction of cassava to the deficiency of each micronutrient involved in cassava nutrition.

Boron (B) deficiency

Symptoms of boron deficiency are rarely seen in the field, but they can be produced easily in plants grown in nutrient solutions.

Since boron, like calcium, is an element with little mobility through the phloem, deficiency symptoms appear mainly in young parts of the plant such as shoots and root tips.

First symptoms generally are seen on the roots, which show poor development and sometimes death of the root tips. These symptoms are sometimes followed by the emergence of short lateral roots having thickened ends; however, not all cultivars present this symptom.

Plants deficient in boron tend to be small because of their reduced internode length. Fully expanded leaves develop numerous small pale gray or brown spots, concentrated mainly on the tips and on the margins of foliar lobes (Figure 8, center pages). Severely affected upper leaves are small and deformed and have short petioles.

Another symptom of boron deficiency is the development of localized lesions on stems and the upper petioles. Lesions at first exude a sticky brown substance and may later turn into cankers.

Boron concentrations in upper leaves of normal plants fluctuate between 20 and 100 ug/g. It has been suggested that a critical concentration for boron in cassava is approximately 17 ug/g in aerial parts of the plant.

Table 3. Summary of micronutrient nutrition in cassava.

Element	Characteristic symptoms of the deficiency	Types of soils (or conditions) where the deficiency is expected or where there are responses to the element	Reaction of cassava to the deficiency
B	Reduced plant height and internodes, short petioles, small and deformed younger leaves; pale gray or brown spots on completely expanded leaves; sticky exudate on stem and petioles; reduced lateral development of roots.	Soils of southern India	Tolerant
Cu	Uniform chlorosis and deformation of upper leaves, upward curling of foliar tips and edges, necrosis of the tips; long, drooping petioles of completely expanded leaves; reduced root growth; plant die-back.	Peat soils	Moderately tolerant
Fe	Chlorosis of upper leaves and petioles; both leaves and petiole turn white under severe conditions; reduced plant growth; young leaves are small but not deformed.	Calcareous soils (Yucatan Peninsula of Mexico); alkaline soils (Salem District of India); sandy, organic and volcanic ash soils with high levels of manganese	Moderately tolerant
Mn	Interveinal chlorosis of the upper or middle leaves that gives the leaves a "fish skeleton" appearance; uniform chlorosis under severe conditions; reduced plant growth; young leaves are small but not deformed.	Calcareous soils (Yucatan Peninsula of Mexico); sandy soils with a high pH (Colombia); sand, acid soils (northeastern Brazil); organic soils.	Moderately tolerant
Zn	Small, yellow or white interveinal spots on young leaves; under severe conditions, these leaves have narrow lobes, a pale and uniform chlorosis, and necrotic tips.	Both acid and alkaline soils	Very susceptible

Cassava seems to be tolerant to boron deficiency, since symptoms have rarely been seen in the field. In Colombia, no response to this element was obtained even on soils with low boron contents; however, on acid soils in southern India, the response has been significant.

Experiments on crops grown in nutrient solution at various temperatures showed that at 19°C boron deficiency could be induced; therefore, it is probable that boron deficiency could appear in colder regions.

Copper (Cu) deficiency

Copper deficiency is not very common in cassava, but it drastically reduces yields on the peat soils of southern Malaysia.

The main symptoms of copper deficiency are a uniform chlorosis and deformation of young leaves. Normally, the foliar tips necrose and leaves curl up (Figure 9, center pages). The length of stem internodes does not decrease much, so that plant height remains more or less normal. Leaves of the middle part of the plant frequently are suspended from abnormally long and drooping petioles.

When copper deficiency is severe, die-back occurs at the tips of the branches; plants resprout from the basal part of the main stem. Root development may also be markedly reduced, causing copper-deficient plants to become susceptible to drought.

Normal contents of copper fluctuate between 7 and 15 ug/g in the upper, fully expanded leaves, and from 2 to 10 ug/g in the roots. A copper content of 14 ug/g has been found in plants that had received an adequate quantity of the element, and a content of 7 ug/g was present in copper-deficient plants. Experiments done at the University of Queensland with plants in nutrient solutions indicated a critical concentration of 7 ug/g in the youngest, fully expanded leaf.

