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Breeding for mineral stress tolerance and management strategies in cassava

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Abstract

Cassava is a major staple for more than 200 million people in East and Central Africa. In this region, cassava became an insurance crop and grows in marginal land with a limited supply of agricultural input and pesticides. Under these conditions cassava can produce reasonably good yields where most other crops would fail. Like any other crop, cassava only realizes its high yield potential when it is supplied with adequate nutrients. Cassava production is highly affected by micro elements beyond its requirement. In acid soils, cassava limits its growth and yields due to nutrient deficiencies and mineral toxicities. Typically, the plant has smaller root systems and restricts their ability to acquire water and nutrients. Cassava is seldom grown on saline alkaline soils and the crop is rather sensitive to high p^H and often problems of micronutrient deficiencies especially zinc. Moreover, the most critical problem limiting sustainable cassava production, and productivity are lack of improved varieties, which are adaptable to wide range of agro-ecologies conditions, tolerance to a biotic stresses and other emerging threats. Therefore, breeding on mineral stress tolerance in association with appropriate management strategies have tremendous impact on sustainable production, to improve the livelihood of rural households and to develop management strategies of cassava.

Keywords: Breeding, Cassava, Management, Mineral stress, Tolerance

Introduction

Cassava (*Mannihot esculenta* Cranz) is the second most important staple food being the major source of food energy in sub-Saharan Africa that could play a major role in sustaining food security for more than 200 million people in East and Central Africa (ECA), mostly in the rural areas (IFAD and FAO. 2000; Montagnac *et al.,* 2009). It is the second most important staple crop in Africa after maize (Allem, 2002). It is the 6th most consumed crops in the world. The Abuja Declaration (2006) identified cassava as one of the crops with the greatest potential to combat poverty and food and nutrition insecurity in Africa.

In the ECA sub-region, over 30 million tons are produced annually, which is more than any other staple crop. On average, the value of cassava production ranks highest among all crops produced in the ECA region. The crop has been prioritized by the New Partnership for African Development (NEPAD) as a 'poverty fighter and an insurance crop' which will spur industrial development in Africa. Moreover, it is a strategic crops to address the Comprehensive African Agriculture Development Program (CAADP) pillar 3 (i.e., increasing food supply, reducing hunger and improving responses to food emergency crises). Indeed, the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) strategy 2007–2016 points to the fact that, the biggest impact on poverty reduction in ECA will come from concentrating on staples crops with cassava ranking highest among the staples with a growing domestic market.

Despite its domestication thousands of years ago by natives of the New World, until the early 20th century cassava was a neglected and less known crop outside the tropical and subtropical belt of Africa, Asia and Latin America, where it is commonly cultivated. However, during the colonial period, mainly in East and South Africa, the plant drew the attentions of the European colonists, and hence was generally researched for its importance as anti-famine food security source by subsistence farming systems.

The unique character of cassava, it can be produced in waste lands when other crops are not survive. However, acid soils limit crop yields due to nutrient deficiencies and mineral toxicities (Kawano, 1990). Non-adapted plants grown on acid soils typically have smaller root systems because high concentrations of soluble aluminum (Al^{3+})

inhibit root elongation (Fermont, 2009). This restricts their ability to acquire water and nutrients from the soil. Plants vary widely in their capacity to tolerate acid soils and even genotypes within species show significant variation. Study on the physiology and genetics controlling this variability is scanty. Currently, lack of improved varieties which are adaptable to wide range of agro-ecologies, lack of resistant varieties to biotic and a biotic stress and other emerging threats, use of traditional management practices followed by farmers and shortage of planting materials and continuous use of low genetic potential cassava varieties are the most critical problem limiting sustainable cassava production in world in general in Africa in particular. Although, there is a little efforts so far done by breeders to develop cassava varieties tolerant to a biotic stresses so as to make it easier for farmers, to achieve the crop's production and expanded utilization goals for income and food security, however, its results is insufficient and no resistant variety was developed. Cognizant to these facts, this review article was design to assess the range of tolerance of cassava for micro elements with its management and develop breeding strategies of cassava production for variable environments.

Mineral nutrient status of cassava: Cassava is well adapted to poor soils and relatively tolerant to drought and grown under marginal soil and climatic conditions and often with cry limited inputs of fertilizers and pesticides. Under these conditions cassava can still produce reasonably good yields where most other crops would fail. Like any other crop, cassava only realizes its high yield potential when it is supplied with adequate light, nutrients and water (Kawano, 1990). Thus, when grown on infertile soils cassava responds well to the application of chemical fertilizers and manures or to the incorporation of green manures. Symptoms of nutrition disorders in cassava, especially the deficiencies of nitrogen (N), phosphorus (P) and potassium (K), are often not readily recognized and farmers are unaware that their crop may be suffering from nutrition stresses leading to reduced yields (Fermont, 2009). This makes the diagnosis of nutrition disorders rather difficult, and in some cases the diagnosis can be made only after soil and/or plant tissue analyses. For this reason, the most common symptoms of various nutrition disorders and critical levels for nutrition deficiencies or toxicities in the plant tissue (Table-1) and soil (Table 2) are given. The values can be used as a general guide for the interpretation of leaf or soil analysis results. Since nutrient concentrations in the plant vary among the different tissues and change during the growth cycle, it is important to standardize the sampling of plant tissue for diagnosing nutrition disorders. It is recommended to sample the blades (without petioles) of youngest fully expanded leaves at 3-4 months after planting (Kawano, 1990).

