IMPROVING PHOSPHORUS UPTAKE BY CASSAVA (*Manihot esculanata Crantz*) USING ARBUSCULAR MYCORRHIZAL FUNGI (AMF)

A dissertation submitted to the school of agricultural, earth and environmental sciences, university of Kwazulu-Natal in fulfillment of the requirement for the award of Master of Science (Agriculture) degree in Soil Science

BY

EMMANUEL ADU POKU

March 2014

DECLARATION

I hereby certify that the research reported in this dissertation is the result of my own investigation, except where otherwise indicated, and that it has not been submitted for a higher degree at any other university or institution.

Signed: _____

Name: Emmanuel Adu Poku Date:

As the candidate's supervisor I have approved this dissertation for submission.

Signed_____

Name: Dr Louis W. Titshall Date:18 March 2014

DECLARATION – PLAGIARISM

I, Emmanuel Adu Poku, declare that

1. The research reported in this dissertation, except where otherwise indicated is my original research.
2. This dissertation has not been submitted for any degree or examination at any other university.
3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a. Their words have been re-written but the general information attributed to them has been referenced.

b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.

5. This dissertation does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the references sections.

Signed: ..... Date: ……..

Emmanuel Poku (candidate)

ACKNOWLEDGEMENT

My sincere gratitude goes to my project supervisor, Dr. L. Titsall, Honorary Lecturer, Soil Science Department, UKZN for his constructive criticisms, guidance and time without which this work would not have been possible. I would like to give special recognition and appreciation to Prof. Jeffry Huges, Head of Soil Science Department (UKZN).

I would like express my profound gratitude to Dr. Kwame Owusu Adu-Tutu (Monsanto, Saint Louis, USA), Dr. Kwadwo Obeng Antwi (CSIR, Kumasi, Ghana) and Dr. Emmanuel H. Y. Bobobee (ARC, Pretoria) for their material support.

A special acknowledgement is extended to Head of Department for financial support; Dr. Alan Manson, and Mrs. Cathy Stevens for the statistical analysis (all from KZN Department of Agriculture). Furthermore, I would like to thank all those whose works were used as references in this research. I cannot forget my children Michael, David and Nana for their invaluable care, as well as spiritual and moral support during the period of this study.

ABSTRACT

Phosphorus uptake cassava (*Manihot esculanta Crantz*) were tested using on thirty-six plants per plot under dryland conditions at four different sites selected Bioresource group 1 (BRG 1) of northern KwaZulu-Natal of South Africa, which is described as Moist, Coastal Forest, Thorn and Palm veld, exhibiting sub-tropical characteristics. Soils in this region are very low in Phosphorus (P) due to high fixation by iron and aluminium oxides. With its high root yields coupled with efficient nutrients miner, cassava removes large quantities of N, P, K and Mg. With the ever-increasing prices of P fertilizer, which impact on the socio-economic livelihood of smallscale farmers, there is the need to look into improving the P uptake by the crop by alternative means apart from using mineral fertilizers. The objective of this study was to investigate the use of Arbuscular Mycorrhizal Fungi (AMF) to improve P uptake by cassava in agricultural soils. Laboratory studies were conducted at Soil Fertility and Analytical Services in Cedara (Pietermaritzburg). A Latin Square design (LSD) was used. Four treatments used were Untreated (Control), P-fertilizer, AMF, and P + AMF. Correlation and path-coefficient (probabilities) were computed. The P + AMF were significantly (p<0.05) taller than those in P-fertilizer treatment plots but were significantly (p<0.05) similar to those in Control and AMF-treated plots. Percent leaf P was statistically similar at the four sites with grand mean of 0.4%. Adding AMF and P+AMF to the soil substantially increased leaf P concentration to 0.5%. Tubers collected from P+AMF-treated plots were significantly (p<0.05) the longest, while those from Control plots were the shortest. P, and AMF-treated plots increased tuber length relative to the Control. All soil treatments significantly (p<0.05) increased tuber yields over the Control-treatment plots. However, AMF and P+AMF treated plots were significantly higher than P and control plots. This study suggests that using AMF or P+AMF can improve cassava yield as compared P alone or control – untreated cassava plants. Cassava producers in northern KwaZulu-Natal should consider using AMF or P+AMF to optimize tuber yield. A further study into the economic implications of the use of AMF is recommended.

DEDICATION

To my mother, Madam Adjoa Serwaa, my late wife Georgina Adu Poku and my children Michael Adu Poku, David Adu Poku and Nana Serwaa Poku.

Table of Contents

List of Figures

List of Tables

CHAPTER ONE
INTRODUCTION

Phosphorus (P) is essential macro-nutrient that plays a major role in plant growth. It also speeds up the conversion of several key biochemical reactions in plants. Phosphorus deficiency is one of the main constraints to food production in tropical African soils due to low native P and high P fixation capacity (Manjula, 2006). Manjula (2006) has reported that the soils in northern KwaZulu-Natal (KZN) are very low in P. In their studies on macadamia fertilization in KwaZulu-Natal (KZN), Manson and Sheard (2007) established that any P concentration in KZN soils that is below 5 mg L^{-1} should be considered as low. This level of P concentration was also confirmed by Miles (2010), after 10 years of studies on the response of productive and unproductive kikuyu pastures to top-dressed nitrogen and phosphorus fertilizer. In the studies it was found that not only does P levels in the soil affect crop response to P fertilizer application but also affected the yield. This, according to Mokwunye *et al*. (1986) and Warren (1992) is due to high P fixation by iron and aluminium oxides in many of northern KwaZulu-Natal soils. Another major factor is the downward migration of P in the profile over an extended period of time (Ludwick, 1998), through the activities of earthworms and other soil organisms or through leaching processes in sandy soils with low P-sorption capacity, which are preferred for cassava production.

The cost of inorganic fertilizers is expected to increase globally in the future due to rising fuel costs. Nitrogenous fertilizer cost is expected to increase seven-fold by 2050 while P fertilization use is forecast to increase from 1.6-fold to 3.4-fold by 2050 (Johnson, 1993; Graham *et al*., 1996; Johnson *et al*. 1997;Tilman *et al*., 2001).Though this increase P is almost negligible for soils even those with clay. However, it can be considerable in sandy soils. According to Leinweber *et al*. (1999), P leaching is dictated by soil texture, land use (grassland, arable, fallow or re-afforestation). The studies, it was noted that sandy soils have some potential of P leaching as compared to the other textures like clay soils. Fortune *et al.* (2005) suggested that $CaCl_2^-$ extractable P may provide an appropriate indicator of soil P concentrations above which significant quantities of P may leach under field conditions. This was mostly observed under sandy soil condition. This observation of Fortune *et al*. (2005) may be due to the fact that soil P is associated more with fine soil particles than coarse particles. There is therefore the need to look into the use of alternative P sources that may be

more economical methods to improve plant uptake and efficiency to ease the financial burdens on farmers due to an increase in fertilizer usage, especially P fertilizers.

Mycorrhizae serve as an integral part of the functioning of most plants in natural systems and occur on 83% of dicotyledonous and 79% of monocotyledonous plants ((Muchovej *et al* 1990). One of the most dramatic effects of infection by arbuscular mycorrhizal fungi (AMF) on the host plant is increasing P uptake due to its capacity to absorb phosphate from the soil and transfer it to the host roots (Asimi *et al.,* 1980; Qiang-Sheng and Ying-Ning, 2009). AMF have symbiotic associations with plants (Daipé and Monreal, 2004). The benefit is that AMF mycelia spread through a larger Soil volume surrounding the root system and increases the ability of the plant roots to access water and nutrients. The plant benefits from this symbiotic relationship, due to improved water and nutrient uptake, enhanced P transport, and drought and disease resistance, while the fungi are supplied with photosynthates. According to Daipé and Monreal (2004) the water, nutrient, and photosynthate exchanges occur via the fungal filament network that bridges the plant rhizosphere and plant root.

Though some international studies have been conducted on cassava production and its nutrient fertilizer requirements (Frossard *et al*., 2000; Agdaje and Akinlosotu, 2004), very little research has been conducted on soil fertility in relation to cassava (*Manihot esculanta Crantz*) production in the northern KwaZulu-Natal region of South Africa. The crop is grown as a secondary crop in KZN according to Department of Agriculture, Forestry and Fisheries (2010). The tubers are eaten fresh after cooking or processed into other food products. The leaves are eaten as vegetables. It is the sixth most important crop in terms of global annual production (Burns *et al*. (2010).Northern KwaZulu-Natal showcases a variety of indigenous and naturalized crops that have the potential to address food security problems in the region where cassava is one of these potential crops. At present, it appears that with the global warming, cassava would be favored in terms of its production as it can withstand harsh conditions where maize and rice cannot cope (Burns *et al*., 2010). The advantage of the crop is that it does not need high levels of management and high input. The crop can be grown on marginal lands and have substantial yield as compared to maize. With the ever-increasing population and subsequent pressure on arable for housing and infrastructure network reducing the size of arable land, the crop has the potential as it can be grown widely, and while changing climate

may impact on yield and crop performance some amount of yield could realized under a range of adverse conditions. The fertilizer requirement depends on nutrient availability in the soil and its removal by the crop. Thus fertilizer application is to replenish what has been lost or expected to be lost from the soil through plant uptake, erosion, leaching, etc. Studies conducted by (Korang-Amoakoh *et al*., 1987) on biological control of cassava pests in Ghana: prospects of other strategies confirm the above. In their studies, it was observed that plots subjected to adverse conditions like planting outside the normal rainfall season with low inputs and management practices could yield 10 tons ha^{-1} but maize was a total failure under the same conditions. Most of the Bioresource Groups (BRG) in northern Kwazulu-Natal exhibit semi-tropical characteristics dominated by sandy soil types, especially BRG 1 (Moist, Coastal Forest, Thorn and Palm Veld; Camp, 1999). As KZN sandy soils contain sufficient clay to fix some phosphorus the soil, AMF mycelia could more readily access the non-labile P that is typically unavailable to plants. In addition, the increased root-to-soil contact area due to AMF hyphae would likely enhance the uptake of any P that becomes available to the plant.

The small-scale cassava producers in the northern Kwazulu-Natal region farm on about 2 % of the total cropland in the region, with a projected increase of 3 % by 2015 of available cropland (KZN Department of Agriculture, 2009). Their crop production has been constrained by the ever-increasing prices of P fertilizer, which can negatively impact their socio-economic livelihood.
The main research questions addressed in this study are:

1. Can arbuscular mycorrhizal fungi increase phosphorus uptake from the soil by cassava and increase production?
2. Does P fertilizer affect the uptake of P by AMF-treated cassava?
3.

Thus the main objective of this study was to:
Investigate the use of AMF to improve cassava production in the northern KwaZulu-Natal coastal region.

The specific objectives were:

1. Use AMF to improve P uptake by cassava in agricultural soils in unfertilized and P-fertilized soils.
2. Examine the role of P and AMF in cassava production.
3.

The dissertation is structured as follows:

- Chapter 2 presents a literature review related to soil phosphorus and AMF in improving uptake by plants;
- Chapter 3 presents the materials and methods for this study;
- Chapter 4 presents the research findings from the investigations; and
- Chapter 5 presents a general discussion and conclusions.

CHAPTER TWO
LITERATURE REVIEW

2.1. Phosphorus in the soil

Phosphorus (P) is an essential macro-nutrient that occurs in mineral soils (Jones, 1997; Bowman and Vigil, 2002; Barančikovaá *et al*., 2007).This occurs when part of organic matter (OM) and phosphates from parent materials and accumulation of residual minerals are fixed to clay minerals and also part as soil minerals (Busman *et al*., 2002). Generally, a large proportion of this element is not readily available for plant uptake as it is easily immobilized by soil microbes and organic P in the soil environment (McKenzie, 2003).According to Beck and Sanchez (1996), solution P concentration depends on the solubility of the inorganic P components, desorption of the inorganic P, and organic P turnover processes. The presence of aluminum and iron sesquioxides and calcium-phosphorus interactions play a major role in the availability of P in the soil for plant use (Higa*et al*., 2000;Johnston, 2000; Turner and Leytem, 2004; Shen *et al*., 2011).This Al and Fe sesquioxides accumulate as residual compounds from mineral weathering (Shaliha *et al*., 2012; Igwe *et al*., 2013). Ca tends to accumulate in soils in arid climates which have low or limited leaching of Ca. P is fixed on sesquioxides and also $CaCO_3$ fix P. This process of sesquioxides affects P availability. Other factors may include organic matter turnover and the clay content of the soil(Berg *et al*., 2001; Baisden *et al*., 2002; Six and Jastrow, 2002; Torn *et al*., 2005; Shen *et al*. 2011) .Phosphorus cycle showing the various P available in the soil solution is shown in Figure1.In Figure 1,the P cycle is almost the as several other mineral nutrients cycles as P exists in soil and minerals, living organisms and water. However, P does not exist in elemental form instead it exists as phosphate (Busman *et al*., 2002) There are three phases of P in the soil: slow inorganic P, Rapid organic and inorganic P, and Slow organic P which are mainly supplied by primary P mineral fertilizer, plants and manure which supply solution P (Syers *et al.,* 2008). There is equilibrium between plants and soluble P. There are also secondary P minerals which supply solution P. This secondary P has equilibrium between occluded P, labile and moderately labile inorganic P which is equilibrium to solution. The solution P is also equilibrium to both microbial P and labile and moderately labile organic P. There is also equilibrium between microbial P and chemically and physically protected organic P which is equilibrium to labile and moderately labile organic P.

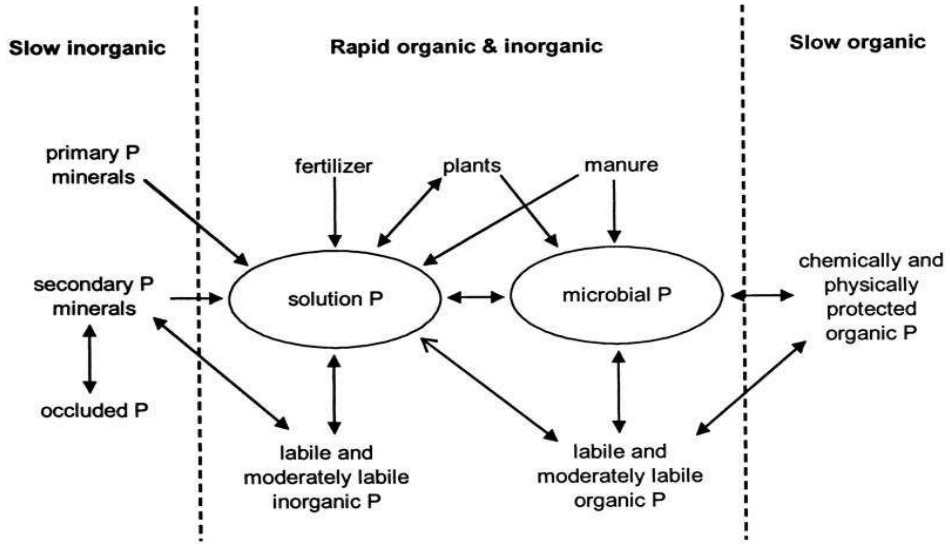

Figure 1. P cycle showing various forms of P available in the soil (Stevenson, 1986).

2.2. Forms of Soil Phosphorus

Soil phosphorus (soil P) is generally found in three soil pools, namely solution (solution P pool), labile (active P pool) and non-labile P (fixed P pool) (Manjula, 2006). The difference between solution P pool andactive Ppool is that solution P pool represents phosphate that is readily available to plant roots, whileactive P is the phosphate that is the dominant form; solid phase includes P on mineral surfaces. It also includes P in occluded soil mineral. P also forms part of soil OM. According to Busman *et al*. (2002), labile P in solid phase can easily be transformed into solution P thereby becoming plant available P which is relatively easily released to the soil solution when pH is between 6 and 6.5 (Syers *et al*., 2008). Research has indicated that the chemistry of P is very complex, as soluble P readily reacts with many different soil constituents to form a wide variety of P compounds of which some has low solubility with soil constituents to form P compounds of very low solubility (P sorption) (Stevenson, 1986). This makes P relatively insoluble in most soils (Syers *et al.*, 2008)). Immediately after P-fertilizer application, a large proportion of the P is readily available for root uptake (Hopkins and Ellsworth, 2003; Hopkins and Ellsworth, 2005; Mikkelsen, 2005).Within a short period of adding soluble P, P level drop rapidly as P is sorbed and complexed by sesquioxides and other soil constituents and will continue to drop over time as the sorbed P becomes more strongly sorbed and occluded. The rate at which this occurs depends both on the soil's mineral composition and environmental factors such as moisture and temperature, though

generally the initial sorption is almost immediate, slowing down as sorption sites becomes saturated. In the long term, Al and Fe as well as $CaCO_3$ present in the soil will react with P. It may also react with OM-Al compound complexes and Al silicate which eventually fix P (Stevenson, 1986; Igwe *et al*., 2013). Plant roots may still access this P as plants are adapted to take P from low concentration solution in the soil. Some plants also acidify the soil in the rhizosphere zone there-by dissolving occulded and precipitated P forms which can then be taken up by plants. The biological activity is increased thereby increasing P in the soil. Eventually, most of the bound P becomes part of the structure of the soil mineral (occlusion and specific sorption), and with its availability to plants being significantly reduced.

Studies conducted by Motavalli and Miles (2002) on inorganic and organic P fractions after long-term fertilizer and manure applications indicated that they have different effects on soil inorganic and organic P pools from applications of commercial P fertilizers. Motavalli and Miles (2002) concluded that both labile and more stable P pools are increased by long-term manure applications. Phosphorus is mostly lost from the soil through surface runoff, soil erosion and leaching. In a very sandy soils P is adsorbed on the non-reactive coarse textured particles and can easily be leached especially in high rainfall areas (Sims and Gartley, 2001).

Work conducted by Ludwick (1998) indicated that there could be leaching of P in the profile over an extended period of time, especially in sandy soils. P leaching does not usually pose a significant concern, as this process of P loss is significantly less than those from surface runoff (Ludwick, 1998). High levels of P can end up in underground water. This happens when there are cracks in soils creating channels that allow soil solution to leach out of the soil. The findings of Manjula (2006) depict low levels of P in the northern KwaZulu-Natal as a result of P loss through tuber and cereal crops harvest. Therefore there is the need to fortify or incorporate P in the soils before and during the growth cycle of crops.

Oberson *et al*. (2001), in their studies on improving P fertility in tropical soils through biological interventions, concluded that soil microbes play a major role in enhancing P availability to plants as they mediate the turnover of P contained in organic amendments and in soil organic matter. Chemical fractionation of soil P indicates that P fertilizer moves preferentially into labile P pools

and then slowly through biomass production and microbes into organic pools. Phosphorus is most efficiently cycled among plants, microorganisms and organic forms of P in the soil, where it is protected from strong sorption in highly weathered soils, which has predominantly Al and Fe sesquioxides and OM-Al compound complexes(Arai and Sparks, 2007; Shen *et al*., 2011). Enhanced organic matter turnover can, therefore, increase P availability for many crops. Phosphorus availability, therefore, depends on the maintenance of high levels of biological activity and stable humus in the soil. This influences the quantity of P in soil solution and continuous dissolution of minerals to maintain an adequate level of soil solution P.

2.3. Factors Controlling Availability of P in the Soil

There are several factors that may affect the availability of P in the soil. These may include: soil minerals, organic matter content, and clay type and amount in the soil (Syers et al., 2008).