Copper deficiency tends to show up in acid, sandy soils with a low content of copper, and in organic or alkaline soils that have a low copper availability. However, severe copper deficiency in cassava has been observed only in peat soils.

This element is very toxic when applied at high rates and so it is advisable to apply low rates on sandy soils. Immersing cassava stakes in a solution of 5% copper sulfate severely affected sprouting.

Iron (Fe) deficiency

Chlorosis of the young leaves is a characteristic of iron deficiency; initially, they are a uniform pale green with the veins a darker green, similar to plants suffering from nitrogen deficiency. As iron deficiency intensifies, the veins lose their color and all of the leaf, including the petiole, turns yellow and afterward, almost white (Figure 10, center pages).

Leaves tend to be smaller than normal, but not deformed; the lobes still have the same length:width ratio as normal leaves. Plant growth also is notably reduced. High levels of manganese, zinc, or copper can induce iron-deficiency symptoms, which disappear when iron levels are increased. Cassava tolerates iron deficiency better than other crops, such as maize or rice.

Iron deficiency is not common in cassava, but it has been observed on calcareous soils of the Yucatan Peninsula in Mexico, and on alkaline soils (pH 8.0) in the Salem District in southern India. Deficiencies of zinc and manganese also were observed on these soils. Iron deficiency is most common on calcareous soils; in addition, it shows up on sandy, organic, and volcanic ash soils with high levels of manganese. Excessive liming or fertilizing with high rates of phosphorus can also induce iron deficiency.

Normal plants have iron contents of from 60 to 200 ug/g in the upper, fully expanded leaves, while their petioles contain only 30 to 50 ug/g. Therefore, to make an accurate diagnosis, leaves and petioles should never be mixed in the same sample.

Experiments at the University of Queensland, with plants in nutrient solutions, indicated a critical concentration of 122 ug/g for iron deficiency in the youngest, fully expanded leaf.

Manganese (Mn) deficiency

Manganese deficiency is characterized by an interveinal chlorosis of recently expanded leaves (Figure 11, center pages). Two characteristics distinguish this chlorosis from that caused by iron deficiency. First, when the plant is deficient in manganese, the veins and tissue adjacent to them remain green, standing out clearly over the yellow background and appearing like a "fish skeleton". If iron deficiency is involved, only the veins remain green when symptoms first appear, but adjacent tissue is chlorotic and not green. Second, symptoms of manganese deficiency can generally be seen on already expanded leaves but not on the younger ones. On the other hand, when manganese deficiency is severe, these differences may disappear and affected leaves can become totally chlorotic with the young leaves also showing symptoms. As in the case of iron deficiency, affected leaves are not deformed, but they may be smaller than normal; plant height is also reduced.

Conditions in well-aerated soils favor the oxidation of available Mn^{++} to insoluble manganese oxides. As a consequence, manganese deficiency tends to be severe during dry periods or in better-drained areas of the field. Due to these dry periods, which change the manganese availability, deficiency symptoms may appear on any part of the plant.

Manganese deficiency is not common in cassava but has been observed in calcareous soils of the Yucatan Peninsula of Mexico, in sandy soils with high pH levels in Colombia, and on sandy, acid soils in northeastern Brazil. Manganese deficiency can also be found in organic soils.

The content of manganese in the upper, fully expanded leaves of normal plants range from 50 to 250 ug/g. Lower leaves tend to show higher concentrations than the upper leaves, especially after excessive rates of manganese have been applied. The critical concentration in the younger, fully expanded leaves is 60 ug/g, according to investigations with plants in nutrient solution.

Zinc (Zn) deficiency

Zinc deficiency is very common in cassava. In young leaves it causes an interveinal chlorosis with the following characteristics: leaves initially have a normal green color, but they develop small, white or light-yellow chlorotic spots between the veins; the shape and color of these spots vary according to the cultivar. Each new leaf that the plant produces is smaller and more chlorotic and foliar lobes become narrow, take on a light green to white color, and curl upward. When deficiency is severe, the foliar tips necrose. The basal lobes of healthy leaves normally point toward the stem, but under zinc deficiency conditions, these two lobes point outward (Figure 12, center pages).