The effect of soil acidity and aluminum toxicity : Acid soils are often low in basic cations, prone to crusting, erosion and compaction but physical constraints and nutrient deficiencies are rarely the main reasons crop plants grow poorly on these soils. Instead, soluble Al^{3+} is the major factor limiting growth due to it inhibits root growth at very low concentrations. Indeed the inhibition of root growth is the primary symptom of plant stress on acid soils. There are exceptions because many plants endemic to tropical and sub-tropical regions cope well and even thrive on acid soils. The growth of these species can even be stimulated by Al^{3+} and some accumulate high concentrations in their leaves. Cassava is well adapted to acid soils due to tolerance to high levels of aluminum (Al) in soil solution. However, in high acid soils with high levels of exchangeable Al and/or low levels of calcium (Ca) the root growth and shoot development became very small and the plant suffer from Al toxicity (Fermont, 2009). This has been observed mainly in high acid Oxisols with a soil pH ranges from 4.2-4.5 and an Al saturation of about 85%. However, in peat soils, with little exchangeable Al but high levels of exchange acidity, cassava produced very well in areas with a pH of 3.4, but showed severe nutrition disorders in areas with pH 3.1 and 6.5 cmol exchange acidity/kg. Symptoms of Al toxicity are not very clear. In some varieties the lower leaves show interveinal yellowing and necrosis, but in most varieties there are few recognizable symptoms: plants are small and lack normal vigor. In nutrient solution culture with high concentrations of Al, cassava plants were found to be small with a short and stubby root system.

Both Al toxicity and soil acidity stress can be prevented by the application of lime, which will decrease the Al saturation and raise soil pH (Fermont, 2009). Rates of 0.5-2.0 t/ha of calcitic or dolomitic lime are generally required to obtain maximum yields in very acid mineral soils, while 3 t/ha of hydrated lime are required for maximum yield on peat soils. Higher rates of liming may result in the induction of micronutrient deficiencies (Spain et at. 1975).

Salinity and alkaline: Cassava is seldom grown on saline alkaline soils because it is not well adapted to these conditions. The crop is rather sensitive to high p^H and the associated problems of salinity, alkalinity and sometimes poor drainage. Moreover, at high pH there are often problems of micronutrient deficiencies, especially that of zinc (Zn). Cassava plants suffering from salinity problems show a uniform yellowing of leaves, which starts at the top of the plant but quickly proceeds downward. Under moderate salinity stress the symptoms are similar to those of Fe deficiency. Under severe stress, the lower leaves become necrotic and fall off and plant growth is severely affected, sometimes leading to plant death. Soil salinity can be improved by leaching out the salts through flooding and draining, while alkalinity can be reduced by the application of elemental sulfur (S) or gypsum; however, this is a long and expensive process. Since cassava varieties differ markedly in their tolerance to salinity problems it is more practical to select adapted varieties and apply micro nutrients when necessary.

The deficiency of essential plant nutrient and management strategies on cassava:

Nitrogen deficiency: Nitrogen deficiency is commonly observed when cassava is grown on light-textured soils with low organic matter content or in very acid soils with a low rate of N mineralization. Nitrogen deficiency seems to be more common in tropical areas. Some varieties show no symptoms of N deficiency, but plants remain small and weak while root yields are markedly reduced (Keating *et al.*, 1988). Other varieties show clear symptoms of N deficiency, plants are uniformly chlorotic and leaves have a uniform light green or yellowish color. Although N-deficiency symptoms first appear in the bottom leaves, they rapidly spread throughout the plant, leading to a generalized chlorosis. Nitrogen-deficient leaves are smaller and may have less lobes and shorter petioles than normal leaves. The critical level for N deficiency in youngest fully expanded leaf blades at 3-4 months after planting is about 5.3% N, while the sufficiency range is about 5.1-5.8% N (Table 1). The critical level is defined as that concentration corresponding to 95% of maximum yield, while the sufficiency range is the concentration corresponding to 90-100% of maximum yield). To control N deficiency in cassava, an application of 50-100 kg N/ha in the form of urea or as a compound fertilizer during the first 2-3 months after planting is recommended (Keating et al., 1988). In light-textured soils, in which N may be lost through leaching; split applications arc recommended, at planting and at 3 months after plant. Nitrogen can also be applied in the form of animal manure (5-10 t/ha), or by the incorporation of or mulching with green manures or cover crops (Keating *et al.,* 1988).

Table (1): Nutrient concentration in young fully expanded leaf blades of cassava at 3-4 months after planting, corresponding to various nutrition states of the plants. Data are the average results of various greenhouse and field trials.