2.3.1. Soil pH

The buffer capacity of a soil (its ability to resist a change in pH) is an important factor (Westermann and Leyterm, 2008). Ludwick (1998) highlighted that P availability is strongly influenced by soil pH. As soil pH is reduced to less than 4.5 with exchangeable aluminium (Al) saturation greater than 60%, soils readily fix P. Thus, in acidic soils high in iron (Fe) and Al oxides, P immobilization is high(Codling, 2008). However, in alkaline soils, where pH is greater than 7.5, P is immobilized through precipitation reaction with calcium (Ca) (Sharma *et al*, 2011). Under these conditions, leaching of soluble P is very limited. In the KwaZulu-Natal coastal sandy belt, plant available P is known to be very low, due to Al saturation and the acidic nature of these soils (Manjula, 2006). Although this Al saturation is seen as low in the soil, it can be high in sandy soils where there are enough clay amounts. In this case, it can adversely affect the performance of a cassava crop.

Soil pH is the single chemical property with the greatest influence on plant growth (Olsen and Sommers, 1982) and, thus, soil productivity. Soils that are too acidic (<5) or too alkaline (>7.5) have adverse effects on soil productivity (Greval and Williams, 2003; Williams, 2004; Moir and Moot, 2010).Intensive and productive farming systems greatly influence soil fertility. Soil pH is the measure of the acidity (hydrogen ion concentrations in the soil). When pH is too low, (<5), soil microbial activity declines and nutrients like P, Mo, Mg, and Ca become less available which in turn

lead to significant decline in agricultural productivity. On the other hand, high pH (>7.5), elements like P, Zn, Mn and Fe are fixed. This less available P and Zn at high pH affects tuber quality (Waterer, 2001).P availability, as affected by different soil pH levels, is shown in Figure 3. The effect of pH is often seen when soil elements change form (Olsen and Sommers, 1982). When pH falls below 5.8, P sorbs and forms complexes with Fe and Al sesquioxides, resulting in lowered availability of P .The ideal pH for P availability is near neutral to slightly acidic (pH 5.8 – 7.0). As pH increases above 7, P forms complexes with Ca forming carbonates. Sometimes these complexes take place in the presence of magnesium (Mg). The formation of these complexes makes P insoluble and unavailable for plant use. Generally, northern KwaZulu-Natal soils are characterized by acidic soils. This acidity is caused by high degree of weathering and leaching, which under normal circumstances would limit some crop production (Manjula, 2006).P fixation is possible in KZN sandy soils as they contain 5-10% clay (Manson and Sheard, 2007).

In Figure 2, when pH falls from 3 and below, P reacts with iron to iron-phosphate which is insoluble. P then becomes fixed. At pH between 3.5 and 5.5, P reacts with aluminium and becomes fixed. Between pH 5.5 and 7, P is liberated and becomes available for plant use. However, when pH increases to 8 and above, P reacts with Ca thereby becoming fixed. P is therefore very sensitive to changes in pH. Under acid and alkaline conditions P reacts with some elements and become fixed but under near neutral to neutral pH, is becomes available.

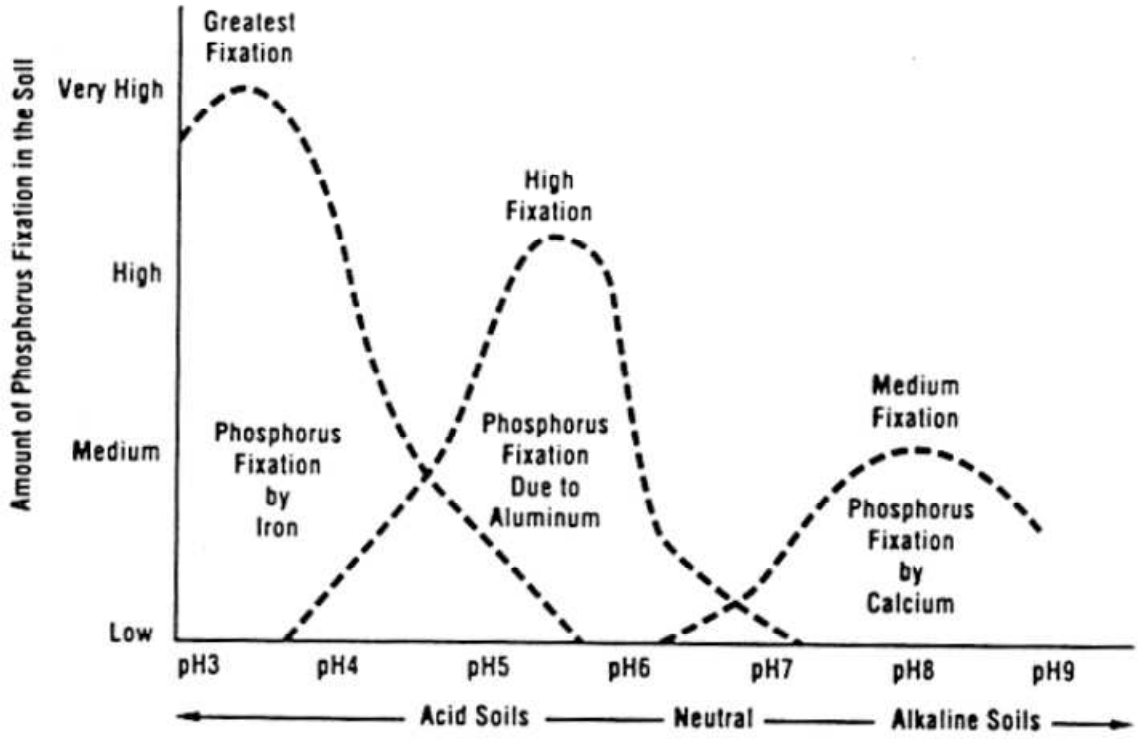

Figure 2. Phosphorus availability as affected by soil pH **(**Adapted from Ludwick, 1998).

2.3.2. Soil Minerals (Fe/Al oxides and Ca-P complexes)

Soil mineralogy plays an important role in the availability of P in the soil. However, precipitation-dissolution and sorption-desorption processes are the two main reactions that control P concentration in solution(Chen *et al*., 2001). Aluminium oxide, hydrous iron, and alumnio-silicate occur in varying quantities in mineral soils (Figure 2). This shows that in acid soils P is fixed mainly by iron and aluminium compounds even at low quantities. Al and Fe oxides react with P in solution to form insoluble P, making it unavailable for plant use (Figure 2)(Arias *et al*., 1995; Ogunwale *et al*., 2006). On the other hand, when pH increases >6.5, Ca reacts with P, forming P complexes such as di-calcium P and tri-calcium P, which are highly insoluble making P unavailable for plant use.

2.3.3. Organic Matter

Soil organic matter is closely linked to plant productivity (Chen *et al*., 2001). It influences both the chemical and physical properties of the soil. These may include soil structure, water holding capacity, availability of diverse soil organisms, as well as nutrient availability. Research by Chen *et*

al. (2001) has indicated that soil organic matter can reduce P-sorption capacity, implying that, for high P-fixing soils, the accumulation of organic matter in the top horizon would increase P availability. This is because certain organic compounds can compete with phosphate for sorption sites. In the long term P sorption by soil mineral components is an important process to control long-term P supply. However, in the short term, soil microbial dynamics are important to improve P availability through organic matter decomposition processes that release assimilated P into the soil solution.. Soils that are high in organic matter normally contain substantial amounts of organic P, which is mineralized to provide available P in the soil for plant growth. Fifty percent of the total P in soil is made available by organic matter (Cooperband,2002; Bot and Benites, 2005; CTAHR, 2007). This makes the mineralization of organic P and microbial turnover very important in the soil.

Organic P is rapidly decomposed in warm, well-aerated moist soils (Mills and Fey, 2003). In this regard, the sandy soils of northern KwaZulu-Natal, where soil temperature is warm in most parts of the season, are supposed to exhibit more organic P availability. According to Condron *et al*. (1989), these would control and maintain the inorganic P in solution. This is realized as the application of heavy organic materials provides acidic compounds during decomposition which increase the availability of mineral P.

2.3.4. Clay

The amount of clay (and its mineralogy) in the soil can affect P availability in the soil, where high clay soils typically have higher P-sorption capacity (Uehara and Gillman, 1981). Soils high in clay content are seen to be high in P-sorption (Uehara and Gillman 1981).Nonetheless, if soil P content is high enough, P sorption sites may be saturated therefore P fixation can be minimal. However, different clay types have different P-fixing capacities. Clays of the 1:1 type (kaolinite) have a greater P-fixing capacity than those of the 2:1montmorillonite clay. Clay of 1:1 has the high the capacity of fixing P because it has high level of Al-OH than 2:1 clay. Studies conducted by Amandoe *et al*. (1997) established that phosphorus solubility was highest in poorly drained as under anaerobic conditions Fe-oxides are reduced releasing any sorbed or occluded P into the soil solution. Under aerobic conditions the Fe is oxidized and readily complexes and sorbed free phosphate ions from the soil thereby reducing availability. Highly weathered clay soils, generally contain high amounts of Fe and Al oxides, which contribute greatly to the fixation of P (Sardik and Csathó, 2002; Wandruszka, 2006).

2.4. Phosphorus Uptake and Use in Plants

2.4.1. The Role of P in Plants

The role P in plants include reproduction and cell division, involvement in all chemical reactions affecting photosynthesis and nutrient adsorption, effective water usage, disease resistance, aiding in crop maturity, and flowering and fruiting(Gilroy and Jones, 2000; Vance et al, 2003). P in plants is responsible for the production of DNA and RNA along with proteins and enzymes for growth. It is also used in making phospholipids. According to Hinsinger (1998), P forms part of the complex nucleic acid structure of a plant. It is this acid that regulates protein synthesis. It is, therefore, critical in plant cell division and reproduction, since it forms part of the building blocks of genes and chromosomes. Another fundamental role of P in plant is that it forms part of all plant processes that involve energy transfer (Berg *et al*., 2005; Fatima *et al*., 2006). This is seen in the chemical structures of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), which are the sources of energy. Phosphorus, therefore, is important for photosynthesis: a process whereby plants manufacture carbohydrates (simple sugars) and release oxygen by using carbon dioxide and water in the chlorophyll in the presence of sunlight (energy).

2.4.2. Uptake of P from the Soil

Phosphorus uptake is influenced by the P ions concentration in the soil solution, higher moisture content and temperature. For crops to take up P in the soil, diffusion process which is more rapid at higher moisture content and temperature than mass flow plays major role in P uptake (Barber, 1984). The role played by interception by roots is also important. According to Smith (2000) the slow rate of diffusion of phosphate in the soil would cause a depletion zone of phosphate ions in solution, causing low phosphate around the plant root. This, in turn, would reduce the uptake of P from such depleted soils. Maintaining adequate phosphate concentration (Smith, 2000) in the soils normally used for plant production is of great importance, as it is most of the time not available for plant use. Thus, understanding the mechanism by which plants take up P from soil is necessary.

Citernesi *et al*. (1998) established that the epidermal and cortical cell walls of young plant roots are composed of fibers that form an open lattice work through which soil solution can move in plant system. The interlaying fibers filter the soil solution and also increase the path length of phosphate ions to be diffused. For a plant to take up P, it must be able to create an uptake surface (Habte, 1994)

close to the soil surface on which the P is absorbed. In this way, the plant can deplete P from the solution, thereby causing desorption from the soil surface. This can then be taken up through diffusion.

2.4.3. The Role of Fertilizers and Economic Implications

From an agricultural point of view, fertilizer can be described as any organic or inorganic material of natural or synthetic origin (besides liming materials) that is added to a soil to supply one or more plant nutrients essential for plant growth(Dailey, 2006). They are broadly divided into two groups: organic fertilizers and inorganic fertilizers. Not only do fertilizers increase crop yields by supplying essential nutrients (in particular those depleted by cropping systems), but they also improve the quality of flowers, fruits and seeds. They also stimulate the microbial activity around the root system and root mass thereby improving the health of the plant (Zhong and Cai, 2007; Richardson and Simpson, 2011). With the ever-increasing world-wide population coupled with climate change, food security has come under threat as agricultural lands are under pressure from housing and road network development. This pressure on agricultural land has resulted in the use of marginal lands that are not suitable for crop production under normal conditions, a situation that demands intensive agricultural production (Nakviroj, 1998). This intensive agriculture, according to Howeler (1990), can be done through the use of NPK fertilizers.

However, the use of P fertilizers in crop production, especially, food crop production, has not been one much in sub-Saharan Africa as the farmers do not see any economic benefits (Bumb and Baanante, 1996; FAO, 2005).In South Africa, P fertilizers are mostly used for commercial agriculture like sugar cane production in KwaZulu-Natal (Stabury, 2000; FSSA, 2003; ARC-ISCW, 2004; Meyer *et al*., 2004; FAO, 2005). This is due to a number of factors, chief among them being economic constraints on farmers (FAO, 2005). In Africa, the majority of farmers are engaged in subsistence farming i.e., producing only enough to feed the family. In this regard, farmers find it constrained to invest in fertilizers, which are considered expensive. Other factors include the value cost ratio of fertilizer usage in Africa which has not been encouraging (CIAT, 1988; NEPAD, 2001; World Bank, 2005; World Bank, 2006). According to Syers *et al*. (2008) fertilizer usage, especially use of phosphorus would not be cost effective to farmers in sub-Saharan Africa nations if a farmland requires as much as 8-10 kg of grain to pay for 1 kg of phosphate (P_2O_5) fertilizer. This is due to the

fact that food prices are not stable and that there are a lot of uncertainties regarding fertilizer usage, such as the returns that may come out of fertilizer application in relation to yield. Furthermore, credit facilities are not available to crop farmers especially the small-scale farmers. Phosphorus fertilizer usage may be cost effective (CIAT, 1988), if producers in sub-Saharan Africa could increase the quantity produced and have an effective supply (delivery) system. This calls for a substantial amount of foreign exchange, which most sub- Saharan Africa countries cannot afford.

2.5. Arbuscular Mycorrhizal Fungi (AMF) and Plant Interactions

AMF exist in natural soils and colonize about 80% of plant species and have a symbiotic relationship with host plants. The host plant benefits from scarce plant nutrients, like P, that is available in the soil, while the AMF benefits from carbon available from the host. Though several studies have been done on AMF (Howeler *et al.*, 1982; Kung'u *et al.,* 2008; Bonafante and Genre, 2010), they are mostly limited to cereal crops. This review is limited to the types, occurrence and functioning of AMF, as well as the use and mechanisms of AMF to improve P uptake by root and tuber crops in agricultural soils. The main nutrient exchange processes in ectomtcorrhizal and AMF symbiosis are illustrated in Figure3.

Figure 3 explains the relationship between plant, fungus and soil. There are three main nutrients involved in the symbiosis relationship between the fungus and the host (plant). The AM fungus tarnsport P in the form of phosphate to the host plant. Not only does it transport P but also NH_4, NO_3 which are converted from AA and ureaas plants do not use AA or urea directly. In an exchange, the host (plant) provides the sugar in the form of glucose, sucrose and fructose as energy to the fungus. This is a mutual symbiosis between the host (plant) and the fungus.

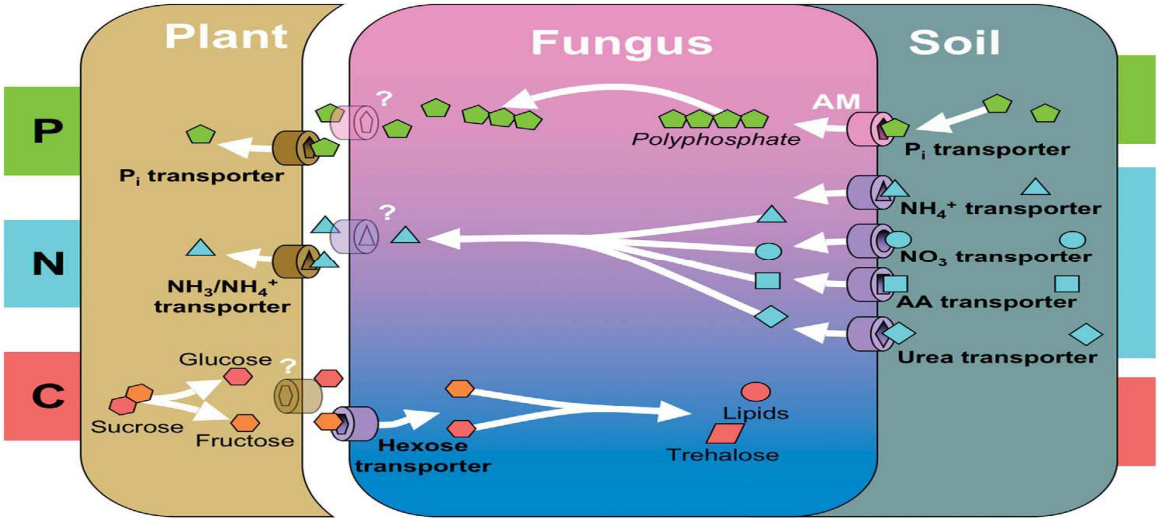

Figure 3. Scheme summarizing the main nutrient exchange processes in ectomtcorrhizal and AMF symbiosis. (Bonafante and Genre, 2010).

2.5.1. Types, Occurrence and Functioning of AMF in Root Crop Production

There are two main types of mycorrhizal fungi: ectotrophic types (ectomycorrhizae) and endotrophic types [endomycorrhizae or arbuscular mycorrhizae (AM)] (Muchovej *et al*, 1990; Muchovej, 2001). Ectomycorrhizae are normally formed on the roots of woody plants. Though this type of mycorrhiza normally has extensive hyphal growth in the cortical cells, few hyphae extend into the soil. For the host plants to benefit from these mycorrhizae, the mycorrhizae have to produce extracellular enzymes that are capable of breaking down organic matter, making it possible to absorb nutrients which are mineralized from organic compounds (Muchovej, 2001).

Endomycorrhizae which colonize within the host include: arbuscular, eriod, arbutoid, monotropoid, and orchid mycorrhizae (Abbott and Robson, 1982). Among these, the arbuscular mycorrhizal fungi (AMF) seem to be found in almost all natural soils. The AMF are found to be common in most agronomic, vegetable, and fruit crops (Muchovej *et al*, 1990; Muchovej, 2001). Though they occur in most natural soils, their availability for commercial agricultural production is hampered by the fact that they are difficult to culture, as this could be done only in the presence of the host; this is not the case with ectomycorrhizae (Muchovej, 2001). The AMF are capable of producing more hyphae on the roots of the host, thereby transporting nutrients from the soil to host. Research has indicated that AMF are found only to be associated with the cortical tissues of very fine feeder roots. This

may suggest the reason why AMF become beneficial to most root and tuber crops (Quilambo, 2003) found in nutrient depleted soils (Bolan *et al.,* 1984).