Although zinc deficiency mainly affects young leaves, older leaves of some cultivars develop necrotic spots very similar to those produced by boron toxicity or infection caused by white leaf spot *(Phaeoramularia manihotis)*.

Since the growing points are the sites affected most, zinc deficiency can drastically decrease cassava plant growth and yield.

Plants generally show symptoms of zinc deficiency shortly after sprouting, if deficiency is not severe, plants can recuperate once they have established a good root system. In this case, healthy leaves appear above affected ones; that is, deficiency symptoms are seen on the old leaves but not the younger ones.

Zinc-deficiency symptoms in cassava have been observed throughout the world, on both acid and alkaline soils. On alkaline soils, deficiency is due to the decreasing availability of this element at high pH; on acid soils, because of low contents of zinc. Large differences exist between cultivars as to susceptibility, and cultivars can be selected that tolerate low contents of zinc in the soil.

Normal zinc levels in young, fully expanded leaf blades vary from 50 to 100 ug/g. Deficiency symptoms for this nutrient generally are observed when zinc concentrations are below 20 ug/g in upper leaves. In plants grown in nutrient solution, the critical concentration in the youngest, fully expanded leaf was 37 ug/g.

Evaluation

1. What is the degree of susceptibility of cassava to deficiencies of B, Cu, Fe, Mn, and Zn?

2. It is possible to find boron deficiency in regions with__________ climates and copper deficiency in _________ soils.

3. Zinc deficiency can be present in both __________ and ___________ soils.

4. How can deficiencies of Mn and Fe be differentiated?

5. Which of the micronutrient deficiencies cause(s) leaf deformation?

6. Classify the micronutrients according to their mobility through the phloem. Where on the plant would the early symptoms caused by deficiencies of these nutrients be expected to appear?

7. Describe the symtoms that characterize zinc deficiency.

8. Describe the symptoms that characterize copper deficiency.

9. Describe the symptoms that characterize boron deficiency.

Toxicities

Table 4 gives the main considerations about toxicities in cassava caused by aluminum, boron, and manganese.

Aluminum (Al) toxicity

Aluminum toxicity is an important component of the infertility complex found on acid soils in many tropical areas. However, it is difficult to separate the specific effects of high concentrations of aluminum from other factors associated with acid soils, such as low pH and deficiencies of phosphorus, calcium, magnesium, and molybdenum.

Aluminum solubility is low in neutral or slightly acid soils, but it increases significantly at pH's below 5.0. At these low pH levels, it is also difficult to separate the effects of aluminum ions from those of hydrogen ions. Moreover, solubility of phosphates is low in the presence of high concentrations of aluminum, so that phosphorus deficiency is often associate with aluminum toxicity. On the other hand, acid soils generally have a low content of available calcium, white aluminum has also been shown to be a powerful inhibitor of calcium absorption. Therefore, symptoms of calcium deficiency can be associated with aluminum toxicity.

High concentrations of aluminum in the soil solution mainly affect root development and the height and vigor of the plant. Aluminum toxicity sometimes produces an interveinal chlorosis in the lower leaves with the intensity of this chlorosis diminishing from the tip to the base of each lobe. Occasionally, lightly colored necrotic spots develop within the chlorotic areas. Aluminum toxicity also adversely affects root growth, and some cultivars are much more susceptible to root damage than others (Figure 13, center pages).

Table 4. Principal factors of Al, B, and Mn toxicities and salinity and alkalinity problems in cassava