			Nutritional status[a]			
Nutrient	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4	4.1-4.8	4.8-5.1	5.1-5.8	>5.8	b
P (%)	<0.25	0.25-0.36	0.36-0.38	0.38-0.50	>0.50	-
K (%)	<0.85	0.85-1.26	1.26-1.42	1.42-1.88	1.88-2.40	>2.40
Ca (%)	<0.25	0.25-1.41	0.41-0.50	0.50-0.72	0.72-0.88	>0.88
Mg (%)	<0.15	0.15-0.22	0.22-0.24	0.24-0.29	>0.29	-
S (%)	<0.20	0.2-0.27	0.27-0.30	0.30-0.36	>0.36	-
B (µg/g)	<7	7-15	15-18	18-28	28-64	>64
Cu (µg/g)	<1.5	1.5-4.8	4.8-6.0	6.0-8.0	10-15	>15
Fe (µg/g)	<100	100-110	110-120	120-140	140-200	>200
Mn (µg/g)	<30	30-40	40-50	50-150	150-250	>250
Zn (µg/g)	<25	25-32	32-35	35-57	57-120	>120

[a] Very deficient = 40% maximum yield, Deficient = 40-80% maximum yield, Low= 40-90% maximum yield, Sufficient= 90-100% maximum yield, High= 100-90% maximum yield, Toxic=<90% maximum yield, [b] no data available

Phosphorus deficiency: Phosphorus deficiency is the most limiting nutrition factor for cassava grown on many acid infertile Oxisols, Ultisols and Inceptisols in Latin America, but it is less common in Asia. Phosphorus deficient cassava plants are generally short and spindly with thin stems, small and narrow leaves and short petioles. During periods of drought the upper leaves tend to droop down from the petioles. The leaves are generally dark green while one or two lower leaves may be dark yellow to orange and in some varieties purplish with necrotic white spots. These lower leaves often drop off, leaving the plant without any recognizable symptoms. The critical level for P deficiency in leaf blades is about 0.41% P (Howeler and Cadavid, 1990) and the sufficiency range is calculated to be 0.38-0.50% P (Table 1). The critical level of available P in the soil is about 4-6 micro g/g Bray II-extractable P (Howeler, 1990). In some soils having only 2-4 micro g/g available P there is still no response to P application due to a highly efficient mycorrhizal association (Howeler *et at*. 1987), which enables the plant to absorb soil P from a greater soil volume. To control P deficiency it is recommended to band apply near the stake 25-50 kg P/ha as highly soluble P sources such as single or triple super phosphate or compound fertilizers: alternatively. P can be applied by broadcasting and incorporating less soluble sources such as basic slag, rock phosphate or thermo phosphate. The latter are good sources of P in acid soils. All P should be applied at or shortly after planting to enhance early growth and plant vigor (Keating *et al.,* 1988).

Potassium deficiency: Cassava extracts large amounts of K in the root harvest and long term fertility trials have shown that sooner or later K deficiency becomes the most limiting nutrition factor if it is grown continuously without adequate K fertilization. Potassium deficient plants are generally short, highly branched and with a prostrate growth habit. In many varieties the upper internodes are very short and prematurely lignified resulting in a 'zigzagging' of the upper stem. In some varieties, the upper leaves are small and chiorotic, while in others a few lower leaves arc yellow with black spots and border necrosis (Keating et al., 1988). During periods of drought leaf borders may curl upward, while during wet periods there may be severe die-back of shoot tips due to K deficiency- induced anthracnose *(colletotrichurn* spp.). In many cases, however, there are no clearly recognizable symptoms and plants are simply shorter and have smaller leaves than those well supplied with K.

The critical level for K deficiency in leaf blades at 3-4 months after planting is about 1.5% K. while the sufficiency range is 1.4-1.9 % K (Table 1). The critical level of exchangeable K in the soil was found to be 0.15-0.17cmol/kg (Howeler 1985a: Howeler and Cadavid 1990).

Potassium deficiency in cassava can be controlled by the application of 50-100 kg K/ha as potassium chloride. Potassium can also he applied as a compound fertilizer or in the form of wood ash. In soils where P deficiency is not a serious problem, compound fertilizers with an $N\text{-}P_2 0_5\text{-}K_2 0$ ratio of about 2:1:3 or 2:1:4 are recommended in order to supply enough K to prevent K exhaustion of the soil. Most K fertilizers are highly soluble and should be band applied near the stake during the first two months after planting. In light-textured soils they should be applied in two smaller doses to prevent losses by leaching.

Calcium deficiency: Calcium deficiency symptoms are easily produced in nutrient solution culture, but are seldom seen in the field: significant responses of cassava to Ca application are also rather rare. Still, in very acid soils with high levels of Al and low levels of Ca. cassava does respond to liming, which is thought to be mainly a response to the application of Ca and/or magnesium (Mg). Since Ca is not very mobile in the phloem. There is little Ca translocation from the older to the younger tissue. When the Ca supply is inadequate, Symptoms of Ca deficiency develop in the growing points of both shoots and roots. Upper leaves are deformed with leaf tips burned and curling either up or down. The growing points of fibrous roots die back, resulting in excessive root branching. In the field, Ca deficiency is characterized mainly by deformation and burning of leaf tips in the upper part of the plant, hut these symptoms cannot be seen in all varieties.