The biological, chemical, and physical soil quality improvement properties of AMF have been well documented (Cardoso and Kuyper, 2006). Some plants (banana, cowpea, maize, etc.) depend almost entirely on AMF for nutrients like P (P lenchette *et al*., 1983; Adesemoye *et al*., 2008; Tavares de Lima *et al*., 2011; Yaseen *et al*., 2011).Due to the large surface area of the mycelia of AMF, host plants are able to absorb water and nutrients from the soil effectively increasing the area for nutrient sorption by roots. Cardoso and Kuyper (2006) found that AMF were able to enhance uptake of nitrogen (N), potassium (K) and some immobile micro- nutrients by host-plants. This confirms the results of earlier studies by Reid (1979), Abbott and Robson (1982) and Augé (2000).The hyphae of AMF are able to penetrate more than 9cm further than the plant roots could reach, and, due to the symbiosis between the fungi and the host plant, it is possible for the mycorrhizae to transport such nutrients to the host by shortening the distance for diffusion (a process of nutrient absorption) by these nutrients. AMF, among other things, increase water availability to host plants (Quilambo, 2000). In the studies on the functioning of peanut under nutrient deficiency and drought stress, Quilambo (2000) reported that AMF inoculation increased leaf and root growth, as compared to plants under these same stress conditions without AMF inoculation. Kung'u *et al*. (2008),in their study on the effect of AM inoculation on drought resistance, observed significant increase in plant height of *Senna spectabilis* inoculated with AMF. The AMF-inoculated *Senna spectabilics* plants increased in shoot height byapproximately 100% (Sivakumar *et al*., 2002; Hemashempagam and Salvaraj, 2011). The water use efficiency contributed by AMF leads to better formation of leaf canopy and subsequently a large photosynthetic surface area, which also leads to high dry matter content. Not only do AMF increase water use efficiency and make nutrients available to the host, they also protect the host from root pathogens like *Phytophthoraparasitica and Fusarium spp.* and nematodes (Pozo *et al.*, 2002; Ryan *et al*., 2002). This may suggest that there is a direct interaction between AMF and pathogens. This was supported by the findings of Quilambo (2003) on AMF symbiosis which established that AMF is able to protect plants from root pathogens.

Poor soil structure leads to poor crop production, as the porosity of the soil is affected, leading to poor aeration (Rasmussen, 1999; Horne and Sojka, 2002; Watson and Kelsey, 2006). Studies on

AMF and soil quality have indicated that soil structure is improved in the presence of the fungi (Miller and Jastrow, 1990; Klironomos and Kendick, 1996). This according to Cardoso (2006), is attributable to the fact that AMF are able to develop external hyphae that grow into the soil and create a skeletal structure that binds soil particles together, forming strong aggregates (crumb structure). This structure directly enhances carbon resources aiding the soil organic matter decomposers in the soil which further cement the soil particles (Cooperband, 2002; Six and Jastrow, 2002).

2.5.2. The Use and Mechanisms of AMF to Improve P Uptake by Crops

There are several mechanisms suggested to improve P uptake by plants through AMF. These according to Bolan (1991), include exploration of larger soil volumes by reducing the distance that P ions have to diffuse to plant roots; fast movement of P into the mycorrhizal hyphae; and, solubilization of soil P.

Research has established that AMF have the ability to absorb soluble phosphate (as well as other nutrients) that is beyond the P-depletion zone (Figure 4) and develop around the root surface (Grant *et al*., 2004). This is probably due to the external hyphae having a higher affinity for P ions and, thus, being capable of decreasing the threshold concentration required for the absorption of P. In the process of diffusion, phosphate is taken up and translocated as polyphosphate granules by protoplasmic streaming before being hydrolyzed in the arbuscules prior to transmembrane transfer into the host cell. In view of this, Saber *et al.*(2009) established that under P-limiting conditions, such as P bound with Al or Fe (Fig. 2.4), proton efflux may constitute an efficient way to increase P uptake. The proton efflux and phytases activity maintain the oxygen diffusion in nodules and this may be an adaptive mechanism for N_2 fixing for crops to respond to P deficiency. This, according to Grant *et al*. (2004), can be done through the excretion of citric acid and siderophores by mycorrhizae, enhancing the supply of bio-available P of the soil.

The use of P fertilization cannot be overlooked in terms of P availability by AMF. In situations where P is almost completely depleted below threshold due to degradation, it has been suggested that the application of P fertilizer may help increase the activities of the mycorrhizae (Miyasaka *et al*., 2003; Selvaraj and Chellapan, 2006). This process would help improve carbon, the nutrient

needed by AMF to induce initial colonization (Ayres *et al*, 2006). However, it is well documented that high P fertilization would limit the effectiveness of the mycorrhizae in seedling establishment (Peters and Habte, 2001; Habte and Osorio, 2001). If P fertilizer could be used or placed near the root zone to be absorbed by plants and is cost effective, it could be applied to induce initial P requirements for seed establishment. In their studies, Grant *et al*. (2004) concluded that a combination of AMF colonization and application of low levels of P fertilizer could help to achieve better yields and strongly emphasized that the use of AMF would be of great benefit.

Even though mycorrhizal associations may be beneficial, they do not always enhance P uptake sufficiently to maximize crop yield when there is enough amount of P readily available in the soil. Studies conducted by Ryan and Ash (1999; 2000), showed that, despite an enhanced mycorrhizal association in biodynamic pastures, the level of P in the forage was below that of conventionally fertilized pastures. The major problem of mycorrhizal association in agricultural systems is that the associations tend to decline as P concentration in plants increases. Higher tissue P in plant would reduce the production of spores and the mycorrhizal association would be affected (De Miranda and Harris, 1994). Olsson *et al*. (1999) observed that increasing P concentrations reduced mycelia formation. There is the need to balance soil P at any given time with regards to agricultural production through plant and soil sampling and analyses.

2.6. Cassava Production

2.6.1. Introduction to Cassava Production

Cassava is an important food crop that is commonly grown by small-scale farmers and is eaten in many parts of sub-Sahara Africa, Asia, and Latin America (FAO, 2008). The crop has many versatile uses for example food for human beings and as animal feed, industrial use as well as pharmaceutical uses (Nduele *et al*, 1993; Alves, 2002; Akinpelu *et al*., 2011). The young leaves are used as vegetables, which are highly nutritious for human consumption (Table 1). The leaves are also used as livestock and poultry feed. Starch from cassava tubers is used as industrial raw material by paper, pharmaceutical, textile, and food processing industries (Tan *et al*., 1984; Nduele *et al*., 1993; Vuilleumire, 1993; Roble *et al*., 2003). Though many people are skeptical about the consumption of cassava tubers, due to their cyanogenic glycoside content, they are very safe once they are processed by heating (FAO, 2005).The tuber has higher levels of carbohydrate as compared

to maize and rice. The leaves typically have higher concentration of protein, minerals and vitamins compared to vegetables such as cabbage, spinach, etc. (Burns et al., 2010). However, the vitamins can be destroyed during cooking. The tender leaves contain up to 25 percent of protein and are also valuable source of iron, calcium and vitamins A (FAO 2008).

Cassava does well in well-drained, deep, loamy soils, as well as in sandy soils. It does well under conditions where other field crops like maize and dry beans might fail, as the crop grows well on acid soils and gives reasonable yields where most other crops would either fail or give very poor yields (Cock and Howeler, 1978).Soil nutrition, especially P is crucial throughout the growing period of this crop under mono-culture condition (Higa, 1991).

Table 1.Nutritional information per 100 g of cassava (Adapted from MOFA-RTIP, 2004)

Item	Unit	Value
Dried matter	G	99.0
Calories	Kcal)	334-360
Proteins	g	1.12
Lipids	g	0.61
Global Glucides	g	87.3
Indigestible Glucides	g	1.82
Ashes	g	1.03
Calcium	mg	50.0
Phosphorus	mg	40.0
Iron	mg	4.56
Thiamin	mg	54.6
Riboflovin	mg	45.5
Niacin	mg	1.00
Ascorbic acid	mg	6.06

Yields of about 20 tons ha^{-1} have been realized under dryland conditions, while up to 40 tons ha^{-1} have been achieved under irrigation in Africa through the research by the Cassava Multiplication Project funded by IFAD in Nigeria (Nweke *et al*.,1994). A joint cassava variety improvement work in Ghana and CIAT in 1987 led to the release of cultivars like Bankyehemaa, Dokuduade, Afisiafi and many other cultivars which have been found to be high yielding when grown under mono-culture conditions (Tetteh and Frimpong, 1991; MOFA-RTIP, 2004).According to the Department of Agriculture, Forestry and Fisheries (2010), a yield of between 15 tons ha^{-1} and 29 tons ha^{-1} can be

realized depending on the cultivar, management and time of planting. To achieve better yields of a cassava crop, it is imperative that one adopt good plant production and protection practices, which include: good site selection; adequate land preparation; soil improvement strategy; choice of variety, and, selection of planting materials (DAFF, 2010). Post-planting measures like weed, insect pest and disease control are very important in the production of cassava(MOFA-RTIP, 2004; DAFF, 2010).

George (1989), at a workshop on trends and prospects of cassava production in India, projected that the demand for cassava as food by the end of 2000 would hit a record high of 197-211 million tonnes. This projection was based on trends from the 1970s, when cassava production rose at an average rate of 2.2 % per annum (Prakash, 2004). FAO (2005) predicted an increase of 2.9% per year in Africa for the next decade. According to Burns *et al*. (2010), cassava has emerged as multipurpose crop for the 21st century thereby increasing its production globally. This shift has come as per the realization of the potential of the crop by policy makers in terms of rural development, urban food security import substitution where cassava flour can be used to replace wheat flour in bread making, renewable energy source, new industrial uses, and adaptation of climate change. It is important that sustainable production of this crop be given adequate attention to help alleviate poverty and improve food security, especially among the poorer rural farming communities.

2.6.2. P Uptake and Use by Cassava

Cassava, like any other crop, depends on soil phosphate for its initial growth and establishment, which eventually affects the yield of the crop (Sieverding and Howeler, 1985). Studies have shown that cassava takes in more P for the first three months than during later growth stages (Nijholt, 1935; Howeler and Cadavid,1983). Though cassava takes up a small amount of P (50kg ha^{-1}), as compared to other nutrients like N(70 kg ha^{-1}) and K(100 kg ha^{-1}), it stores a greater part of the P (60%) in the roots (Howeler and Cadavid, 1983).In Africa few experiments have been done on the extractable P considered to be adequate for cassava production. However, responses to P application have been reported mainly in Ghana and Madagascar. Ofori (1973) reported that the required extractable P for effective production of the crop depends on the physical and chemical status of a particle field. The same view was shared by Howeler and Cadavid (1990) but later Howeler (1992b), in his studies on mineral nutrition of cassava reported that the critical level of P in the soil which is considered to be adequate for cassava production is between 4-6µg/g Bray II. Apart from P, cassava production is

also influenced by other nutrients such as N, K, Ca, Mg, OM and Zn. Other factors besides nutrient include rainfall, temperature, time of planting and cultivar selection. Agbaje and Akinlosotu (2004), in their studies on the influence of NPK fertilizer on tuber yield of early and late-planted cassava in a forest afisol of south-western Nigeria found positive correlation between fertilizer application, time of plant and climate. Similar results was found by Ezekiel *et al.* (2012), confirming the importance of the above-mentioned factors in cassava production. Continuous production of this crop on the same piece of land without any form of additional external nutrient like P could lead to low productivity. According to Van der Zaag *et al*. (1979), infecting cassava roots with AMF makes it possible to increase P and N uptake from the soil.

2.7. The Role of Fertilizers in Cassava Production

Major roles played by fertilizers in cassava production may include initial crop establishment, water retention, re-population of native mycorrhizae in depleted soil and increase in tuber yields (CTCRI, 1983). Cassava, especially, improved varieties like "Afisiafi" in Ghana, responds very well to fertilizers in P depleted soils (MOFA-PTIP, 2004). On depleted soils, native AMF are eliminated or reduced, affecting cassava establishment and overall yield in such soils (Ofori, 1973). Farmers normally do not fertilize cassava, as they often harvest a minimum of about 15 tons ha^{-1}, even without fertilizers (Bableye, 1996). Though inoculation of planting materials with effective strains may increase the build-up of P, the availability of such inoculants in commercial production may be limited. Application of chemical fertilizers especially P would help in the initial build-up of the mycorrhizae leading to soil stability, high crop establishment and increased yield per unit area. Studies on cassava in Thailand (Sittibusaya *et al*., 1988) established that, after 31 years of continuous cassava farming on the same piece of land, the crop responded very well to fertilizer application of 2:1:2 (100kg N, 50kg P_2O_5, and 100kg K_2O per ha^{-1}producing 26tons ha^{-1}. Similar studies conducted by Howeler (1990) produced similar results. Research has recorded 400% yield increase with the application of fertilizers in cassava production in Trvandum in India (John *et al*., 1998). Ayoola and Makinde, (2007) recorded yield increases of 11.8 and 11.0tons $ha^{-1}$with the application of organic fertilizer, and inorganic fertilizer respectively, compared to 7.91tonsha^{-1} without fertilizer application. With application of complete chemical fertilizer, in addition to compost or crop residue, soil organic matter and pH could be increased.

2.8. The Role of AMF in Cassava Production

Limited supply of P in the early growth stage affects cassava production and the overall returns (Howeler, 2002; Salami and Sangoyomi, 2013).Release of P to cassava plants depends greatly on soil biological activity, especially of AMF. Cassava has higher mycorrhizal dependency and responds well to colonization by the fungus. Sieverding and Howeler (1984) monitored a trial of cassava for the occurrence of AMF in acid soils in Colombia. Different P levels ranging from 0 to 200kgha^{-1} were used. They found differed types AMF species and that the total root length and the infected root length of the plants were realized at the optimum of 50 to100kg ha^{-1}AMF, depending on the fungus species. It was found that AMF increased cassava tuber yield up to 3-fold (Oyetunji and Osonubi, 2007). Arbuscular mycorrhizal fungi form a link between the soil and the crop, thereby making nutrients more accessible to the crop. Cassava under alley cropping system, which is mostly practiced by cassava producers in sub-Saharan Africa, was found to be less, as compared to those inoculated with AMF. Oyetunji *et al*. (2003) suggested that integrating alley cropping with myccorrhizal technology may be of great help in terms of cassava tuber yields. Oyetunji *et al*. (2007) reported that AMF helped in micro-nutrient uptake by cassava. They further established that AMF could alleviate the adverse effect of water stress and adverse temperatures more than non-inoculated cassava plants. In view of this, the crop is able to do well in the tropics and semi-arid areas where many crops may not survive. Augé (2001) and Osundina (1995) also highlighted the role played by AMF with regards to cassava production. They found that AMF-colonized cassava plants were able to withstand a high sodium range in which many crops would not survive. This may be through the mechanism by which AMF detoxify the excess salt through biological processes, as it is able to purify the nutrient from the soil to the plant and vice-versa. Under such conditions, Oyetunji *et al.* (2007) observed an increase in cassava leaf area in AMF-inoculated plants as early as 2-3 weeks after planting as compared to non-inoculated plants of the same age. Though researchers have indicated that AMF colonization of cassava is not affected by planting material (Howeler *et al*., 1982), studies by Habte and Byappanahalli (1994) concluded that cassava grown from bigger cuttings were marginally dependent on AMF as compared to small cuttings.

2.9. General discussion and conclusion

The need for increased food production in sub-Saharan Africa cannot be over-emphasized. Increasing population has pushed crop production to marginal lands, resulting in low production levels. These lands are low in P which is essential in many plant processes, including cell division, photosynthesis and nutrient uptake and promotes water efficiency, disease resistance, crop maturity, and crop yields. It has been established that the high levels of P immobilization by iron (Fe) and aluminium (Al) oxide, the formation of complexes between P and Ca and Mg and run-off reduce the availability of P for plant use in KZN soils (Manson and Sheard, 2007). P is also removed from the soil during crop harvest, when plant parts that have accumulated P are not returned to the soil. Chemical fertilizer applications, including P fertilizer applications, to replenish soil nutrients, are beyond the financial reach of the resource-poor subsistence farmers in sub-Saharan Africa. An alternative or supplemental means to chemical fertilizer application for soil improvement is needed for improving crop yields.

The availability of mycorrhizae, including AMF, in most natural soils needs to be explored in KZN. The benefits of the symbiotic relationship between AMF, and plants, as documented by many research works are similar to those provided by P fertilizers. These include improvement in soil structure, root disease resistance and drought resistance, as well as increased crop yields through increased leaf area for higher photosynthesis and root growth. AMF-treated plants have been shown to survive and do better in high sodium soils than other plants. Arbuscular mycorrhizal fungi need P for the initial hyphal establishment. The marginal, impoverished, acidic soils of KZN in which the native AMF are probably low or have been depleted, should benefit from P fertilizer application and AMF inoculation.

Most of the research work on AMF has been done in cereal crops. Cassava has the potential to alleviate the food problem in sub-Saharan Africa. Research has established that high yields may be obtained through the use of P fertilizer and AMF inoculation. There is no information on the performance of cassava in KZN soils when treated with a combination of P fertilizer and AMF.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Experimental Site

Experiments were conducted at four different locations in northern KwaZulu-Natal, where cassava has been produced by some small-scale farmers using some local varieties like “Mama omunthle”, “OSCA 1”, “Qualindela,” “Erico 1”, and “Feli 2”. These areas are in the Bioresource Group (BRG) 1 of KwaZulu-Natal (Table 2 and Figure 4)

Table 2.GPS coordinates for the study areas.

LOCATION	GPS CO-ORDINATES	
Owen Sitole College of Agriculture (OSCA)	S 28.73007	E 31.943830
Mtubatuba	S 28.08009	E 34.631266
Mtunzini	S 28.92670	E 34.625596
Empangeni	S 28.68900	E 31.917474

The BRG 1 is a coastal strip which lies along the entire coastal belt of the Province of KwaZulu-Natal. The climate of the BRG is warm with a mean annual temperature of 22 ^{o}C north and 18.5 ^{o}C in the south. The mean annual rainfall ranges from 820 mm to 1423 mm. The above climatic capability is rated as C1 which means that the area exhibits high yielding potential for crop production. The terrain is gently rolling in the north whiles it becomes steeper to very steep in the south. The dominant natural vegetation is forest. However, in some areas, Acacia *spp*. and palm *spp*. can be found. The type soils found in the north are mainly sands, while poor quality duplex soils are found between Tugela River and Mtunzini, with Glenrosa as common soil form. Approximately 37% of the BRG is considered as arable of which only 6% has high potential soils. This BRG has been extensively cultivated under sugarcane, timber banana as well as vegetables (KZNDAE, 1995). Patches of cassava are found in the northern part of the BRG mainly under smallscale holdings. The slope gradients at the study sites are similar except OSCA that has some wide variations. OSCA has predominantly steep slope define as 12% but has some moderate slopes in some areas varying from 5 to 12%. Mtunzini and Empangeni have similar slope gradients which are predominantly moderate ranging from 5 to 12% whereas Mtubatuba has gentle slope defined as <5% (KZNDAE, 2012).