Nutritional problem	Characteristic symptoms	Types of soils and/or conditions where the problem is expected	Reaction of cassava to the problem
Al toxicity	Reduction in height and vigor of the plant and in root growth; under severe conditions, chlorosis of older leaves.	Acid Oxisols, Ultisols, and Inceptisols with pH levels below 5.0	Tolerates up to 80% Al saturation
B toxicity	Dwarfing and chlorosis in lower leaves; necrotic spots on lower leaves	Alkaline soils having high levels of B; soils with excessive rates of boron applied	a/
Mn toxicity	Small brownish to purple spots along the veins of the lower leaves; affected leaves yellow, become flaccid and fall; upper leaves may show symptoms of Fe deficiency since Mn inhibits absorption of Fe	Poorly drained acid soils	Moderately tolerant
Salinity and alkalinity	Under moderate conditions, generalized chlorosis of the plant and a decrease in growth. Under severe conditions, necrosis of tips and margins of young leaves with defoliation. Die-back of the plant	Soils with pH above 7.9 and conductivity greater than 0.05 mmhos/cm; Na saturarion above 2.5% in both coastal areas and valleys with low precipitation and high evaporation	Susceptible

a/ Not observed under natural field conditions.

Results of field and greenhouse experiments suggest that cassava is more tolerant to aluminum toxicity than other crops, such as maize, sorghum, rice, soybeans, and beans. In general, cassava tolerates high levels of aluminum in the soil; however, differences exist between cultivars. Research at CIAT indicates that cassava generally tolerates an aluminum saturation up to 80% of the exchangeable-cation complex of the soil, whereas many other crops are severely affected by aluminum saturation levels below 50%.

Aluminum toxicity is common on acid Oxisols, Ultisols, and Inceptisols with a pH 5.0. Rarely is it necessary to apply high rates of lime to cassava to decrease aluminum toxicity; this can be counterproductive by inducing micronutrient deficiencies, especially of zinc.

Boron (B) toxicity

In experiments in nutrient solutions and in sand, boron toxicity has resulted in the development of whitish or grayish necrotic spots on the lower leaves (Figure 14, center pages). These spots are generally surrounded by halos of darker tissue; later the leaf spots become necrotic and fall away, leaving the leaf margins ragged and torn. In alkaline soils in which an excess of boron had been applied, plants showed poor vigor and chlorosis on lower leaves; the intensity of the chlorosis was greater on the tips of the lobes.

Boron toxicity has been observed in the field only after applying high rates of boron fertilizers or on plants growing from stakes that had been treated with boron; plants generally recuperated. Experiences with other crops suggest that natural boron toxicity in cassava is to be expected in some alkaline soils having high levels of boron.

The critical concentration for boron toxicity in the aerial part of young plants has been determined as 140 ug/g.

Manganese (Mn) toxicity

The first symptom of manganese toxicity is usually the appearance of small brown or purple spots concentrated along the veins of lower leaves (Figure 15, center pages). As toxicity increases, the foliar areas without spots take on a yellowish or greenish-yellow color; later these leaves become flaccid, hang from the petioles, and finally fall. Manganese toxicity affects growth of both the aerial part and the root system.

A high supply of manganese inhibits iron absorption so that the plant may show iron-deficiency symptoms on its upper leaves and manganese-toxicity symptoms on the lower ones.

Cassava has been found to be more tolerant to manganese toxicity than are soybeans and beans and less tolerant than crops like pigeonpeas and *Centrosema*.

Manganese toxicity occurs mainly in acid soils. In Colombia, it is common in soils derived from volcanic ash. Since manganese oxides are reduced to Mn^{++} under anaerobic conditions, manganese toxicity is greater in poorly drained soils during the rainy season. Symptoms of severe toxicity and partial defoliation may also show up during the dry season due to excessive accumulation of the element in the lower leaves while the plant is not growing because of drought.

Manganese toxicity can be corrected by improving soil drainage and by applying lime, which increases soil pH and decreases manganese solubility.

Critical levels for manganese toxicity varied from 250 to 1450 ug/g in the aerial part of young plants of different cultivars. A level of 1000 ug/g in lower leaves has been associated with manganese toxicity; in this case, the concentration was greater in older leaves than in the younger ones.

Salinity and alkalinity

Although cassava is rather tolerant of acid soils, it is sensitive to a high pH and to problems produced by salinity, alkalinity, and poor drainage. Also, micronutrient deficiencies can be induced in high pH soils. Table 4 also indicates the principal factors of salinity/alkalinity problems in cassava. The symptoms are characterized by a uniform yellowing of the upper leaves, with this chlorosis extending rapidly over the entire plant. Young leaves show necrosis on the tips and edges, and these leaves later fall (Figure 16, center pages). The plant also gradually dies back, beginning at the tips and continuing along the stem until the whole plant finally dies. Under less severe conditions, the plant shows a generalized chlorosis and its growth and yield decrease.