The critical concentration for Ca deficiency in leaf blades at 3-4 months after planting was found to be 0.56% Ca and the sufficiency range calculated to be about 0.50-0.72% Ca (Table 1). However. Ca concentrations in leaf blades can vary markedly among different varieties. Calcium deficiency is generally controlled by the application of 200-400 kg Ca/ha in the form of calcitic or dolomitic limestone, as calcium oxide or hydroxide, or as gypsum. Gypsum is a more soluble source, which supplies Ca as a nutrient hut without affecting soil pH or exchangeable Al. All these Ca sources should be broadcast and incorporated before planting.

Magnesium deficiency: Magnesium deficiency symptoms are often found in acid infertile soils such as Oxisols, Ultisols and certain inceptisols. Magnesium deficiency is characterized by interveinal chlorosis of the lower leaves, which starts out as slight yellowing of leaf margins and may eventually develop into necrosis of leaf tips and margins. Symptoms appear first at the lowest leaves and progressively move up the plant. Critical concentrations for Mg deficiency in leaf blades at 3-4 months after planting were found to be 0.25% Mg and the sufficiency range was calculated as 0.24-0.29% Mg (Table 1). No critical levels for soil exchangeable Mg have been reported, but Mg deficiency symptoms and a response to Mg application were found in soils with less than 0.2 me quiv. Mg/kg (Table 2). Magnesium deficiency can be controlled by the application of 40-60 kg Mg/ha in the form of magnesium oxide, dolontitic limestone or magnesium sulphate. The first two sources are relatively insoluble and should be broadcast and incorporated before planting. Magnesium sulphate is a soluble source, which may be band-applied near the stake shortly after planting. It has no effect on soil pH or exchangeable Al. hut can he used as a source of S.

Sulfur deficiency: Sulfur deficiency in cassava is easily produced in nutrient solutions, but is not often found in the field. It is characterized by a uniform chlorosis or yellowing of leaves (similar to N deficiency) in the upper and middle part of the plant. Eventually the whole plant becomes chlorotic. Leaves are small and plant height may be reduced, hut leaves are not deformed. The critical concentration for S deficiency in leaf blades was found to be about 0.3 1% S. while the sufficiency range was calculated to be 0.30-0.36% S (Table 1). Critical levels in the soil have not been determined, but S responses were obtained in soils with 25-30 micro g/g phosphate-extractable S. Sulfur deficiency can be controlled by the application of 10-20 kg S/ha as elemental sulfur or as sulfates of ammonium, potassium, calcium or magnesium. The latter four sources are relatively soluble and can be band applied near the stake at planting; while elemental sulfur should he broadcast and incorporated before planting.

Copper deficiency: Symptoms of Cu deficiency in cassava have been produced in nutrient solution culture but arc seldom seen in the field. Severe symptoms and yield reductions due to Cu deficiency were found only on the peat soils of Malaysia. where high levels of organic matter result in the completing of Cu with humic acids, making the Cu unavailable to plants. Copper deficiency in cassava is characterized by chlorosis, deformation and wrinkling of upper leaves with necrosis of leaf tips and margins; leaf lips curl either up or down. Leaves in the middle and lower part of the plant are rather large and suspended on long and bent-down petioles. A critical concentration for Cu deficiency in leaf blades after 9 weeks of growth in nutrient solution was reported to be 6 microg/g, while that for Cu toxicity was about 15 micro g/g (Howeler *et al.* 1982). The sufficiency range was calculated to be about 6-10 microg Cu/g (Table 1). However, high yields on peat soils in Malaysia were obtained with Cu concentrations of 14-15 microg Cu/g in leaf blades (Chew *et al.* 1978). Critical levels of available Cu in the soil have not been determined, but about 0.3-1.0 microg/g double-acid extractable Cu is considered a normal range for cassava (Table 2). Copper deficiency can be controlled with the application of 2.5-3.5 kg Cu/ha as $CuSO_4.5H_20$, hand-applied near the stake at planting. Copper deficiency can also he controlled by foliar application of 0.05% CuSO4.51-120: higher concentrations resulted in reduced yields (Chan and Ramli, 1987).

Table (2): Approximate classification of soil chemical characteristics according to the nutrition requirements of cassava.

Nutrient	Very low	Low	Medium	High	Very high
P^H	<3.5	3.5-4.5	4.5-7.0	7-8	>8.0
Org. matter	<1.0	1.0-2.0	2.0-4.0	>4.0	-
Al-saturation(%)	-	-	<75	75-85	>85
Salinity (ms/cm)	-	-	<0.5	0.5-1.0	>1.0
Na-saturation(%)	-	-	<2.0	2-10	>10.0
P (µg/g)	<2.0	2.0-4.0	4.0-15	>15	-
K (me/100g)	<0.1	0.10-0.15	0.15-0.25	>0.25	-
Ca (me/100g)	<0.25	0.25-1.0	1.0-5.0	>5.0	-
Mg (me/100g)	<0.2	0.2-0.4	0.4-1.0	>1.0	-
S (µg/g)	<20	20-40	40-70	>70	-
B (µg/g)	<0.2	0.2-0.5	0.5-1.0	1.0-2.0	>2.0
Cu (µg/g)	<0.1	0.1-0.3	0.3-1.0	1.0-5.0	>5.0
Mn (µg/g)	<5.0	5-10	10-100	100-250	>250
Fe (µg/g)	<1.0	1-10	10-100	>100	
Zn (µg/g)	<0.5	0.5-1.0	1.0-5.0	5.0-50.0	>50

Boron deficiency and toxicity: Symptoms of boron (B) deficiency are not commonly observed in the field, but are easily produced in nutrient solution. Since B is a phloem-immobile element, deficiency symptoms arc mainly found in the growing points of shoots and roots. Thus extremely B-deficient plants have small and deformed leaves in the upper part of the plant with, in some cases, exudation of a brown gummy substance from the upper petioles. Root tips often die, resulting in a small and excessively branched root system (Ashcr *et al*. 1980). In the field these symptoms are seldom observed. Boron deficiency in the field is generally characterized by white or brown speckles on leaves in the middle part of the plant. Some varieties are much more susceptible than others, but in general cassava is quite tolerant of low levels of available B in the soil.