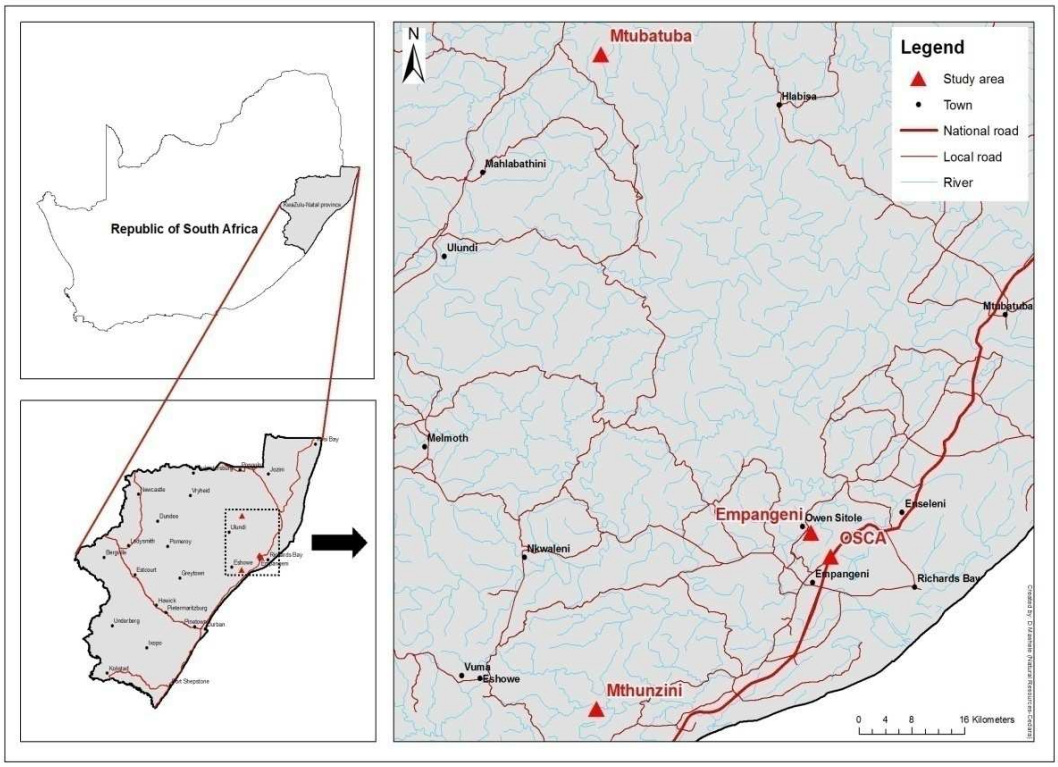

Figure 4. Map showing the study areas denoted by red triangles.

3.2. Climatic Factors

The rainfall and temperature regimepatterns for the four study areas (stations) namely Owen Sitole College of Agriculture (OSCA), Mtubatuba, Mtunzini and Empangeni are presented in Figures 5 and 6, respectively. Climate plays major role in cassava production.

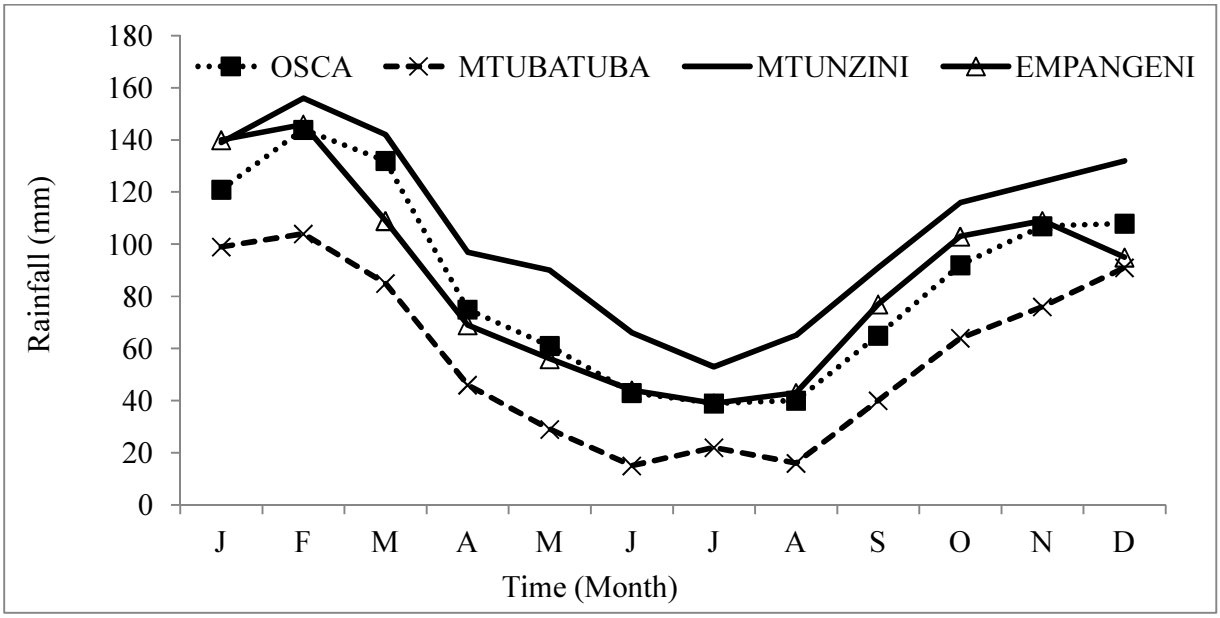

Figure 5Mean rainfall over 20 years including the trial period (KZNDAE, 2012)

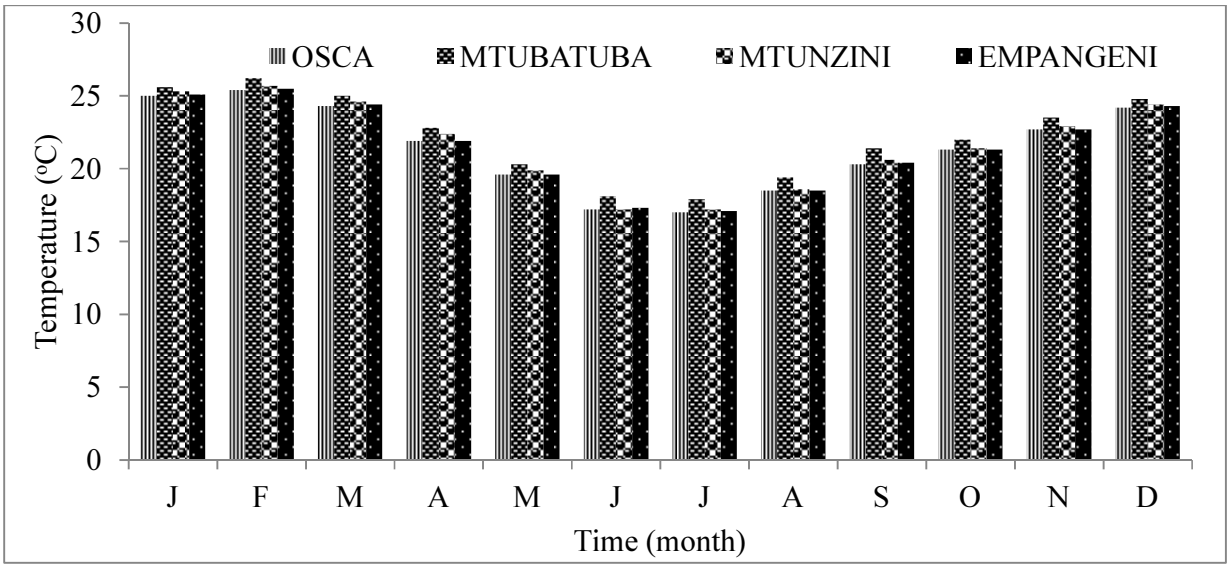

Figure 6 Mean temperature over 20 years including the trial period (KZNDAE, 2012)

Generally, the study sites have high rainfall during the summer months and during the winter, the rainfall drops. However, there is not frost in these areas. The mean annual rainfall ranges from 928 mm in Mtubatuba to 1271 mm in Mtunzini. These areas are warm climatic areas with mean annual temperatures ranging from 21.5°C at Empangeni and OSCA to 21.9°C at Mtubatuba. The mean

sunshine hours ranges from 6.5 hours at OSCA, Empangeni and Mtubatuba to 6.6 hours at Mtunzini (KZNDAE, 2012).

The above climatic parameters exhibit sub-tropical to tropical conditions. Cassava requires minimum average annual rainfall of 400 mm but much higher yields can be obtained with higher rainfall. In terms of temperature, the crop prefers 20^{o}C-29^{o}C for optimum production. However, the crop can survive wide range of temperatures but not below 10^{o}C as the crop is sensitive to frost (MOFA-RTIP, 2004).During high rainfall months, plant nutrient concentration is becomes weak whereas during the low rainfall months the concentration is strong. These areas are, therefore, ideal for cassava production, which does well under such climatic conditions.

3.3. Soil and Topography

The majority (54 %) of the soils in this BRG is arable and 53% of that is of high potential for field crop production (Table 3) (Camp, 1999). The elevation ranges from 0 to450m above sea level. The bioclimatic group is made up of dystrophic soil with deep sandy soils of about 36% clay, and has good rapid permeability and is acidic with soil pH ranging from 4.1 to 4.5 (Webster, 1990).

Table 3. 20 year yield ranges for commonly grown crops in BRG 1 from 1992 (KZNDAE, 2012)

Site	Crop	Yield tons/ha (Maxi)	Yield tons/ha (Mini)
OSCA			
	Cabbage	55.7	47.3
	Maize	4.2	2.3
	Sugarcane	89	60.7
	Tomato	55.9	44.7
	Banana	37.6	26.4
Mtubatuba			
	Cabbage	57.1	48.5
	Maize	3.3	1.8
	Sugarcane	86.1	58.7
	Tomato	62	49.6
	Banana	39.7	31.8
Mtunzini			
	Cabbage	54.1	46
	Maize	4.5	2.8
	Sugarcane	114.1	77.8
	Tomato	57.1	45.7
	Banana	37.6	22.6
Empangeni			
	Cabbage	55.4	47.1
	Maize	4.5	2.5
	Sugarcane	98.6	67.2
	Tomato	56.2	44.9
	Banana	37.7	26.4

The above crops are crops are not commercially managed except at OSCA which is a Research and Training site. With rest of the sites, according to survey conducted before establishing the trial, all the growers indicated that they do not use fertilizer, no pest control and continue to plant on the same plot for long period. However, OSCA put control measures to ensure optimum yield. In terms

of yield, OSCA realizes an average of 25 tons ha^{-1} while the rest of the sites realize average of 10 tons ha^{-1} for lettuce. For cabbage, OSCA realizes an average of 55 tons ha^{-1} and the rest of the sites realize an average of 43 tons ha^{-1}.

3.4. Current Land Use

The selected sites had been previously used for dryland vegetables production such as cabbage, spinach and lettuce for a number of years. Initial survey done to ascertain the land use at various sites before the establishment of the trial of which the results was not included in the work as it was not formally structured, revealed that crop rotation is virtually out of use in these areas. To increase the fertility of the soils, land users have been applying inorganic fertilizers, like N, P, K, without any routine soil analysis. At harvest, almost the entire current crop is taken and residues are burnt to make land preparation easier prior to the following planting season.

3.5. Experimental Design

Sixteen plots, each measuring 5 x $5m^2$ were established at each site, with a 1-m alley around each plot and a 1-m buffer strip around the whole plot area. Each plot was divided into four subplots, and subplots were separated from each other by 2-m inter-row buffer strips (Table 4). The subplots were necessary as the trial was a destructive trial therefore in event of any loses in the main plot, the data could still be taken from the subplots for analyses, though the subplots were not part of the statistical design. The trial consisted of four treatments and was laid out in a Latin Square Design (LSD) with four replicates. For convenience, the same design was repeated and randomized at all other sites. Several methods are used in planting cassava stakes. These include: mounds on pits; mounds; and flat land with different tilting angles. These methods are mostly informed by the expected number of shoots, tubers, possibility of lodging by wind and the easiness of harvesting (MOFA-RTIP, 2004).The mounds make harvesting easier while the flat land induces more root formation leading to more tubers. It also prevents the crop from lodging while lodging is common on mounds. Though each of them has its own pros and cons, the flat land with tilting angle was used in this experiment. This was to reduce the possibility of lodging by wind as wind is very prevalent these areas and also to make sure that harvesting is done at ease as this was expected to fall in dry season. A planting distance of 1 m x 1m was used (36 plants per plot). The four treatments consisted of 1) control (no fertilizer applied treatment), 2) P fertilizer, 3) AMF inoculation at 50 g ha^{-1}, and 4) P-fertilizer +

AMF inoculation. Fifty kg ha^{-1} of phosphorus fertilizer [P_2O_5 (double superphosphate)] was applied by placing it in furrows where planting has to be made. The 50 kg ha^{-1}amount of P fertilizer, according to Ofori (1973) and Cobbina and Thompson (1987)is the required P amount for optimum cassava production. A blanket fertilizer at all sites was selected due to the lack of clear fertilizer recommendations for this crop in the region. However, MOFA-RTIP (2004), recommended that 95 kg^{-1} N, 45 kg^{-1} P_2O_5, 95 kg^{-1} K_2O should be applied but emphasized that this must be seen as a general rule but the final recommendations rest with nutrient removal which can be determined through soil analyses. The AMF (*Glomus manihotis*) was applied at a rate of 50 g ha^{-1}(Clement and Habte, 1995; Sieverding and Howeler, 1985). The AMF was buried at a depth of about 3 cm in the furrows prior to planting. Stakes were not pre-rooted. Stakes were carefully selected to meet the following criteria: a) the base and the middle parts of a healthy and strong cassava plant that is 8-10 months old: b) a cutting must be about 20-30 cm long and 2 cm thick and have about 5 to 7 nodes (Figure 7a): c). Plants must have matured tubers, since they would produce the strongest new plants and grow more quickly (Figure 7b) and produce more tubers than younger plants.

Planting was done at all the sites on the same day on 1st February, 2010. The crop was allowed to grow under natural conditions and harvesting done on 31stJanuary, 2011.

Table 4. Experimental design for the trial using 5 x 5m^2/plot

Slope	Block/Plot	Treatment			
	A	2	1	3	4
	B	4	3	1	2
	C	1	4	2	3
	D	3	2	4	1

2m Buffer strip

1m alleys

1) Control (No fertilizer)
2) PhosphorusFertilizer only (P)
3) Arbuscular Mycorrhiza Fungi (AMF) inoculated only
4) P and AMF inoculated

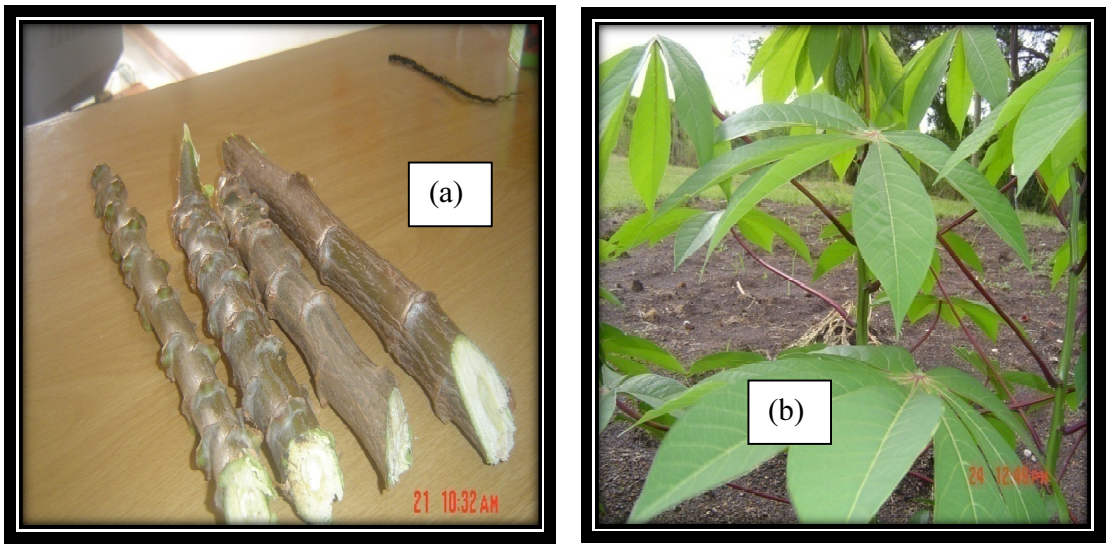

Figure 7. (a) A healthy matured cassava plant for planting and (b) A new cassava plant growing from healthy and matured cuttings at OSCA site [3 Months after planting (MAP)].

3.6. Soil and Plant Sampling Analysis

3.6.1. Soil

Eight composite top soil samples were collected from each site at the beginning of the experiment prior to treatment application and at harvest and analyzed by the Soil Fertility and Analytical Services Laboratory (Cedara, Howick, South Africa) for basic fertility parameters. Soil samples were analyzed for pH (KCl), exchangeable acidity, exchangeable phosphorus, exchangeable base cations [calcium (Ca), magnesium (Mg), potassium (K), extractable zinc (Zn), manganese (Mn) and copper (Cu)]. Mid-infrared analysis for total nitrogen (N), organic carbon (C), and clay content was also done. Acid saturation and the sum of bases were calculated. In preparation of samples for laboratory analysis, samples were spread out in drying trays, and air-dried at room temperature. After being dried, the samples were crushed between rubber belts on a soil crusher and passed through a 1-mm sieve. Materials coarser than 1 mm that could not be crushed were discarded. Though soil is defined as 2 mm and smaller but this done through the Cedara Soil Fertility and Analytical Services' protocol as the analyses was done at that laboratory.

The samples were then scooped into trays containing 11 PVC cups (a capacity of 70mL); a tray was used for nine unknown samples, one standard soil sample, and one blank. Batches of three trays (27 samples, three unknowns, and three blanks) were used for operations like dispensing and stirring, and also for quality control. Multiple dispensers and diluters were used to dispense aliquots of extractants to three samples at a time. Soil samples were then analyzed on a volume, rather than a mass, basis. To enable the conversion of the results to a mass basis, the mass of a 10-mL scoop of dried and milled sample was measured and the calculated sample density was reported (Manson and Roberts, 2009).

To determine soil pH, 10 mL of soil sample was scooped into sample cups. Twenty-five mL of 1*M* KCl solution was added and the suspension was stirred at 400 revolutions per minute (rpm) for 5 minutes, using a multiple stirrer. The suspension was allowed to stand for about 30 minutes, and the pH was measured using a gel-filled combination glass electrode, while stirring. The extractable (1 *M*

35

KCl) Ca, Mg, and acidity were determined by scooping 2.5 mL of soil sample into sample cups. Twenty-five mL of 1 *M* KCl solution was added and the suspension was stirred at 400 rpm for 10 minutes, using a multiple stirrer.

The extracts were filtered, using Whatman No. 1 paper. Five mL of the filtrate was diluted with 20 mL of 0.0356 *M* $SrCl_2$, and Ca and Mg were determined by atomic absorption. To determine extractable acidity, 10 mL of the filtrate was diluted with 10 mL of de-ionised water containing 2 to 4 drops of phenolphthalein, and titrated with 0.005 *M* NaOH (Manson and Roberts, 2009).

Extractable P, K, Zn, and Mn were determined using Ambic-2 extracting solution, which consisted of 0.25 *M* NH_4CO_3 + 0.01 *M* Na_2EDTA + 0.01 *M* NH_4F + 0.05 gL^{-1} Superfloc (N100) and was adjusted to pH 8 with a concentrated ammonia solution. Twenty-five mL of this solution was added to a 2.5 mL soil sample, and the suspension was stirred at 400 rpm for 10 minutes using a multiple stirrer. The extracts were filtered using Whatman No.1 paper (Manson and Roberts, 2009). Phosphorus was determined on a 2-mL aliquot of filtrate using a modification of the Murphy and Riley (1962) molybdenum blue procedure (Hunter, 1974). Potassium was determined by atomic absorption on a 5-mL aliquot of the filtrate after dilution with 20 mL de-ionised water. Zn and Mn were determined by atomic absorption on the remaining undiluted filtrate. The effective cation exchange capacity (ECEC) was calculated as the sum of KCl extractable Ca, Mg, and acidity and Ambic-2 extractable K. Percent acid saturation of the ECEC was calculated as extractable acidity/ECEC x 100 (Manson and Roberts, 2009).