Yields of most cultivars can be expected to decrease when the soil pH is above 7.9, conductivity values are greater than 0.5 mmhos/cm, and sodium saturation is above 2.5%. Cassava is more susceptible to these factors of salinity and alkalinity than beans, maize, sorghum, or rice.

Salinity is caused by high concentrations of salts in the soil solution, among which the chlorides and sulfates of sodium and magnesium are the most injurious to plants.

Salinity and alkalinity are evidenced by the so-called "saline patches" or "salt spots" (Figure 17), and occur principally in coastal areas or in valleys having relatively low precipitation and high evaporation.

Leaching of the salts by washing with good-quality water, improving drainage, and applying amendments, including sulfur and gypsum, can help lessen the problem, but the best recommended practice is planting tolerant cultivars.

Figure 17. Salt spot.

Evaluation

1. Explain why aluminum toxicity is an important component of the infertility problem in acid soils of the tropics.
2. Describe the symptoms caused by aluminum toxicity.
3. Describe the symptoms caused by boron toxicity and state under what conditions or in what type of soil boron toxicity can be expected to be present.
4. Describe the symptoms of manganese toxicity and explain in what soil type toxicity of this element is likely to occur.
5. Which elements, when present in toxic quantities, cause symptoms of iron deficiency?
6. Describe the symptoms caused by salinity problems.
7. List the conditions characterizing saline-alkaline soils.
8. What is the degree of susceptibility of cassava to toxicities of Al, B, and Mn and to salinity-alkalinity?

Summary

Cassava tolerates better than other crops a low pH (optimum ranges: 5.5 to 7.5), low concentrations of N, K, Ca, and B, and high concentrations of Al and Mn; however, to obtain maximum production, cassava's external requirements for N, K, and Ca are similar to those of other crops but can be greater in the case of P. Similarly, cassava grows relatively well on acid soils of low fertility, but may need considerable fertilization to produce maximum yields.

On the three types of soils (Oxisols, Ultisols, and Inceptisols) , representing the greatest area in the tropics, phosphorus is the element most limiting for cassava production. Recent research has demonstrated that cassava is highly dependent on mycorrhiza for P absorption in soils having a low content of this element. Also, it is susceptible to deficiencies of sulfur and mangnesium.

Cassava responds to low rates of lime, but does not tolerate excessive liming, which can induce micronutrient deficiencies; it is especially susceptible to zinc deficiency.

Micronutrient deficiencies in cassava are not reported frequently, but these may be more common than is generally recognized.

As has been mentioned, cassava is rather tolerant of acid soils but it does not tolerate a high pH and is rather sensitive to salinity and alkalinity.

Complementary Readings

ASHER, C.J.; EDWARDS, D.G. and HOWELER, R.H. 1980. Desórdenes nutricionales de la yuca. Cali, Colombia. Centro Internacional de Agricultura Tropical, CIAT. 48 p. (English version available).

CENTRO INTERNACIONAL DE AGRICULTURA TROPICAL. 1977. Cassava production systems program. *In* Annual report 1976. Cali, Colombia, pp. B-1-B-76.

———. 1978. Cassava program. *In* Annual report 1977. Cali, Colombia, pp. C-1-C-68.

———. 1979. Cassava program. *In* Annual report 1978. Cali, Colombia, pp. A-1-A-100.

———. 1981. Cassava program. *In* Annual report 1980. Cali, Colombia.

HOWELER, R.H. 1978. The mineral nutrition and fertilization of cassava. *In* Cassava Production Course. Cali, Colombia, Centro Internacional de Agricultura Tropical, CIAT. pp. 247-292.

———. 1978. Nutrición mineral y fertilización de la yuca (*Manihot esculenta* Crantz). Cali, Colombia, Centro Internacional de Agricultura Tropical, CIAT. Serie 09SC-4. 55 p.

Notes

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