Symptoms of B toxicity have been found only when B was applied at too high rates. In that case, lower leaves are deformed with yellow or brown spots and necrosis of leaf tips and margins. Since 13 is not translocated to the growing points, plants gene rally recuperate from an initial B toxicity. The critical concentration for 13 deficiency in leaf blades, as determined in two nutrient solution experiments, were found to be 21 and 35 micro gram B/g, while those for B toxicity were 50 and 100 micro gram B/g (Howeler *et al*. 1982). However, B concentrations of less than 10 microgram B/g were found in leaf blades of apparently normal field-grown plants. A sufficiency range was calculated to be about 18-28 micro gram B/g (Table 1). Symptoms of B deficiency and some response to B application have been found in soils with 0.2-0.3 micro gram B/g of hot water-soluble B. A normal range of B in the soil is about 0.5-1.0 micro gram B/g (Table 2). Boron deficiency can be controlled by the application of 1-2 kg B/ha in the form of sodium borates, such as Borax or Solubor. These sources are rather soluble and can be band-applied near the stake at planting. Alternatively, stakes can be dipped in a solution of 1% Borax before planting; however, concentrations above 1% may result in B toxicity.

Manganese deficiency and Toxicity: Manganese (Mn) deficiency is found mainly in high pH calcareous soils or in acid soils treated with excessive amounts of lime. Its symptoms are similar to those of Mg deficiency, but are found mainly in the middle part of the plant. Manganese-deficient plants have leaves with intervenal chlorosis in which the green veins stand out in a 'fishbone' pattern on a yellow background. Under severe conditions the whole leaf may turn almost uniformly yellow (similar to Fe deficiency), while plant height is reduced. Leaves usually maintain their normal size and are not deformed (Cock *et al.,* 1988). Manganese toxicity is usually found in very acid soils, especially under conditions of excess water resulting in the reduction of higher oxides of Mn to the more soluble Mn_2 form. However, Mn toxicity may also occur during the dry season when stagnated growth can lead to excessive accumulation of Mn in the lower leaves. It is characterized by brown or black speckling along the veins of lower leaves. These leaves are initially green, but later turn yellow to orange (Cock et. al, 1988). They may be hanging flaccid on the petioles before they fall off. Manganese toxicity may also severely reduce root growth. The critical concentration for Mn deficiency in leaf blades was found to be about 50 microg Mn/g, while that for Mn toxicity was about 250 microg Mn/g (Iloweler *et al*. 1982). The sufficiency range was estimated at 50-150 microg Mn/g. Critical levels of available Mn in the soil have not been determined, but about 10-100 microg /g of double-acid extractable Mn may he considered a normal range for cassava (Table 2). Manganese deficiency can be corrected by soil application of manganese oxide or sulfate, by a foliar spray with Mn chelates or a 1-2% solution of $MnSO_4$.$4H_2$,O, or by dipping the stakes in a 5% solution of $MnSO_4$.$4H_20$ for IS minutes before planting. Manganese toxicity can be controlled by the application of lime in acid soil and by providing better internal drainage by loosening compacted soil (Cock et. al, 1988).

Iron deficiency and Toxicity: Iron (Fe) deficiency is quite common when cassava is grown on calcareous soils. It has also been observed when cassava is grown on leveled off termite hills; these soils have high concentrations of Ca, Mg and K and an elevated soil p^H. Iron deficiency can also be induced by high applications of lime and/or P in acid sandy soils of low Fe content, as well as by excessive absorption of Mn. Iron-deficient plants have a uniform chlorosis of the upper leaves including the veins. Under severe conditions the upper leaves may turn completely white, while lower leaves become increasingly chlorotic. Plant height may be reduced and seriously affected plants may die. Symptoms of Fe deficiency are most serious during the dry season and may completely disappear again during the following wet season. The critical concentration for Fe deficiency in leaf blades could not he clearly established (Ilowcler *et al.* 1982), but a sufficiency range was estimated to be 120-140 microg Fe/g (Iloweler 1983). Concentrations of over 400 microg /g may result in a reduction in plant growth, but no symptoms of Fe toxicity nor a reduction in root yield have been observed. Critical levels of available Fe in the soil have not been determined, but about 10-100% microg Fe/g is a normal range for cassava (Table 2). Iron deficiency is best controlled by a foliar spray of iron chelates or a 1-2% solution of $FeSO_4$.7H,O. Dipping stakes in a solution of 5% $FeSO_4$.$7H_20$ for 15 minutes before planting had no adverse effect on germination, hut its effectiveness in controlling Fe deficiency still needs to be determined.