3.6.2. Plant

3.6.2.1 Leaf Nutrient uptake and Plant Height Measurements

A total of 144 leaf samples were collected per plot from young but fully open leaves (Figure 9a) during each of the following sampling periods: 2, 3, 4, 5, and 9 months after planting (MAP) to establish nutrient intake by the crop at different growth stages. These sampling periods were used based on the findings and recommendations of studies conducted by Howeler and Cadavid (1983). In their studies on accumulation and distribution of dry matter and nutrient during a 12 month growth cycle of cassava, they found that phosphorus intake by the crop changes at the various times as it starts increasing from 2 months after planting (MAP) to 4 MAP and thereafter stabilizes. The

sampling schedule used was to test whether or not it is applicable to other places. Young, fully expanded leaves were taken from near the top of non-systematically selected plants from each treatment. Plant height was also measured at 2, 3, and 9MAP to establish the effect of P on cassava growth at different stages. To establish the effect of P availability on root establishment with regards to cassava production, roots were counted and root lengths were assessed at 4MAP. Destructive sampling was done by harvesting a representative number of plants from each treatment in Block A at each site and physical counting was done. Roots lengths were measured using a measuring tape.

3.6.2.2 Leaf chemical analysis

Plant leaves were analyzed to determine nutrient uptake by the plants. Samples were oven dried at 75^{o}C, and milled to pass through a 0.84 mm sieve. Subsamples were then ashed at 450^{o}C overnight in a furnace and the ash dissolved in 1 *M* HCl (Manson and Roberts, 2009). The P concentration was determined calorimetrically by the same method used for soil extracts, and K, Na, Ca, Mg, Cu, Mn, and Zn were determined by atomic absorption spectrophotometry.

Total C, N and Sulphur (S) were analyzed by the Automated Dumas dry combustion method using a LECO CNS 2000 (Leco Corporation, Michigan, USA; Matejovic, 1996). This was done by weighing samples into a ceramic crucible, to which 0.5g of vanadium pentoxide was added as a combustion catalyst. The crucible was introduced into a horizontal furnace; samples burnt in a stream of oxygen at 1350^{o}C. The gases produced were passed through two infra-red cells, where S (as SO_2) and carbon (as CO_2) were determined. Nitrogen was determined (as N_2) in a thermal conductivity cell.

3.7. Tuber Yield

At the end of the experiment, randomly selected tubers per plot were separated from the crown and counted and the wet yield weight was assessed to determine tuber production (Figure 8b).

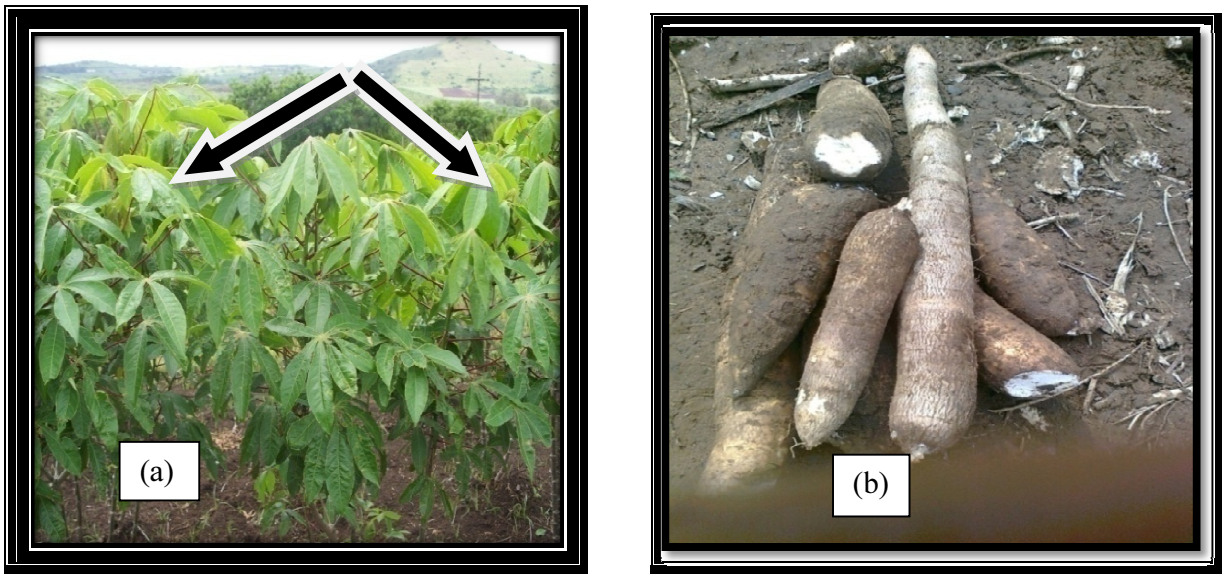

Figure 8(a) Leaf sample area from the experimental sites shown with arrows; (b) Root tubers taken from the experimental sites

3.8. Data Analysis

3.8.1. Statistical Analysis

A two-way analysis of variance (ANOVA) was used to compare soil data, plant chemical data, plant heights, number of tubers and the weight of tubers using Genstat 14.1(14th Ed).Both the fertilizer and AMF treatments (4 treatments) were used as treatment factors in the analysis. Thus Site and treatment were individual effects and site X treatment interaction was a factorial factor. Where the F-statistic was significant (p<0.05) the means were compared using Fisher's Protected Least Square Differences at the 5% level of significance (p<0.05). Correlation matrices between plant and soil parameters were carried out using Genstat 14.While it may have been better to investigate total P of the soil, logistic constraints did not allow for this level of analysis. In this regard, the plant available extraction was considered adequate to represent the labile P available for uptake by the plant directly or through AMF interactions.

CHAPTER FOUR
RESULTS

4.1. Soil Analyses

4.1.1. Initial Soil Analyses

The results of the composite soil samples taken from various sites before land preparation are shown in Table 5. This forms the background situation of the fertility status of the sites used for the trials and is used to test the impact of the treatments during growing and harvesting periods. OSCA exhibited the highest levels of P (22.2 mg kg^{-1}) with Mtubatuba and Mtunzini having the least levels (4.62 mg kg^{-1}) which are considered to be critically low in terms of cassava production at both sites. Whiles these soils at all sites were acidic, OSCA was slightly acidic and Empangeni was very acid (pH (KCl) 5.67 and 3.79 respectively. The available P and K at all sites followed the similar trend.

Table 5. Soil sample analysis before planting

	P	K	Ca	Mg	pH
Site	mg kg^{-1}	cmolc kg^{-1}	cmolc kg^{-1}	cmolc kg^{-1}	(KCl)
OSCA	22.2	1.01	14.8	7.42	5.67
Mtubatuba	4.62	0.209	2.44	1.30	4.51
Mtunzini	4.62	0.242	2.34	0.918	4.83
Empangeni	12.5	0.356	1.19	0.412	3.79

4.1.2. Phosphorus (P)

There was no significant difference for site by treatment interaction ($p = 1.0$) for the P concentration in the soil. The effects of site (averaged across treatment) and effect of treatment (averaged across sites) were both highly significant ($p< 0.001$). Least significant difference (LSD%) showed that OSCA had significantly ($p<0.05$) higher P concentration (31.5 $mgkg^{-1}$averaged across all treatments)than the other sites. Phosphorus concentration at Empangeni and Mtunzini were not significantly different from one another, but that both were significantly higher than at Mtubatuba (Table 6). Applying P fertilizer and AMF at all sites did not alter soil P levels appreciably relative to the untreated control. However, applying P+AMF significantly ($p<0.05$) increased soil P over the control. In the case of the mean treatment responses (averaged across sites) both the AMF and

P+AMF treatments were significantly higher than the control and P treatments (14.4 and 16.8 mg kg^{-1}, respectively), which were themselves not significantly different from one another. Throughout the sites, AMF and P+AMF had higher soil P concentration than the P fertilizer treatment. The least soil P concentration was recorded at Mtubatuba. Similar trends were recorded at all sites (Table 6).

Table 6. Soil P content (mg kg^{-1}) as affected by site and treatment. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for mean treatment effect is 3.333.

	Treatment				
Site	Control	P	AM F	P+AMF	Site mean
OSCA	27.3	29.4	34.3	35.0	31.5a
Mtubatuba	6.10	8.00	12.4	14.7	10.3c
Mtunzini	10.6	13.5	18.4	21.6	16.0b
Empangeni	13.6	16.2	20.8	22.8	18.3b
Treatment mean	14.4a	16.8a	21.5b	23.5b	

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.1.3. Potassium (K)

The mean K concentration was 0.953cmolc kg-^{1} K in soils across all sites, and treatments. OSCA had significantly (p<0.05) more K (1.534cmolc kg-^{1}) than the other sites; there were no significant (p<0.05) differences between Empangeni (0.744cmolc kg^{-1}), Mtubatuba (0.639 cmolc kg-^{1}), and Mtuzini (0.835cmol kg-^{1}) in K levels. Applying P, AMF, and P+AMF significantly (p<0.05) reduced the amount of K in the soil relative to the untreated control (0.527cmolc kg-^{1}). K levels in P, AMF, and P+AMF-treated soils were statistically similar to each other (Table 7). The increase in K levels was in the order P, AMF, P+AMF.

Table 7. Soil K content (cmolc kg-[1]) as affected by site and treatment. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for mean treatment effect is 0.2154.

	Treatment				
Site	Control	P	AMF	P+AMF	Site mean
OSCA	1.01	1.05	1.96	2.12	1.53b
Mtubatuba	0.296	0.476	0.818	0.966	0.639a
Mtunzini	0.465	0.753	1.01	1.11	0.835a
Empangeni	0.338	0.639	0.989	1.25	0.744a
Treatment mean	0.527a	0.729a	1.26b	1.36b	

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.1.4. Calcium (Ca)

Mean Ca was 8.79cmolckg^{-1}. There was significantly (p<0.05) more Ca at OSCA than at the other sites. Mtunzini had more Ca than Mtubatuba and Empangeni. Applying P and/or AMF had a substantial change on Ca levels compared to the untreated control. However, applying P, AMF, and P+AMF produced similar (p<0.05) Ca levels across all sites. The AMF-treated soil at Mtubatuba had the lowest Ca level of all soils at all sites. At Mtunzini, only AMF significantly (p<0.05) increased Ca in the soil, relative to the control. At OSCA, though there were no statistical differences between the treatments, P+AMF provided the highest Ca level among all treatments at all sites (Table 8).

Table 8. Soil Ca content (cmolc kg^{-1}) as affected by site and treatment. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for mean treatment effect is 1.732.

	Treatment				
Site	Control	P	AMF	P+AMF	Site mean
OSCA	13.7	15.3	15.7	15.8	15.1c
Mtubatuba	4.28	5.12	5.28	5.29	5.00a
Mtunzini	6.45	9.64	9.91	9.96	9.00b
Empangeni	4.33	6.33	6.73	6.79	6.10a
Treatment mean	7.19a	9.11b	9.41b	9.45b	

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.1.5. Magnesium (Mg)

The mean Mg concentration was 6.08cmolckg^{-1}across sites and treatments. Mtubatuba had significantly (p<0.05) less Mg than OSCA and Empangeni but was similar with Mtunzini. Mtunzini had significantly less Mg than OSCA but similar amounts as Empangeni. Applying P, AMF, and P+AMF provided a significant (p<0.05) increase in Mg over the control across all sites. However, at OSCA, there was a numerical but insignificant increase in Mg levels from all soil treatments, compared to the control. At all sites, there was no significant difference between P, AMF, and P+AMF.

4.1.6. pH (KCl)

Soil pH was generally acidic (5.38). pH at Empangeni was significantly (p<0.05) lower than those at the other sites (Table 10); soils at Mtubatuba and Mtunzini had significantly (p<0.05) lower pH than that at OSCA. Applying P, AMF, and P+AMF substantially increased soil pH; the differences between P andAMF or P+AMF was significant (p<0.05). At Empangeni, AMF, and P+AMF significantly (p<0.05) increased pH over the control. However, P fertilizer did not affect pH appreciably, compared to the control. At Mtubatuba, P, AMF, and P+AMF significantly (p<0.05) increased pH, compared to the control; there were no significant (p<0.05) differences between P, AMF, and P+AMF. At Mtunzini, all soil treatments increased pH relative to the control, with

P+AMF providing the highest increase. At OSCA, soil treatment did not affect pH, though there was a tendency for pH to increase with soil treatment.

For the calculation of the ANOVA tables for soil phosphorus, soil potassium, soil magnesium and soil pH (KCl) at harvest after treatment with phosphorus and arbuscular mycorrhiza fungus, refer to Appendix 1.

Table 9. Soil Mg content (cmolc kg^{-1}) as affected by site and treatment. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for mean treatment effect is 1.617.

	Treatment				
Site	Control	P	AMF	P+AMF	Site mean
OSCA	6.65	7.89	8.22	8.24	7.80c
Mtubatuba	2.79	4.83	5.44	5.44	4.63a
Mtunzini	4.22	5.96	6.21	6.25	5.70ab
Empangeni	3.15	7.01	7.48	7.51	6.30bc
Treatment mean	4.20a	6.42b	6.84b	6.90b	

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

Table 10. Soil pH (KCl) as affected by site and treatment. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for mean treatment effect is 0.2037.

	Treatment				
Site	Control	P	AMF	P+AMF	Site mean
OSCA	5.56	5.72	5.81	5.83	5.73c
Mtubatuba	5.22	5.40	5.51	5.52	5.41b
Mtunzini	5.20	5.31	5.44	5.45	5.35b
Empangeni	4.60	4.91	5.34	5.35	5.04a
Treatment mean	5.13a	5.33b	5.53c	5.54c	

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.2. Plant Growth

4.2.1. Plant Height

Cassava plant height at maturity averaged 161 cm across all treatments and sites. At 2 MAP, plants were significantly (p<0.05) taller at Mtubatuba (9.84cm) and OSCA (9.30cm) than at Mtunzini (8.09 cm) and Empangeni across all treatments. There were significant (p<0.05) differences in plant height due to soil treatment. Plants in P+AMF-treated plots were a significant taller than those in P-treated plots, but were statistically similar to those in the control and AMF-treated plots. There was no significant site x treatment interactions. At harvest, plants measured 161 cm on average. There were significant differences between sites with respect to plant height. Plants in P+AMF, control, and AMF plots were statistically similar in height, but significantly (p<0.05) taller than those in P-treated plots (Table 11). There was no (p<0.05) significant site x treatment interactions (Table 11).
45

Generally, there were significant (p<0.05) differences in time (MAP). At 9 MAP, plants measured 161 cm tall, being significantly taller than at 3 MAP (13.2 cm) and 2 MAP (8.8 cm): the difference between 3 and 2 MAP was significant apart from P treated plants as compared to AMF- treated plants, control plants, and P+AMF-treated plants were similar in height but (p<0.05) significantly taller than P-treated plants. Refer to Appendix 2 for the ANOVA table for plant height and the interactions with different treatments during the growing period. P

Table 11. Cassava plant height (cm) as affected by site and treatment at harvest. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 8.74.

	Treatment					
Site	**Control**	**P**	**AMF**	**P+AMF**	**Grand mean**	**Site mean**
OSCA	171	149	167	170		164ab
Mtubatuba	178	151	172	171	161	168a
Mtunzini	156	145	157	163		155c
Empangeni	154	153	158	164		157bc
Treatment mean	165a	149b	163a	167a		

Control = untreated; P = Phosphorus; AMF = arbuscular mycorrhizal fungus.

4.2.2. Tuber Length

Tuber length averaged 44.0 cm across all treatment and trial sites. Soil treatment produced high tuber length. Tubers collected from P+AMF-treated plots were the longest, while those from the control plots were the shortest (Table12). P and AMF soil treatments also significantly (p<0.05) increased tuber length, relative to the untreated control. Tubers produced at Empangeni and Mtubatuba were (p<0.05) significantly longer than those produced at OSCA.

Table 12. Mean cassava tuber length (cm)as affected by site and treatment. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 2.696.

	Treatment				
Site	Control	P	AMF	P+AMF	Site mean
OSCA	36.3	39.4	43.2	46.7	41.4a
Mtubatuba	39.6	43.4	46.0	49.7	44.7b
Mtunzini	37.9	41.0	45.6	49.5	43.5ab
Empangeni	38.8	43.3	50.4	53.3	46.5b
Treatment mean	38.1a	41.8b	46.3c	49.8d	

Control = Untreated; P = phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.2.3. No. of Tubers

Number of cassava tubers averaged 13.8 across all treatment and trial sites. There was significant (p<0.05) interaction between treatment and site. Tubers collected from P+AMF-treated plots were the highest as compared to those collected from the control plots (Table13). P and AMF soil treatments also significantly (p<0.05) increased number of tubers, relative to the untreated control. Number of tubers produced at OSCA and Mtubatuba were (p<0.05) significantly higher than those produced at Mtunzini and Empangeni. There was no significant (p<0.05) between OSCA and Mtubatuba. Same scenario was observed between Mtunzini and Empangeni.

4.2.4. Tuber Yield

Differences in yield among two sites (55, and Empangeni) were not significant. OSCA produced significantly (p<0.05) higher tuber yields than the other sites. Table 14 shows that soil treatments with P did not significantly (p<0.05) increase tuber yields over the control. However, AMF, and P+AMF treatments significantly (p<0.05) increased tuber yields relative to the control.

Table 13. Mean number of cassava tubers as affected by site and treatment at harvest. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 1.268.

	Treatment					
Site	**Control**	**P**	**AMF**	**P+AMF**	**MAP mean**	**Site mean**
OSCA	12.8	14.5	15.3	15.0		14.4a
Mtubatuba	13.3	14.3	14.5	14.5	13.8	14.2a
Mtunzini	12.8	13.0	13.0	14.5		13.3b
Empangeni	13.5	12.8	13.8	14.3		13.6b
Treatment mean	13.1b	13.7b	14.2ab	14.6a		

Control = Untreated; P = phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

Table 14. Mean cassava tuber yield (kg m^{-2}) as affected by site and treatment at harvest. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 0.4517.

	Treatment				
Site	Control	P	AMF	P+AMF	Site mean
OSCA	3.46	3.81	4.08	4.19	3.90a
Mtubatuba	2.85	3.36	3.92	3.66	3.45ab
Mtunzini	2.27	2.76	3.39	3.31	2.93c
Empangeni	2.40	2.91	3.68	3.35	3.10bc
Treatment mean	2.80c	3.21bc	3.80a	3.63ab	

Control = untreated; P = phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.3 Plant leaf analysis

4.3.1. Phosphorus (P)

Percent leaf P was statistically similar at the four sites, with a grand mean of 0.479%. Inoculating cuttings with AMF, P+AMF, and P fertilizer to the soil significantly (p<0.05) increased leaf P, as compared to the untreated control. Differences between P fertilizer and AMF or P+AMF treatments were not significant (p<0.05). Leaf P levels at 3 MAP were significantly (p<0.05) higher than those at other sampling times (Tables15). The highest leaf P were in leaves from Mtunzini at 3 MAP and least in those collected from OSCA at 2 MAP; site and time significantly (p<0.05) influenced the effect of treatment on leaf P contents.

4.3.2. Nitrogen (N)

Cassava leaf N was significantly (p<0.05) higher at Mtubatuba (4.93%) and Mtunzini (4.77%) than at Empangeni (4.13%) and OSCA (4.21%). Soil treatment with P did not appreciably increase leaf N. Treatment with AMF, and P+AMF, significantly (p<0.05) increased leaf N content over the untreated control. Nitrogen content was highest at 3 MAP, being significantly (p<0.05) higher than at other times. There were no differences in N content between 2, 4, 5, and 9 MAP. Site did not 50 influence N content at 3 MAP (Table 16); however a significant (p<0.05) site x MAP interaction showed that at Mtubatuba and Mtunzini leaves had the highes tN content at 2 MAP. At OSCA and Empangeni, the lowest N content was recorded at 4 MAP.