Zinc deficiency and Toxicity: Zinc deficiency is a rather common nutrition disorder in cassava and is observed both in high pH soils, due to a reduced availability of Zn, and in low pH soils, due to their low levels of total Zn. In cassava it is characterized by white speckling or striping in the interveinal region of upper leaves. These leaves may become chlorotic, they are usually small in size and have narrow leaf lobes which tend to point away from the petiole and stem. Under more severe conditions the leaves in the growing point become increasingly chlorotic and deformed, while in some varieties the lower leaves have white necrotic spots or generalized chorosis in the interveinal areas. Zinc deficiency is often observed when plants are young, but they may grow out of it once the root system is better developed. Under severe Zn deficiency stress, shoot tips die back or the whole plant may die. The critical concentration for Zn deficiency in leaf blades was found to be 40 microg Zn/g, while the sufficiency range was calculated to be 35-57 microg Zn/g. A critical level for soil-available Zn has been reported as I Jig/g of double-acid extractable Zn (Howeler 1985b): a Zn level of 1-5 microg /g can be considered as a normal range for cassava (Table 2). Zinc deficiency can be controlled by hand-application of 5-10 kg Zn/ha as $ZnSO_4.7H_20$ or by broadcast-application of 10-20 kg Zn/ha as ZnO. In high pH soils, in which applied Zn soon becomes unavailable to plants, it is more effective to make foliar applications of 1-2% solutions of $ZnSO_4.7H_20$ or to dip stakes for 15 minutes in a solution of 2-4% $ZnSO_4.7H_20$ before planting. The latter is a very cheap and effective method of preventing serious Zn deficiency in alkaline or calcareous soils.

Breeding for mineral Stress Tolerance in cassava: Implication for crop Improvement:

Comparative Soil Nutrient Extraction by Cassava: In contrast with the high input technology used in the Green Revolution crops (*i.e*. rice, wheat and maize), most of cassava production in the tropical and subtropical agro-ecosystems is done by resource poor small farmers on marginal lands, with often degraded soils, virtually without application of purchased agrochemicals (Hershey and Jennings, 1992).

Cassava is tolerant to tropical highly leached acidic soils low in pH, high in exchangeable aluminum and particularly low in phosphorus (P). Mid-term cassava responses in infertile sandy soils in northern Colombia (private farm) and long-term responses to acidic clayey soils low in nutrient contents at CIAT Experimental Station, Santander de Quilichao, illustrate both the level of tolerance of cassava to poor soils and the positive responses to fertilization (Nassar and Ortiz. 2007). In the sandy soils, cassava kept producing > 2 t/ha oven-dried storage roots without fertilization during several consecutive cropping cycles, with noted differences among cultivars (the highest tolerance level and greatest response to NPK fertilizers were in cultivar M BRA 191). In the acidic clayey soils, cassava kept producing during 6 years of consecutive crop- ping reasonable yields (>15 t/ha fresh storage roots) in absence of application of any major element, *i.e.* N, P, and K (Nassar and Ortiz. 2007). There were positive responses to applications of these elements, with the largest responses observed with the application of K. At 12 years of consecutive cultivation in this trial, dry root yields in absence of N application, but with P and K, were 7.9 t/ha for M Col 1684, and 4.7 t/ha for CM 91-3. In absence of P application, but with N and K, dry root yields at the 12 the year were 6.1 and 4.7 t/ha, for M Col 1684 and CM 91-3, respectively. Without K application until the 12^{th} year, but with N and P, yields were extremely low at 2.9 and 1.7 t/ha dry matter for M Col 1684 and CM 91-3, respectively (Hershey and Jennings, 1992).

This was due to the removal of more than 70% of absorbed K along with the harvested starchy roots, indicating that K is the most critical nutrient. However, in absence of annual application of the three nutrients (N,P,K) during 12 years of consecutive cropping, oven-dried storage root yields remained at 2.9 t/ha for M Col 1684 and 2.1 for CM 91-3, attesting to cassava high tolerance to exhausted acidic soils. Noteworthy, in absence of NPK fertilization, production of reproductive organs (flowers, fruits and seeds) was enhanced, and HI increased, indicating phonology changes in cassava growing on infertile soils as previously observed. Without NPK applications for 12 years, average seasonal P N of upper canopy leaves, as measured with photosynthetic active radiation >1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and in normal air having 350 ppm, was around 20-25 μmol CO_2 $m^{-2} \cdot s^{-1}$, compared to 30 - 35 μmol CO_2 $m^{-2} \cdot s^{-1}$ in plants receiving annually 100 kg/ha each N, P and K. The leaf photosynthetic capacity in cassava remains remarkably high, compared to other warm-climate legume (e.g. common beans, C_3) and cereal (e.g. maize, C_4) food crops, under extremely low soil nutritional status, which may underlie its ability to sustain reasonable yields. Another plant trait that may explain the reasonable carbon uptake rates in absence of NPK application was the lower leaf area per plant as well as lower LAI because of restricted new leaf formation with smaller size and lower specific leaf area (leaf area/unit leaf weight), thus allowing concentrated and sustainable leaf NPK contents. In these soils, it appears that the limitation to cassava storage root production, when grown continuously for long period on the same land, are in decreasing order: K > P > N. Very few, if any, food crops will tolerate such poor soils and be able to produce reasonably without fertilization, compared to cassava (Bellotti, 2002). This comparative advantage in favor of cassava have led many to erroneously believe that cassava removes high volumes of nutrients, and hence renders the already poor soil unsuitable for cultivation of other food crops. It is clear from these data that cassava removed less N and P per ton of dry root than values in harvested products of other crops (Bellotti, 2002). Removal of K was either similar or lower than some other crops. Because of the high yield in cassava, the crop removed equal amounts of N and P per hectare as with other crops. However, cassava removed more K per hectare than any other crop, as >70% absorbed K is removed in storage roots (El-sharkaway, 1993). Thus, the negative reputation concerning cassava cultivation as a cause of soil degradation is not based on sound scientific facts as illustrated here and in published literature. Cassava is very resilient and highly tolerant to a biotic stresses, an advantage over many other staple food crops as shown by its higher predicted suitability to climatic changes.