Table 15. Mean cassava leaf P content (%) as affected by site x time (MAP) x treatment after planting. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 0.01426.

		Treatment					
MAP	Site	Control	P	AMF	P+AMF	MAP mean	Site mean
2	OSCA	0.345	0.375	0.438	0.463	0.426c	0.405c
	Mtubatuba	0.413	0.453	0.498	0.490		0.463a
	Mtunzini	0.398	0.425	0.450	0.438		0.428b
	Empangeni	0.373	0.400	0.423	0.433		0.407c
3	OSCA	0.403	0.455	0.523	0.550	0.513a	0.481b
	Mtubatuba	0.475	0.525	0.563	0.550		0.528a
	Mtunzini	0.440	0.505	0.600	0.573		0.529a
	Empangeni	0.458	0.493	0.568	0.535		0.513a
4	OSCA	0.390	0.433	0.513	0.510	0.484b	0.461c
	Mtubatuba	0.435	0.473	0.528	0.508		0.486b
	Mtunzini	0.413	0.480	0.568	0.553		0.503a
	Empangeni	0.420	0.458	0.550	0.515		0.486b
5	OSCA	0.400	0.438	0.503	0.500	0.483b	0.460c
	Mtubatuba	0.443	0.480	0.513	0.515		0.488b
	Mtunzini	0.428	0.478	0.550	0.548		0.501a
	Empangeni	0.425	0.460	0.533	0.525		0.486b
9	OSCA	0.400	0.443	0.518	0.515	0.488b	0.469b
	Mtubatuba	0.433	0.465	0.505	0.490		0.473b
	Mtunzini	0.448	0.498	0.540	0.525		0.503a
	Empangeni	0.433	0.483	0.573	0.550		0.509a
Treatment mean		0.419b	0.461a	0.523a	0.514a		

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

Table 16. Mean cassava leaf N content (%) as affected by site x time (MAP) x treatment after planting. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 0.1632.

		Treatment					
MAP	Site	Control	P	AMF	P+AMF	MAP mean	Site mean
2	OSCA	3.94	3.82	4.56	4.61	4.33b	4.23c
	Mtubatuba	4.33	4.35	4.57	4.94		4.55a
	Mtunzini	4.20	4.17	4.63	4.53		4.38b
	Empangeni	3.93	3.82	4.29	4.57		4.15c
3	OSCA	4.42	5.08	5.26	5.26	5.12a	5.00b
	Mtubatuba	4.87	5.28	5.60	5.66		5.35a
	Mtunzini	4.65	4.86	5.32	5.30		5.03b
	Empangeni	4.77	5.13	5.20	5.20		5.07b
4	OSCA	3.68	3.79	3.95	3.98	4.38b	3.85c
	Mtubatuba	4.58	4.80	5.22	5.09		4.92a
	Mtunzini	4.28	4.72	5.26	5.13		4.85b
	Empangeni	3.87	3.96	3.94	3.88		3.91bc
5	OSCA	3.68	3.83	4.20	4.22	4.38b	3.98b
	Mtubatuba	4.67	4.81	5.23	5.15		4.96a
	Mtunzini	4.36	4.64	5.25	5.11		4.84ab
	Empangeni	3.80	2.98	4.18	3.98		3.73c
9	OSCA	3.76	3.92	4.10	4.06	4.34b	0.468a
	Mtubatuba	4.48	4.79	5.20	5.04		0.473a
	Mtunzini	4.22	4.62	5.72	4.94		0.503a
	Empangeni	3.88	2.96	2.15	4.08		0.509a
Treatment mean		4.22b	4.32b	4.69a	4.74a		

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

4.3.3. Calcium (Ca)

There were no significant differences in leaf Ca content between the sites. All soil treatments increased Ca levels over the control. Applying P, AMF, and P+AMF significantly (p<0.05) increased Ca compared to the untreated (control).Calcium levels in P and AMF plots were significantly higher than those in P+AMF plots. Ca levels were highest at 3 MAP and lowest at 2 MAP, the difference being highly significant (p<0.05). Ca levels were statistically similar at 4, 5, and 9 MAP, but significantly (p<0.05) higher than at 2 MAP and significantly lower than at 3 MAP. Table 17 shows that highest leaf calcium content was in AMF-treated plots at 3 MAP and the lowest was in the untreated (control) plots at 2MAP. The interaction between site and MAP was significant (p<0.05). Mtubatuba and had the lowest leaf Ca content at 2 MAP, while OSCA had the highest levels at 3 MAP. Calcium levels in leaves in P fertilizer-treated plots were significantly higher at OSCA and Mtunzini than Empangeni and Mtunzini.

4.3.4. Potassium (K)

There were no significant differences in leaf K among the sites. Applying AMF and P+AMF significantly (p<0.05) increased K in leaves over the control. P fertilizer significantly (p<0.05) increased leaf K levels over the control by 9%; however, the levels were significantly less than those in leaves from AMF and P+AMF-treated plots. K levels at 4 MAP, 5 MAP, and 9 MAP were statistically similar. They were, however, significantly (p<0.05) higher than those at 2 MAP and 3 MAP; the differences between 2 MAP and 3 MAP were statistically significant (p<0.05). The trend was for increasing K in the order: control, P, AMF, P+AMF at all sample collection times (Table 18).There were no significant (p<0.05) differences between sites.

Table 17. Mean cassava leaf Ca content (%) as affected by site x time (MAP) x treatment after planting. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 0.05143.

		Treatment					
MAP	Site	Control	P	AMF	P+AMF	MAP mean	Site mean
2	OSCA	0.958	1.27	1.07	1.07	1.09a	1.09bc
	Mtubatuba	0.956	1.04	1.00	1.00		0.999a
	Mtunzini	1.12	1.2	1.25	1.27		1.21c
	Empangeni	1.00	1.15	1.00	1.04		1.05b
3	OSCA	1.20	1.57	1.56	1.48	1.41c	1.45b
	Mtubatuba	1.16	1.37	1.50	1.50		1.38a
	Mtunzini	1.00	1.57	1.52	1.49		1.40a
	Empangeni	1.28	1.49	1.42	1.46		1.41a
4	OSCA	1.14	1.34	1.37	1.25	1.18b	1.28c
	Mtubatuba	0.938	1.07	1.44	1.28		1.18b
	Mtunzini	1.09	1.25	0.96	1.00		1.08a
	Empangeni	1.10	1.23	1.29	1.10		1.18b
5	OSCA	1.17	1.38	1.41	1.33	1.20b	1.32c
	Mtubatuba	0.933	1.09	1.46	1.29		1.19b
	Mtunzini	1.11	1.27	0.96	1.01		1.09a
	Empangeni	1.10	1.27	1.33	1.16		1.22bc
9	OSCA	1.14	1.37	1.37	1.26	1.18b	1.29c
	Mtubatuba	0.933	1.08	1.46	1.26		1.18b
	Mtunzini	1.10	1.27	0.872	0.917		1.04a
	Empangeni	1.13	1.30	1.32	1.14		1.22bc
Treatment Mean		1.08a	1.28c	1.28c	1.22b		

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

Table 18. Mean cassava leaf K content (%) as affected by site x time (MAP) x treatment after planting. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 0.0639.

		Treatment					
MAP	Site	Control	P	AMF	P+AMF	MAP mean	Site mean
2	OSCA	1.53	1.75	1.82	2.00	1.78b	1.78a
	Mtubatuba	1.69	1.75	2.05	1.85		1.84a
	Mtunzini	1.51	1.68	1.77	1.72		1.67b
	Empangeni	1.65	1.82	1.85	1.94		1.82a
3	OSCA	1.62	1.80	1.93	2.10	1.72b	1.86a
	Mtubatuba	1.56	1.64	1.78	1.66		1.66b
	Mtunzini	1.41	1.53	1.64	1.62		1.55a
	Empangeni	1.69	1.73	1.85	1.94		1.80a
4	OSCA	1.73	1.89	2.08	2.25	1.98a	1.99b
	Mtubatuba	1.74	1.99	2.43	2.20		2.09a
	Mtunzini	1.55	1.85	2.09	2.00		1.87c
	Empangeni	1.81	1.87	2.07	2.11		1.97b
5	OSCA	1.73	1.91	2.09	2.22	1.99a	1.99b
	Mtubatuba	1.75	2.01	2.45	2.25		2.12a
	Mtunzini	1.56	1.85	2.10	2.00		1.88c
	Empangeni	1.81	1.88	2.09	2.14		1.98b
9	OSCA	1.73	1.48	2.02	2.32	1.96a	1.89c
	Mtubatuba	1.73	1.99	2.46	2.13		2.08a
	Mtunzini	1.53	1.86	2.12	2.04		1.89c
	Empangeni	1.81	1.90	2.14	2.12		1.99b
Treatment	mean	1.66c	1.81b	2.04a	2.03a		1.89

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

54

4.3.5. Magnesium (Mg)

Differences in leaf Mg contents were small among the four sites, though Mtunzini had the highest content at 9 MAP. All soil treatments increased Mg content over the control. Leaves in P fertilizer-treated plots had significantly higher Mg levels than those in all the other treatments; leaves in AMF- and P+AMF- treated plots had significantly more Mg than the control. Mg levels increased with time (MAP). Magnesium levels at 9 MAP was the highest while 4 MAP and 2 MAP were similar, but significantly (p<0.05) higher than those at 3 MAP. Leaf Mg at 3 MAP was particularly low, being significantly (p<0.05) lower than any other time of sample collection (MAP) at all sites. Mg contents with respect to time were dependent on soil treatment. The highest levels were obtained when leaf samples were collected from P fertilizer-treated plots at 9 MAP, while the lowest were in samples collected from P+AMF plots at 3 MAP (Table 19).

4.3.6. Zinc (Zn)

Leaf Zinc levels were significantly (p<0.05) different among the sites. Leaves collected at Mtubatuba had significantly (p<0.05) more Zn than those collected at OSCA, Mtunzini and Empangeni, Applying P, AMF and P+AMF significantly (p<0.05) reduced leaf zinc content relative to the untreated (control); differences among P and/ or AMF treatments were also significant (p<0.05). However, the effect of soil treatment on leaf zinc content significantly (p<0.05) depended on the site, There was significantly (p<0.05) more Zn in leaves from P- and AMF-treated plots at Mtubatuba than those from the control plots at OSCA. Leaf zinc levels tended to decrease with time (Table 20). There was more Zn in the leaves at 2 MAP than at the other sampling times. Leaf Zn levels at 3 MAP were significantly higher than those at 4 and 9 MAP: the differences in Zn levels between 4, 5, and 9 MAP were not significant. The decrease was higher between 2 MAP and 3 MAP at Mtubatuba than between the times at the other sites. The highest leaf zinc content was in leaves in the control and P-treated plots at Mtubatuba and the lowest were in leaves in the AMF- and P+AMF-treated plots at OSCA.

Table 19.Mean cassava leaf Mg content (%) as affected by site x time (MAP) x treatment after planting. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 0.0617.

		Treatment					
MAP	Site	Control	P fert	AMF	P+AMF	MAP mean	Site mean
2	OSCA	0.383	0.423	0.400	0.435	0.412b	0.410a
	Mtubatuba	0.388	0.430	0.425	0.428		0.418a
	Mtunzini	0.370	0.408	0.443	0.420		0.410a
	Empangeni	0.395	0.413	0.410	0.423		0.410a
3	OSCA	0.348	0.385	0.383	0.363	0.365b	0.370a
	Mtubatuba	0.365	0.393	0.385	0.375		0.380a
	Mtunzini	0.350	0.355	0.315	0.300		0.330a
	Empangeni	0.363	0.390	0.385	0.380		0.380a
4	OSCA	0.383	0.463	0.475	0.430	0.419b	0.438a
	Mtubatuba	0.375	0.408	0.445	0.413		0.410a
	Mtunzini	0.363	0.388	0.430	0.408		0.397a
	Empangeni	0.390	0.450	0.470	0.420		0.432a
5	OSCA	0.390	0.460	0.498	0.448	0.441ab	0.449a
	Mtubatuba	0.383	0.465	0.475	0.460		0.446a
	Mtunzini	0.400	0.403	0.463	0.438		0.426a
	Empangeni	0.403	0.448	0.483	0.445		0.445a
9	OSCA	0.420	0.480	0.488	0.453	0.502a	0.460b
	Mtubatuba	0.383	0.478	0.493	0.420		0.443b
	Mtunzini	0.368	1.295	0.453	0.458		0.643a
	Empangeni	0.425	0.463	0.498	0.460		0.461b
Treatment Mean		0.382b	0.470a	0.441a	0.419ab		

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

Table 20. Mean cassava leaf Zn content (%) as affected by site x time (MAP) x treatment after planting. Means followed by the same letter do not differ from each other significantly at 5% level of confidence. LSD 5% for site mean and treatment effect is 1.902.

		Treatment					
MAP	Site	Control	P	AMF	P+AMF	MAP mean	Site mean
2	OSCA	70.5	76.3	78.5	75.5	81.7c	75.2b
	Mtubatuba	122	103	89.0	86.3		100a
	Mtunzini	73.0	74.5	73.5	75.5		74.1b
	Empangeni	79.5	74.8	77.0	75.5		76.7ab
3	OSCA	76.8	76.3	78.3	73.3	77.7b	76.2b
	Mtubatuba	81.8	83.8	75.8	75.8		79.3a
	Mtunzini	77.3	79.8	77.8	73.3		77.1b
	Empangeni	78.5	79.5	78.3	74.5		77.7ab
4	OSCA	66.5	68.8	58.0	59.5	66.7a	63.2c
	Mtubatuba	78.8	73.0	72.3	67.8		72.9a
	Mtunzini	70.8	63.5	59.5	59.5		63.3c
	Empangeni	69.5	71.5	68.5	61.0		67.6b
5	OSCA	66.0	67.0	57.0	59.3	65.3a	62.3c
	Mtubatuba	77.3	72.0	71.3	67.0		71.9a
	Mtunzini	69.0	62.3	58.5	59.3		62.3c
	Empangeni	68.5	69.3	64.8	59.3		65.5b
9	OSCA	63.5	67.5	56.3	57.8	64.7a	61.3c
	Mtubatuba	77.5	70.0	70.8	67.3		71.4a
	Mtunzini	68.8	62.5	57.3	57.8		61.6c
	Empangeni	70.3	67.8	63.5	59.3		65.2b
Treatment mean		75.3a	73.2a	69.3b	67.2c		71.2

Control = untreated; P = Phosphorus fertilizer; AMF = arbuscular mycorrhizal fungus

The ANOVA tables for plant leaf phosphorus, nitrogen, calcium potassium magnesium and zinc with their interactions with various treatments are given in Appendix 3.

4.3.7. Correlation Matrices

According to table 18, there was negative correlation between plant nutrient content and height with the exception of P which shows a positive correlation but not significant. Though there were positive correlation between Ca, tuber yield and number of tubers, this was not significant. The similar observation was made with K. Plant height show a positive correlation with yield but also not significant. Number of tubers also had positive correlation with tuber yield but there were no significant results. There was an overall negative correlation between soil acid saturation and all plant nutrients with the exception of Zn at 9 MAP. Exchangeable acidity also had negative correlation with P, N, Mg, K and Ca but had positive correlation with Al and Zn though not significant. There was a positive correlation between soil phosphorus and plant phosphorus availability. However, this was not significant. Similarly, soil Zn also show positive correlation with plant available P but also not significant. Soil pH (KCl) was positively correlated with P, N, K, Ca, and Mg but had negative correlation with Al and Zn at 9 MAP. Soil K had a significant correlation with Al but had negative correlation with all the other nutrients (Table 21).

Table 21. Correlation between soil available nutrient and plant nutrient content at 9 MAP

	Plant nutrient content						
Soil Nut.	Al	Ca	K	Mg	N	P	Zn
Acid sat	0.377	-0.253	-0.543	-0.297	-0.212	-0.549	0.140
Exch Acidity	0.485	-0.070	-0.900	-0.147	-0.172	-0.173	0.245
Potassium	0.712	-0.179	-0.390	-0.245	-0.384	-0.549	-0.152
Magnesium	-0.117	-0.101	-0.032	-0.044	-0.199	0.173	-0.594
Nitrogen	0.331	-0.373	-0.353	-0.007	-0.123	-0.193	-0.132
Phosphorus	-0.229	-0.111	0.229	-0.182	-0.113	0.380	-0.664
Zinc	-0.121	-0.173	-0.190	-0.029	-0.119	0.063	-0.631
pH (KCl)	-0.252	0.145	0.233	0.084	0.306	0.013	-0.491

Though the effect of plant nutrient on height was negative (p = -.0273, N = -.0582, K = -.1594) their correlation on plant height were not significant and their probability were low (p=.830, p=.648 and p=.208 respectively). However, there were significant correlations between tuber numbers and some plant nutrients (Table 20).

Table 22. Correlation between plant nutrient, height, tuber yield and number of tubers at 9 MAP. The highlighted figures were significant at p=0.05 probability levels.

	Correlations: Marked correlations are significant at p < .05000; N=64													
Variable	N	Ca	Mg	K	Na	Zn	Cu	Mn	Fe	P	Al	Ht	Tuber No	Tuber yld
Height	-.0582	-.1467	-.1122	.1594	-.0985	.1271	.2036	.0913	-.1195	-.0273	-.0628			
Probability	p=.648	p=.247	p=.377	p=.208	p=.439	p=.317	p=.107	p=.473	p=.347	p=.830	p=.622			
Tuber No	-.0167	.2132	**-.2543**	.1017	.0917	-.1453	**-.2552**	-.0124	-.0203	.1165	**-.2736**	.0442		
Probability	p=.896	p=.091	**p=.043**	p=.424	p=.471	p=.252	**p=.042**	p=.922	p=.873	p=.359	**p=.029**	p=.728		
Tuber yield	-.0334	.1873	-.1277	**.2576**	**.3525**	**-.3512**	-.1962	-.1259	-.0158	.0939	**-.3013**	.2448	.1984	
Probability	p=.794	p=.138	p=.315	**p=.040**	**p=.004**	**p=.004**	p=.120	p=.321	p=.901	p=.460	**p=.016**	p=.051	p=.116	

CHAPTER FIVE
DISCUSSION

5.1. Effect of Treatment on Available nutrients

Generally, all the soils were acidic (Table 5) and highly weathered which makes them to be considered as poor in soil nutrients. The results showed a significant increase in P at harvest as compared to before-planting. Many factors might have happened during the growth stage that might have affected the P availability in the control plots. It was observed, though not scientifically proven, that the longer the crop stay in the soil, the more the Al and Fe concentration were reduced. This might have increased the solution P availability in the soil by the reduction of Al and Fe during the growing period as the pH was increased during this period (Table 10). This according to Ayoola and Makinde (2007) the nutrient levels at tuber harvest were lower than at pre-planting. Though this was not expected in the studies, the changes in nutrient availability might have been cause by the AMF which might have re-conditioned the soil thereby increasing the soil pH making more P available than before planting (Sriddevi and Ramakrishnan, 2013). Plants treated with AMF and P+AMF had the highest levels of P at harvest. This increase could be due to the availability of more soluble P as a result of the symbiosis between AMF and the host plant (Table 11). This finding agrees with Grant *et al*. (2004) who reported that AMF are able to absorb soluble phosphate and other nutrients that are beyond the P-depletion zone in the soil. The data analysis show strong correlation between P and AMF (Table 14). Despite large uptake of P at all sites, P alone treatment had significantly reduced P levels at harvest (Table 6). This may be due to the insoluble nature of P which is affected by soil factors like pH, soil minerals, organic matter content and clay type as reported by Westermann and Leyterm (2008).