Selection for tolerance of low fertility acidic soils: As most cassava production by smallholders occurs in marginal lands with low levels of soil fertility cassava breeding strategy at CIAT focused on selection for adaptation to farmers' field conditions. Cassava soil-and-plant nutrition management section, and later cassava physiology section, oriented their research objects toward characterization of CIAT cassava germplasm in response to infertile, low-P, acidic soils in the South American tropics. From 1982 to 1996, more than 1,800 accessions, including land races, common varieties and elite CIAT breeding lines have been evaluated for responses to P, and many clones with high level of adaptation to low P (and with high response to P application) have been identified and included in crop improvement program. Later several dozens of cassava core germplasm have also been tested for their tolerance to low-K soils, with few clones with high level of tolerance have been identified (El-sharkaway, 1993). In the following subsections, data of many tested accessions for their tolerance of low-P and low-K soils, as well as responses to P or K fertilizer application, are presented (Nassar and Ortiz. 2007).

Performance of some cassava clones at zero and 75 kg P/ha: For screening large accessions for response to low fertility soils, we adopted a simple field method to test at two levels of P, *i.e*., zero and 75 kg P/ha. A calculated adaptation index to low P, taking into account yields of a given clone in relation to the overall mean of the trial at both low and adequate levels of applied P fertilizer, indicates the degree of tolerance. Data of a group composed of 33 clones from CIAT core germplasm, including land races, common varieties and advanced breeding materials, that were tested for three years and in Table (3). Clones with low-P adaptation index above the overall mean of the trial (1.0), have been identified as having a reasonable degree of tolerance. In this group, there were 13 clones with high and moderate degree of tolerance, with several CIAT breeding materials are highly to moderately tolerant. Two cultivars of Brazilian origin, *i.e*., MBRA 390 and MBRA 589, are tolerant to low-P soils, indicating the efficient selection under poor soils in Brazil. In previously tested group of accessions, another two Brazilian cultivars, M BRA 191 and M BRA383, were identified with high level of tolerance. Table-3 presents plant traits, leaf gas exchange characteristics of upper canopy leaves, along with correlations of these traits with Low-P adaptation index, determined on another 33 accessions. At zero P, *P N* was significantly higher than values at 75 kg/ha P, and this coincided with increases in stomatal conductance to water vapor and in mesophyll conductance to CO_2 diffusion, suggesting that the difference may be attributed to both stomatal behavior as well as to mesophyll biochemical and anatomical differences. Since LAI was significantly lower at zero P, the higher *P N* could be partly due to less water stress resulting from lower transpiration water losses by crop canopy. Alternatively, the difference in *P N* may be also attributed to feed- back inhibition at adequate P because of larger LAI, which represents greater crop photosynthetic surface capacity. It is likely, therefore, that source-sink relationship for photosynthetic products was implicated in this sort of phenomenon. Application of P increased significantly number of storage roots per plant, shoot biomass and dry root yield, but HI was lower, compared to zero P. Except with stomatal conductance, Low-P adaptation index was highly significantly correlated with all of the growth and gas exchange traits measured, indicating the validity of this index as a measure for identifying plant traits related to productivity. It may be concluded that, carbon assimilation rates and sources (*i.e*. leaf *P N* and canopy seasonal LAI) as well as sink strength and capacity for photo-assimilates (storage root number and capacity) are of paramount importance as selectable traits for cassava improvement under diverse edaphic environmental conditions.

Table (3): Productivity, growth and physiological characteristics of cassava grown at low and adequate P-levels at Santander de Quilichao, and correlation with Low-P adaptation index. Values are means of 33 clones.

Parameter	Zero P	75kg P/ha	Correlation coefficients with Low P adaptation index)
Ps(µmol $Co2m^{-2}s^{-2}$	31*	27	0.51**
Stomata conductance (H_20)$mmolm^{-2}s^{-11}$)	928	851	0.30ns
Mesophyll conductance(Co_2)$mmolm^{-2}s^{-1}$)	206	178	0.57**
Dry root yield(t/ha)	8.8*	12.5	0.99**
Shoot dry biomass(t/ha)	3.8*	5.7	0.58**
Total biomass(t/ha)	12.6*	18.2	0.96**
Number of storage root/plant	9*	12	0.67**
LAI(m^2 m^{-2}	2.0*	3.1	0.55**
HI(dry root/total biomass)	0.81*	0.70	0.73*

Means of the two P levels across 33 clones: ns not-significant at 5%, *= significant at 5%, **significant at 1%.