Plots treated with AMF or P+AMF showed significant increases in K, Ca, and Mg availability over control at all sites. This may be attributed to AMF being able to increase the surface area of plant roots for nutrient sorption. Similar reports were made by Cardoso and Kuyper (2006), who, in their studies on AMF, concluded that AMF hyphae could penetrate the soil matrix about 9 cm further than plant roots could reach.

Leaf P uptake increased with time especially between planting and the first 3 months. Table 14 shows that P uptake was stabilized after 3 months from planting (3MAP).There was no significant change in P uptake by leaves from 3 MAP until harvest. These observations support the findings of Njihott (1935) and Howeler and Cadarid (1983, El-Sharkawy, 2007), who reported that cassava takes up more P for the first 3 months after germination. This stabilization of P may be due to the fact that the initial P uptake is used for shoot development, while more P is used for tuber development after 3MAP.

Though cassava leaf N, K, and some other immobile nutrients were increased at all sites with treatment, the application of P did not significantly increased the N over the control, as compared to AMF-treated plots (Table 15). However, all treatments increased leaf Ca, but did not significantly increase K levels. These changes may be due to the fact that AMF is able to absorb soluble phosphate as well as other nutrients that are beyond the P-depletion zone and develop around the root surface. Another fact may be that phosphate can be taken up and be translocated as polyphosphate through the process of diffusion as reported by Grant *et al* (2004).

5.2. The Effect of treatment on Yield

Soil treatment did not influence tuber yield due to high rainfall at the trial sites. A long-term mean annual rainfall at trial sites ranges from 928 mm to 1271 mm (Figure 5) which affected the nutrient retention in sandy soils. Rainfall pattern and its intensity affected P fertilizer efficiency on cassava yield (Agbaje and Akinlosotu, 2004).The parameters of yield that determine fresh root yield include average tuber length/plant and tuber weight, as well as the number of roots/plant (Tetteh,and Frimpong, 1991). Fresh root yield (tuber length and tuber weight) related well with treatments. This might have been to the low levels of nutrient especially P at pre-planting (Table 5). From the table, OSCA was having a higher level of P concentration in the soil as compared to the other sites. This might have affected the overall colonization AMF which influence nutrient uptake with subsequent yield levels. Similar results had been reported by (Sridevi and Ramakrishnan (2013).Though there were increase in tuber weight at all sites over the control, where AMF, and P+AMF had almost the same yield and had the highest yield as compared to the other sites (Figure 10).AMF treated plots had the highest yield over the other treatments with the exception of OSCA, The increased cassava tuber yield must have resulted from enhanced nutrient uptake (Okon *et al*., 2010; Okon, 2011) by

the introduction of AMF whose hyphae must have spread beyond the rooting zone to extract nutrients for its host (cassava). On the other hand, the variation yield with sites might have been caused by the nature of the land use at different trial sites (Ande *et al*., 2008). Similar results were reported by Aiyelari *et al*. (2002), and Asuming-Brempong (2009).

Tuber weight was also affected by the different treatments. Though, all the soil treatments increased tuber yield (weight), the increase was much higher in AMF and P+AMF plots than in P-fertilizer and control plots. Sieverding and Howeler (1984) and Oyetunji and Osonubi (2007) had earlier given similar report. This may be attributed to the increase in nutrient availability and uptake by plants due to the activities of AMF. This is supported by Oyetunji *et al.*, (2007), who reported that AMF inoculation could alleviate the adverse effect of water stress and increase uptake than non-inoculated cassava plants. This though not scientifically proven, it was observed at all trial sites: a situation that requires further studies.

5.3. Correlation between Plant height, number of tubers and tuber yield

To select fresh tubers to weigh per plot in cassava production, it is important to look at the number of tubers that could result in low diameter (Amsalu, 2003), as well as the plant height, and other parameters like number of branched stems, canopy diameter, length of roots/plant, weight of above ground plant parts and root dry weight. Though apart from plant height numbers of tubers and tuber length, the rest were not considered in this work, the positive correlation coefficient between plant height and tuber yield. There were also positive correlation between tuber number and tuber yield. Plant height also had a positive correlation with number of tubers. Similar results were reported by Pandy *et al.*, 2005; Ayenew, 2012).

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

The objectives of this study were to investigate the use of P fertilizer to improve cassava production in the northern KwaZulu-Natal; to investigate the use AMF to improve P uptake by cassava in agricultural unfertilized and P-fertilized soils, and to examine the role of P and AMF in cassava production. Ordinary, cassava yield might have ranged from 10-32 tons ha^{-1} has been reported elsewhere in Africa with highest reported at research stations at IITA in Nigeria and CSRI in Ghana using improved cultivars. With the inoculation of AMF, about 36 to 38 tons ha^{-1} were realised under normal conditions which was very significant (Table 14).

The study showed that:

1. Cassava tuber yield was significantly (p<0.05) increased when plots were treated with AMF or P+ AMF.
2. P uptake as well as that of other nutrients, was improved when soils were treated with P, AMF, and P+AMF over the unfertilized soils.
3. pH of the treated soils was increased thereby increasing cassava tuber yield over the untreated plots.
4. Though the trial was conducted under dry land condition, there was enough moisture for the AMF- and P+AMF-treated plots.

This study was conducted for only one production cycle (February 2010 to January 2011) and it is highly recommended that the trial is repeated for about three production cycles for a more comprehensive conclusion to be made, as continuous production on the same trial site may influence the colonization of AMF, as well as nutrient recycle. It is also recommended that further studies be conducted to establish the economic implications of the use of the various treatments taking into account the lack of resources of small-scale cassava producers. A future study to investigate the wetness and increased biomass around the vicinity of AMF and P+AMF treated cassava plants is recommended.

REFERENCES

Abbott, I. K., and Robson, A. D. (1982).The Role of Versicular-arbuscular Mycorrhizal fungi in Agriculture and the Selection of Fungi for Inoculation.*Australian. J. Res.* 33: 389-408.

Adesemoye, A. O., Torbert, H. A. and Kloepper, J. W. (2008).Enhanced Plant Nutrient Use Efficiency with PGPR and AMF in an Integrated Nutrient Management System.*Canadian J. Microbiol.* 54: 876 – 886.

Agbaje, G. O., and Akinlosotu, T. A. (2004). Influence of NPK Fertilizer on Tuber Yield of Early and Late-planted Cassava in a Forest Alfisol of South-Western Nigeria. *African J. Biol*. 3: 547-551.

Aiyelari, E. A., Ndaeyo, N. U., and Agboola, A. A. (2002).Effects of Tillage Practices on Growth and Yield of Cassava (*Manihot esculenta Crantz*) and some Soil Properties in Ibadan, Southwestern Nigeria.*Tropicultura*. 20:29-36.

Alves, A. A. C. (2002). Cassava Botany and Physiology. In: Cassava: Biology, Production and Utilization. R. J. Hillocks, J. M Thresh, and A. C. Bellotti (eds).

Akinpelu, A. O., Amamgbo, L. E. F., Olojede, A. O., and Oyekale, A. S. (2011).Health Implications of Cassava Production and Consumption. *J. Agri. Soc. Res*. 11:1.

Amador, J. A., Glucksman, A. M., Lyon, J. B. and Gores, J. H. (1997). Spatial Distribution of Soil Phosphatase Activity Within a Riparian Forest. *Soil Sci.* 162: 808-825.

Ande, O. T., Adediran, J. A., and Akinlosotu, T. A. (2008).Effects of Land Quality, Management and Cropping systems on Cassava Production in Southern Western Nigeria.*African J. Biotech*. 7: 2368-2374

Arai, Y., and Sparks, D. L. (2007). Phosphorus Reaction Dynamics in Soils and Soil Minerals: a Multiscale Approach. *Adv. Agron.* 94: 135-179.

ARC-ISCW.(2004). Overview of the Status of the Agricultural Natural Resources of South Africa.*ARC-ISCW Report No.GW/A/2004/13. ARC Inst. For Soil Climate and Water*. Pretoria.

Arias, M., Barral, T., and Diaz-Fierros, F. (1995).Effects of Iron and Aluminium Oxides on the Colloidal and Surface Properties of Kaolin.*Clay and Clay Minerals*.43: 406-416.

Ascota-Martinez, V., and Tabatai, M.A. (2000).Enzyme Activities on Limed Agricultural Soil. In: *Biol. and Fertility of Soils*. 31: 8591

Asimi, S., Gianinazzi-Pearson, V., and Gianinazzi, S. (1980). Influence of Increasing Soil Phosphorus Levels on Interactions Between Vesicular-arbuscular Mycorrhizae and rhizobium in Soybeans. *Canadian. J. Bot*. 58: 2200-2205.

Asmalu, N. (2003). Characterization and Divergence analysis in Cassava (*Manihot esculenta Crantz*) Genotypes at Jima. *MSc thesis*. Alemaya University. Ethiopia.

Augé, R. M. (2001). Water Relations, Drought and Vesicular-arbuscular Mycorrhizal Symbiosis. Mycorrhiza.11:3-42.

Ayoola, O. T. and Makinde, E. A. (2007). Fertilizer Treatment Effect on Performance of Cassava Under two Planting Patterns in a Cassava-based Cropping System in South West Nigeria. *Res. J. Agri. and Biol. Sci.* 3: 13-20.

Ayres, R. L., Gange, A. C., and Aplinb, D. M. (2006). Interaction BetweenArbuscular Mycorrhizal fungi and Intraspecific Competition Affect Size, and Size Inequality of *Plantago lanceolata* L. *J. Ecol.* 94:285-294.

Bableye, T.(2006).Cassava. African's Food Security Crop. IITA, Ibadan, Nigeria.

Baisden, W. T., Amundson, R., Cook, A. C., and Brenner, D. L. (2002).Turnover and Storage of C and N in Five Density Fractions from California Annual Grassland Surface Soils. *Global Biogeochem.Cycles*.16:1117.

Barančikovaá, G., Liptaj, T., and Prónayová, N. (2007). Phosphorus Factors in Arable and Mountain Soils and their Humic Acids. *Soil and Water Res*. 4:141-148.

Barber, S. A. (1984). Soil Nutrient Availability – A Mechanistic Approach. New York, U.S.A. Wiley.*Interscience*.398.

Beck, M. A. and Sanchez, P. A. (1996). Soil Phosphorus Movement and Budget After 13 Years of Fertilized Cultivation in Amazon Basin. *Plant and Soil*. 184:23-31.

Berg, B.M., McClaugherty, C., De Santo, A. W., and Johnson, D. (2001). Humus Buildup in Boreal Forests: Effects of Litter Fall and its N Concentration. *Canadian J. Forest Res. – Revue Canadienne De Recherche Forestiere.* 31: 988-998.

Berg, W. K., Cunningham, S. M., Brouder, S. M., Joern, B. C., Johnson, K. D., Santini, J. and Volenec, J. J. (2005). Influence of Phosphorus and Potassium on Alfalfa Yield and Yield Component. *Crop Sci*. 45: 297-304.

Bonfante, P. and Genre, A. (2010).Mechanisms Underlying Beneficial Plant-fungus Interactions in Mycorrhizal Symbiosis. *Nature Comm*.

Bolan, N. S. (1990). A Critical Review on the Role of Mycorrhizal fungi in the Uptake of Phosphorus by Plants. *Plant and Soil*. 134: 189-207.

Bolan, N. S. (1991).Critical Review on the Role of Mycorrhizal fungi in the Uptake of Phosphorus by Plants. *Plant Soil*. 141: 1-11.

Bot, A., and Benites, J. (2005). The Importance of Soil Organic Matter: Key to Drought-resistant Soil and Sustained Food and Production. *FAO Soil Bull.*80:78.

Bowman, R. A., and Vigil, M. F. (2002).Soil testing for Different Phosphorus Pools in Cropland Soils of the Great Plains.*J. Soil and Water Conservation Soc*.

Bremner, D. C., and Mulvaney, J. M. (1982).Total Nitrogen. In: A.L. Page. R.H. Miller and D. R. Kenney (Eds).Methods of Soil Analysis.9 (2).*American Soc. Agron*.

Bumb, B. L., and Baanante, C. A. (19996).World Trend in Fertilizer Use and Projections to 2020.*Inter. Food Policy Res. Inst.*

Burns, A., Gleadow, R., Cliff, J., Zacharias, A., and Cavagnaro, T. (2010). Cassava: The drought, war and famine crop in changing world. *Sustainability*. 2:3572-3607.

Busman, L., Lamh, J., Randall, G., Rehm, G., and Schmitt, M. (2002).Phosphorus in the Agricultural Environment. Regents of the University of Minnesota.

Camp, K. G. T. (1999). A Bioresource Classification for KwaZulu-Natal. South Africa.University of Natal, PMB.

Cardoso, I. M., and Kuyper, T. W. (2006). Mycorrhizas and Tropical Soil Fertility. *Agric. Ecol. Environ*. 116:72-84.

Chang, S. C., and Jackson, M. L. (1958).Soil Phosphorus Fractions in Some Representative Soils.*J. Soil Sci*. 9: 109-119.

Chrissie, R. (2006). Improvement of Cassava for Social and Economic benefits.*Southern African Soc. Plant Pathol.*

Citernesi, A. S., Vitagliano, C., and Giovannetti, M. (1998). Plant Growth and Root System Morphology of *Olea europa L.* Rooted Cuttings as Influenced by Arbuscular Mycorrhizae. *J. Hort. Sci. Biol.* 73: 647-654.

Clement, C. R.,and Habte, M. (1995).Genotype Variation in Versicular-arbuscular Mycorrhizal Dependence of Oil Palm. *J. Plant Nutri*. 18: 1907-1916.

Cobbina, J., and Thompson, E. J. (1987).Response of Cassava to NPK Fertilization in a Coastal Savannah Zone of Ghana. *Legon Agric. Res. Bull*. 2:32-37.

Cock, J. H., and Howeler, R. C. (1978).The Ability of Cassava to Grow on Poor Soils. In: Crop Tolerance to Sub optimal Land Conditions. (Ed. Jung, G. A.).*American Soc. Agron*.Special Publication. 32: 145 – 154.

Codling, E. C. (2008).Effects of Soil Acidity and Cropping on Solubility of By-product-immobilized Phosphorus and Extractable Aluminium, Calcium, and Iron from Two High-phosphate Soils. *J. Soil. Sci.* 173: 552-559.

Cooperland, L. (2002). Building Soil Organic Matter with Organic Amendments: A resource for Urban and Rural Gardeners, Small Farmers, Turf grass Managers and Large-scale Producers. Center for Integrated Agricultural Systems. Wisconsin-Madison.

CTCRI - Central Tuber Crop Research Institute (1983). Annual Report for1982. Trivandrum, India.

Dailey, R. (2006). Nutrient for the Soil. Desert and Water-wise Garden.

Daipé, Y., and Monreal, M. (2004).Arbuscular Mycorrhiza Inoculums to Support Sustainable Cropping Systems. *Crop Manag*. 10: 1094-1096.

De Miranda, J. C. C, and Harris, P. J. (1994).Effects of Soil Phosphorus on Spore Germination and Hyphal Growth of Arbuscular-mycorrhizal Fungi. *New Phytol*. 128: 103-108.

DAFF - Department of Agriculture, Forestry and Fisheries (2010).Cassava Production Guide. Pretoria, South Africa.

FAO – Food and Agriculture Organization (2005).Fertilizer Use by Crop in South Africa. Land and Plant Nutrition Management Service. Land and Water Development Division. Rome.

FAO– Food and Agriculture Organization (2008).Corporate Document Repository.[Online].The Impact of HIV/AIDS on the Agricultural Sector:/*www.fao.org/DOCREP/005/Y4636e05.htm*.

Frossard, E., Condron, L. M., Oberson, A., Sinaj, S., and Fardeau, J. C. (2000).Processes Governing Phosphorus Availability in Temperate Soils. *J. Environ. Qual.* 29: 15-23.

FSSA - Fertilizer Society of South Africa (2003).Fertilizer Handbook. *Fifth Rev. Ed*. Pretoria.

Fatima, Z., Zia, M., and Chaudhary, M. F. (2006).Effect of Rhizobium Strains and Phosphorus on Growth of Soybean (*Glycine max*) and Survival of Rhizobium and P Solubilizing Bacteria. *Pakistan J. Bot.* 38: 459-464.

Fortune, S., Lu, J., Addiscott, T. M., and Brookes, P. C. (2005).Assessment of Phosphorus Leaching losses from Arable land. *Plant and Soils*. 269:99-108.

George, P. S. (1989). Trends and Prospects of Cassava in India. In: Sarma, S. S. (Ed). Summary Proceedings of a workshop on "Trends and Prospects of Cassava in the Third World".IFPRI. Washington, D.C. U.S.A.

Gilroy, S., and Jones, D. L. (2000). Through Form to Function: Root Hair Development and Nutrient Uptake. *Trends in Plant Sci.* 5: 56-60.

Graham, J. H., Drouillard, D. L., and Hodge, N. C. (1996). Carbon Economy of Sour Orange in Response to Different *Glomus spp*. *Tree Physiol*. 16: 1023-1029.

Grant, C., Bittman, S., Montreal, M., Plenchette, C., and Morel, C. (2004). Soil and Fertilizer Phosphorus: Effects on Plant P Supply and Mycorrhizal Development. *Canadian J. Plant Sci*. 85:3-14.

Grewal, H. S., and Williams, R. (2003). Liming and Cultivars Affect Root Growth, Nodulation, Leaf to Stem Ratio, Herbage Yield, and Elemental Composition of Alfalfa on an Acid Soil. *J. Plant and Nutri*.

Habte, M. and Byappanahalli, M. N. (1994).Dependency of Cassava (*Manihot esculanta* Crantz) on Vesicular-arbuscular Mycorrhiza Fungi. Department of Agronomy and Soil Science.University of Hawai. 4:421-245.

Habete, M., and Osorio, N. W. (2001). Arbuscular Mycorrhizas: Producing and Applying Arbuscular Mycorrhizal Inoculum. CTAHR. University of Hawaii at Manoa.

Harrison, M. J. and Van Buuren, M. L. (1995). A Phosphate Transporter from the Mycorrhizal Fungus *Glomus veriforme*. *Nat*. 378:626-628.

Havlin, J. L., Beaton, J. D, Tisale, S. L. and Nelson, W. L. (1999). Soil Fertility and Fertilizers: An Introduction to Nutrient Management. (6thed.). Prentice Hall, N. J.

Haynes, R. J., Domimy, C. S., and Graham, M. H. (2003).Effect of Agricultural Land Use on Soil Organic Matter Status and the Composition of Earthworm Communities in KwaZulu-Natal, South Africa. *Agric. Ecol. and Environ*. 95:2

Heffer, P., and Prud'homme, M. (2008).Medium-term Outlook for Global Fertilizer Demand, Supply and Trade. 2008-2012 Summary Report.76th IFA Annual Conference. Vienna, Austria.

Hemashenpagam, N., and Selvaraj, T. (2011).Effect of Arbuscular Mycorrhizal (AM) Fungus and Plant Growth Promoting Rhizomicroogranisms (PGPR's) on Medicinal Plant *Solanum viarum seedlings*. *J. Eniron. Bio*. 32: 579-583.

Higa, T. (1991).Effective Microorganisms. 8 – 14. In: Pratt, J. F., Hornick, S. B., and Whitman, C. E. (eds). Proceedings of First International Conference on Kyusei Nature Farming. U.S Department of Agriculture. Washington, D.C. U.S.A.