Conclusions

Cassava is a major staple for more than 200 million people in East and Central Africa. In this region, cassava became an insurance crop and used as fill seasonal food gaps when other crops are not in the field. It grows in marginal land with a limited supply of agricultural input and pesticides. Although, cassava can produced in waste lands, its sustainable production is affected by different biophysical factors, mineral toxicity and deficiency, lack of improved varieties, which are adaptable to wide range of agro-ecologies conditions, tolerance to a biotic stresses are a few to mentioned. In high acidic soil, the root and shoot development of the plant hindered by aluminum toxicity and unavailability of other mineral elements. Thus, application of lime is the best solution to avoid this problem. Cassava is highly sensitive to saline soil, and application of green manure is vital to improve the growth and development of the plant. Moreover, development of new varieties for mineral stress tolerance in association with appropriate management strategies has tremendous impact on sustainable production, to improve the livelihood of rural households who live in the developing world.

References

Allem, A.C. 2002. The Origin and Taxonomy of Cassava. In: R.J. Hillocks, J.M. Thresh and A.C. Bellotti, ed., Cassava : Biology , Production and Utilization , CABI Publishing, New York, 1-16pp.

Asher, C.I.; Edwards, D.G. and Howeler, R.H. 1980. Nutritional Disorders of Cassava. Department of Agriculture. University of Queensland. St Lucia. Qld. Australia,48pp.

Bellotti, A.C. 2002. Cassava : Biology, Production and Utilization. CABI Publishing, New York, 149-166pp.

Chan, S.I.C. and Ramli, K. 1987. Evaluation of three methods of copper fertilization for cassava on peat. Proceedings National Seminar. Kuala Lumpur. Malaysia, 69-78pp.

Chew, W.Y.; Joseph, K.T. and Ramli, K. 1978. Influence of soil-applied micronutrients on cassava (*Manihot escul enia*) in Malaysian tropical oligotrophic peat. Exper. Agric., 14: 105-111.

Cock, J.H. and El-Sharkawy, M.A. 1988. The physiological response of cassava to stress, Proceedings 7th Symposium of the International Society of Tropical Root and Tuber Crops, Gosier (Guadeloupe), 1-6 July 1985, Institute National de la Recherche Agronomique (INRA), Paris, 451-462pp.

El-Sharkawy, M.A. 1993. Drought-tolerant cassava for Africa, Asia, and Latin America, Bioscience, 43(7): 441-451.

Fermont, A.M.. 2009. Cassava and Soil Fertility in Intensifying Smallholder Farming Systems of East Africa, Ph.D. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands, 12-19pp.

Hershey, C.H. and Jennings, D.L. 1992. Progress in breeding cassava for adaptation to stress. Plant Breed. Abst., 62: 823-831.

Howeler, R.H. 1985a. Analisis del Cejido vegetal en ci diagn ostico de problemas nutricionales de aigunos cultivos tropicales. Centro Internacional de Agncultura Tropical (CIAT), Cali, Colombia, 28pp.

Howeler, R.H. and Cadavid, L.F. 1990. Short-and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. Fertilizer Res., 26: 61-80.

Howeler, R.H.; Sieverding, E. and Sail. S. 1985b. Practical aspects of mycorrhizal technology in some tropical crops and pastures. Plant and Soil, 100: 249-283.

Howeler, R.H.; Edwards, D.G. and Asher, C.I. 1982. Micro- nutrient deficiencies and toxicities of cassava plants grown in nutrient solutions. I. Critical tissue concentrations. J. Plant Nutr., 5: 1059 1076.

IFAD and FAO. 2000. The world cassava economy, facts, trends and outlook, international fund for agricultural development, Food and Agriculture Organization of the United Nations, Rome,. http://www.scribd.com/doc/48938803/The-world-cassava -economy-I

Kawano, K. 1990. Harvest index and evolution of major food crop cultivars in the tropics, Euphytica, 46(3): 195-202.

Keating, B.A.; Wilson, G.L. and Evenson, J.P. 1988. Effects of length, thickness, orientation, and planting density of Cassava (*Manihot esculenta Crantz*) planting material on subsequent establishment, growth, and Yield, East Africa Agric. Forest J., 53: 145-149.

Montagnac, J.A.; Davis, C.R. and Tanumihardjo, S.A. 2009. Nutritional value of cassava for use as staple food and recent advances for improvement, Composite Rev. Food Sci. Food Safe., 8(3): 181-194.

Nassar, N.M.A. and Ortiz, A.R. 2007. Cassava improvement: Challenges and impacts. J. Agric. Sci., 145(2): 163-171.

Spain, J.M.; Francis, C.A.; Iloweler, R.H. and Calvo, F. 1975. Differential species and varietal tolerance to soil acidity in tropical crops and pastures. Soil Management in Tropical America. North Carolina State University, Raleigh, 14-17pp.