Higa, B., Johnson, A. E., Salter, J. L., and Dawson, C. J. (2000).Some Aspects of Achieving Sustainable Phosphorus Use in Agriculture. *J. Environ. Qual.* 29: 80-87.

Hinsinger, P. (1998). How do Plant Roots Acquire Mineral Nutrients? Chemical Processes Involved in the Rhizosphere. Adv. *Agron*. 64: 225-265.

Hopkins, B.G., Ellsworth, J. W. (2003). Phosphorus Nutrition in Potato Production. p. 75-86. *In* L. D. Robertson *et. al.* (eds.). *Proceedings of the Winter Commodity Schools*.2003.Vol. 35.University of Idaho-Cooperative Extension System. Moscow, Idaho.

Hopkins, B.G., and Ellsworth, J. W. (2005).Phosphorus Availability with Alkaline/Calcareous Soil. Western Nutrient Management Conference. Vol. 6.University of Idaho.

Horne, D. J. and Sojka, R. E. (2002). Aeration, Tillage Effects on. *Ency. Soil Sci*. 30-32

Howeler, R. H., Cadavid, L. F., and Burckhardt, E. (1982).Response of Cassava to VA Mycorrhizal Inoculation and Phosphorus Application in Greenhouse and Field Experiments. *Plant and Soil*. 69:327-339.

Howeler, R. H., and Cadavid, L. F. (1983). Accumulation and Distribution of Dry Matter and Nutrients during a 12 Month Growth Cycle of Cassava. *Field Crops Res*. 7: 123-139.

Howeler, R. H., Sieverding, E., and Saif, S. (1987). Practical Aspects of Mycorrhizal Technology in Some Tropical Crops and Pastures. *Plant and Soil*. 100: 249-283.

Howeler, R. (1992b). Fertility Maintenance and Liming of Cassava. CIAT Regional Office in Asia. Bangkok, Thailand.

Howeler, R. H. (2002). Cassava Mineral Nutrition and Fertilization. In: Hillocks, R. J., Thresh, M. J. and Beloti, A. C. (eds.). Cassava Biology Production and Utilization.115-147.

Hunter, A. (1974). Tentative ISFEI Soil Extraction Procedure. International Soil Fertility and Improvement Project.N.C.State University, Raleigh, NC.

Igwe, C. A., Zaret, M., and Stahr, K. (2013).Stability of Aggregates of some Weathered Soils in South-eastern Nigeria in Relation to their Geochemical Properties. *J. Earth syst. Sci*. 122:1283-1294.

IITA – International Institute for Tropical Agriculture.(1990). Cassava in Tropical Africa .A Reference Manual. IITA, Ibadan, Nigeria.

Jen-Hshuan, C., Jeng-Tzung W., and Wei-Tin, H. (2001).Effects of Compost on the Availability of Nitrogen and Phosphorus in Strongly Acidic Soils. *Taiwan Agric. Res. Inst*.

Johnson, A. E. (2000). Soil and Plant Phosphate. *International Fertilizer Industry Association*.

Johnson, N. C. (1993). Can Fertilization of Soil Select Less Mutualistic Mycorrhizae? *Ecol. Appl*. 3: 749-757.

Johnson, N. C., Graham, J. H., and Smith, F. A. (1997).Functioning of Mycorrhizal Associations Along the Mutualism-parasitim Continuum. *New Phytol*.135: 575 -586.

Jones, R. D. (1997). Phosphorus Cycling. In: Manual of Environmental Microbiology. (Ed. J. C. Hurst, G. R. Knudsen, J. M. Mclnemey, L. D. Stetzenbuch, and M. V. Walter). Washington D.C.: AMS Press, 730-735.

Klironomos, J, N.,and Hart, M. M. (2001).Animal Nitrogen Swap for Plant Carbon.*Nat*. 410: 651-652.

Klironomos, J. N., and Kendrick, B. (1996).Palatability of Microfungi to Soil Arthropods in Relation to the Functioning of Arbuscular Mycorrhizae. *Biol. Fertil. Soils* 21:43-52.

Korang-Amoako, S., Cudjoe, R. A., and Adams, E. (1987).Biological Control of Cassava Pests in Ghana. Prospects for the Integration of Other Strategies.

Kung'u, J. B., Lasco, R. D., Cruz, D., Cruz. R. E. D., and Husain, T. (2008).Effect of Vascular-arbuscular Mycorrhiza (VAM) Fungi Inoculation on Cropping Ability and Drought Resistance of *Senna spectabilis*. Pak. *J. Bot.* 40(5): 2217-2224.

KZNDAE – KwaZulu-Natal Department of Agriculture and Environmental Affairs (1995). The Bioresource Groups of KwaZulu-Natal: Preliminary Report.

KZNDAE – KwaZulu-Natal Department of Agriculture and Environmental Affairs(2005).Cassava Cultivar Selection for KwaZulu-Natal. *Res. Owen Sitole College of Agriculture*, Empangeni(*Unpublished*).

KZNDAE – KwaZulu-Natal Department of Agriculture and Environmental Affairs (2012). Long-term Climatic Data of northern KwaZulu-Natal. Cedara, Pietermaritzburg.

Leinweber, P., Meissner, R., Eckhardt, K. U., and Seeger, J. (1999). Management Effects on forms of Phosphorus in Soil and Leaching losses. *European J. Soil Sci*. 50:413-424.

Ludwick, A. I. (1998). Phosphorus Mobility in Perspective. News & Views. Potash &Phosphorus Institute of Canada (PPIC).

Manjula, Y. N. (2006). Use of phosphorus Desorption Characteristics of Soils in Improving P Fertilizer Use Efficiency of Agronomic Crops in South Africa. UMSAEP. Final report.

Manson, A. D., and Roberts, V. G. (2009).Analytical Methods Used by the Soil Fertility and Analytical Services Section. KZN Department of Agriculture and Environmental Affairs, Cedara, Pietermaritzburg.

Manson, A. D., and Sheard, A. (2007).Macadamia Fertilization in KwaZulu-Natal. *KZN Agric. Report*. N/A/2007/10.

Matejovic, I. (1996). The Application of Dumas Method for Determination of Carbon, Nitrogen, and Sulphur in Plant Samples. Rostlinna Vyroba 42: 313-316.

Mwangi, W. M. (1997). Low Use of Fertilizers and Low Productivity in sub-Saharan Africa.*Nut.Cycl.In Agron*. 47: 135-147.

McKenzie, R. H. (2003). Soil pH and Plant Nutrients.*http://www.agric.gov.ab.ca/agdex6607*.

Mclean, P. N.(1982).Soil pH and Lime Requirement. In: Methods of Soil Analysis. Part 2.Inorganic and Microbial Properties. *Agron. Mono*. 9: 199-244.

Meyer, J. H., Wood, R. A., Schumann, A.W., Schroeder, B. L., Rampersad, A. L., and Nixon, D. J. (2004). The SASEX Fertilizer Advisory Service: A Review of 50 Years Dedicated Service to the South African Sugar Industry. *Proc. S. Afr. Sugar Technol. Ass*. 78:359-372.

Mikkelson, R. L. (2005). A Closer Look at Phosphorus Uptake by Plants. *Potash and Phos. Inst. Canada* (PPIC).

Mills, A. J., and Fey, M. V. (2003)).Declining Soil Quality in South Africa: Effects of Land use on Soil Organic Matter and Surface Crusting. *South African J. Sci*.

Miller, R. M., and Jastrow J. D. (1990).Hierarchy of Root and Mycorrhizal Fungal Interactions with Soil Aggregation. *Soil Biol. Biochem.*22:579-584.

Miyasaka, S. C., Habte, M., Friday, J. B., and Johnson, E. V. (2003).Manual on Arbuscular Mycorrhizal Fungus Production and Inoculation Techniques. Soil and Crop Management.SCM-5.College of Tropical Agriculture and Human Resources (CTAHR). Hawai.

MOFA-RTIP – Ministry of Agriculture – Root and Tuber Improvement Porgramme. (2004). Cassava Production Guide: A Resource and Reference Manual. Kumasi, Ghana.

Mokwunye, A. U., Chien, S. H., and Rhodes, E. (1986).Phosphorus Reactions with Tropical African Soils. In: Management of Nitrogen and Phosphorus Fertilizers in Sub-Saharan Africa. Eds. A.U. Mokwunye and Vlek. P. L. G. 253-281.

Moir, J. L., and Moot, D. J. (2010).Soil pH, Exchangeable Aluminium and Lucerne Yield Response to Lime in a South Island High Country Soil: *Proceedings of the New Zealand Grassland Assoc*. 72: 191-196.

Moss, P. (1961). Limit of Interference by Iron, Manganese, Aluminium and Phosphate in EDTA Determination of Calcium in Presence of Magnesium Using Cal-red as Indicator. *J. Sci. Agron*. 12: 30-34.

Motavalli, P. P., and Miles, R. J. (2002).Inorganic and Organic Soil Phosphorus Fractions after Long-term Animal Manure and Fertilizer Application. *Better Crops*. 86:3

Muchovej, R. M. C. (2001). Importance of Mycorrhizae for Agricultural Crops. University of Florida. SS-AGR-170

Muchovej, R. M. C., Kassay, M. C. H., and Muchovij (1990).Effect of Time of Inoculation on Ectomucorrhizal Colonization of *Eucalyptus grandis* by *Pisolithus tinctorum* or *Paxillus involutus*. In: Innovation and Hierarchical Integration. *Proceedings of the Eighth North American Conference on Mycorrhiza*.5-8.

Murphy, J., and Riley, J. R. (1962).A Modified Single Solution Method for the Determination of Phosphates in Natural Waters. *Analytica Chimica Acta*, 27: 31-36

Nakviroj, C. (1998). Soil Research and Fertilizer Use for Cassava in Thailand. In: Cassava Research and Development for Production. Rayong. Thailand.

Nelson, D. W., and Sommers, L. E.(1982). Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 2.Inorganic and Microbial Properties.*Agron.Mono*.9.

NEPAD (New Partnership for Africa's Development). 2001. The NEPAD Frame Document. *http//www.nepad.org/2005/files/documents/inbrief.pdf*. Downloaded July 7, 2005

Njiholt, J. A. (1935). Opname van voedingsstoffen uit don bodem bij Cassava (Absorption of Nutrients from the Soil by a Cassava Crop). Buitenzog. Algemeen Proefstation voor den Landbouw. Korte, Mededeelingen. No. 15: 1035.25.

Nduele, M., Ludwig, A., and Van Ooteghem, M. (1993).The Use of Cassava Starch in the Formulation of Gelatin Capsules.*J.de Pharmacie de Belgique*. 5: 325-334.

Nweke, F. I., Dixon, A. G. O., Asiedu, R.,andFolyan, S. A. (Eds.). (1994). Collaborative Study of Cassava in Africa: Cassava Varietal Needs of Farmers and the Potential for Growth in Africa. COSCA working paper.No. 10. 1994.

Oberson, A., Bounrmann, E. W. K, Friesen, D. K. Rao, L. M., Smithson, P. C., Turner, B. L., and Frossard, E. (2001). Improving Phosphorus Fertility in Tropical Soils through Biological Interventions. *Plant and Soil*. 37: 531–546.

Ofori, C. S. (1973). Decline in Fertility Status of Tropical Forest Ochrosol Under Continuous Cropping. *Experi. Agri*. 9: 15–22.

Ogunwale, J. A., Olarinde, B. D., and Aduloju, M. O. (2006).Effects of Organic Matter Removal and Adsorbate Solution Composition on Phosphate Sorption by Selected Soils of Kwara State, Nigeria. *Agrosearch*. 1: 1-12.

Olsen, S. R., and Sommers, L. E. (1982).Phosphorus. In: Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. In: Page Webster, R. M..R.H. Miller & D.R. Keeney (EDs.). Madison, Winsconsin: *American Soc. Agron*. 403-427.

Olsson, P. A., Thingstrup, L., Jakobson, I., and Baath, E. (1999).Estimation of the Biomass of Arbuscular-mycorrhzal Fungi in a Linseed Field. *Soil Biol*. *Biochem*. 31: 1879 – 1887).

Osundina, M. (1995).Responses of seedlings of *Parkia biglobes* (African locust bean) to Drought and Inoculation with Vesicular-arbuscular Mycorrhiza. *Nigerian J. Bot*. 8:1-10.

Oyetunji, O. J., Ekanayake, I. J., and Osonubi, O. (2007). Chlorophyll Fluorescence Analysis for Assessing Water Deficit and Arbuscular-mycorrhizal Fungi (AMF) Inoculation in Cassava (*Manihot esculanta* Crantz). Adv.In*Biol. Res*. I. 34: 108-117.

Oyetunji, O. J., and Osonubi, O. (2007). Assessment of Influence of Alley Cropping System and Arbuscular Mycorrhizal (AM) Fungi on Cassava Productivity in Derived Savanna Zone of Nigeria. *World J. of Agric. Sci.* 3(4): 489-495.

Oyetunji, O. J., Osonubi, O., and Ekanayake, I. J. (2003). Contribution of an alley cropping systems and arbuscular mycorrhizal fungi to maize productivity under cassava intercrop in the derived savannah zone. *J. Agric. Sci*. 140: 1-6.

Pandey, S. K., Singh, S. V., and Manivel, P. (2005).Genetic variability and Casual Relationship over season in Potato. *Crop Res*. 29: 277-281.

Peters, S. M., and Habte, M. (2001).Optimizing Solution P Concentration in a Peat-based Medium for Producing Mycorrhizal Seedlings. Arid Land Research and Management (in press).

Plenchette, C., Fortin, J. A., and Furlan, V. (1983). Growth Response of Several Plant Species to Mycorrhiza in a Soil of Moderate P Fertility: Mycorrhiza Dependency Under Field Conditions. *Plant and Soil*. 70: 191-209.

Qiang-Sheng, W. U., and Ying-Ning, Z. O. U. (2009). Mycorrhizal Influence on Nutrient Uptake of Citrus Exposed to Drought Stress. *Philippian Agric. Sci.* 92: 33-38.

Quilambo, O. A. (2000). Functioning of Peanut (*Arachis hypogaea* L.) Under Deficiency and Drought Stress in Relation to Symbiotic Associations. PhD Thesis. University of Groningen, The Netherlands. Van Denderen, B.V. Groningen.

Quilambo, O. A. (2003). The Vesicular-arbuscular Mycorrhizal sysmbiosis. *African J. Biotech*. 2: 539-546.

Rasmussen, K. J. (1999). Impact of Ploughless Soil Tillage on Yield and Soil Quality. A Scandinavian Review. *Soil Till. Res*. 53: 3-14.

Reid, C. P. P. (1979). Mycorrizae and water stress. In: Reidacher, A., Gagnaire-Michard, G. (eds). Root Physiology and Symbiosis, IUFRO Proc. Nancy, France. 392-408.

Richardson, A. E., and Simpson, R. J. (2011).Soil Microorganisms Mediating Phosphorus Availability. CSIRO Sustainable Agriculture. *Nat. Res.* Flagship.

Roble, N. D., Ogbonna, J. C., and Tanaka, H. L. (2003). Lactic Acid Production From Raw Cassava Starch in a Circulating Loop Bioreactor with Cells Immobilized in Llofa (*Luffa cylindrical*). *Biol. Letters*. 13: 1093-1098.

Ryan, M., and Ash, J. (1999).Effects of Phosphorus and Nitrogen on Growth of Pasture Plants and VAM Fungi in SE Australian Soils with Constructing Fertilizer Histories (conventional and biodynamic).*Agric. Ecosyst. Environ*. 73: 51-62.

Ryan, M., and Ash, J. (2000). Phosphorus Controls the Level of Colonization by Arbuscular mycorrhizal Fungi in Conventional and Biodynamic Irrigated Dairy Pastures. *Australian J. Exp. Agri.* 40: 663-670.

Ryan, M. H., Norton, R. M., Kirkegaard, J. A., McCormick, K. M., Knights, S. E., and Angus, J. F. (2002). Increasing Mycorrhizal Colonization does not Improve Growth and Nutrition of Wheat on Vertsols in South-eastern Australian. *J. Agr. Res*. 53(10): 1173-1181.

Sardik, K., and Csathó, P. (2002).Studies on the Phosphorus Adsorption of Different Soil Types and Nutrient Levels. *17th WCSS*, Thailand. 588: 1-6.

Salami, B. T. and Sangoyomi, T. E. (2013).Soil Fertility Status of Cassava Fields in South Western Nigeria. *American J. Exp. Agri.* 3: 152-164.

Sarber, K., Debezi, A., Plassads, C, Drevons,, J. J., and Abdelly, C. (2009). Effects of Phosphorus Limiting on Phytase Activity, Proton Efflux and Oxygen Consumption by Nodulated-roots of Common Bean (*Phaseolus vulgaris*)*http://w.w.w.academicjournals.org.*

Selvaraj, T., and Chellapan, P. (2006). Arbuscular Mycorrhizae: A Diverse Personality. *J. Central European Agri*. 7(2):349-358.

Shaiiha, J. A., Arifin, A., Hanzandy, A. H, Abdul-Latib, S., Majid, N. M., and Shamshuddin, J. (2012).Emphasizing the Properties of Soils Occurring in Different Land use Types of Tropical Rainforest in Sarawak, Malaysia. *African J. of Agric. Res*. 7:6479-6487.

Sharif, M., Abida, M, Khan, J., and Ul-Haq, I. (2010).Extractable Phosphorus as Affected by Humic acid Application in Salt Affected Soils. *Sarhad J. Agric*. 26:381-386.

Sharma, S., Kumar, V., and Tripathi, R. B. (2011).Isolation of Phosphate Solubilizing Microorganism (PSMs) From Soil. *J. Microbiol. Biotec. Res*. 1: 90-95.

Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, W., and Zhang, F. (2011). Phosphorus Dynamics: From Soil to Plant. *Plant Physio*. 156: 997-1005.

Sieverding, E., and Howeler, R. H. (1985).Influence of Species of VA Mycorrhizal Fungi on Cassava Yield Response to Phosphorus Fertilization. *Plant Soils*. 88:213-222.

Sims, J. T., and Garthley, K. L. (2001).Phosphorus Management and Phosphorus Saturation Ratio. *Plant and Soil*. Newark.

Sittibusaya, C., Nakviroj, C., and Tummaphirom, D. (1988). Cassava Soils Research in Thailand. In: R. H. Howeler and K. Kwawano (Eds.). Cassava Breeding and Agronomy Research in Asia.Proceedings of a Regional Workshop, held in Rayong, Thailand.145-156.

Sivakumar, B. S., Earanna, N., Farooqi, A. A., Bagyaraj, D. J., and Suresh, C. K. (2002).Effect of AM Fungus and Plant Growth Promoting Rhizomicroorganisms (PGPR's) on Growth and Biomass of Geranium (Pelargonium graneodens). *J. Soil Biol. Ecol*. 23: 80-86.

Six, J., Elliot, E. T., and Paustian, K. (2000). Soil Macroaggregate Turnover and Microaggregate Formation: A Mechanism for C Sequestration Under No-tillage Agriculture. *Soil Biol. and Biochem.*32: 2099-2103.

Six, J., and Jastrow, J. D. (2002).Organic Matter Turnover. *Ency. of Soil Sci*.

South African Weather Service.(2009). Climatic Information on Northern KwaZulu-Natal.

Stabury, J. (2000). Challenges and Opportunities for the Fresh Produce Export Industry. *FSSA J.*

Stevenson, E. J. (1986). Cycle of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. John Wiley and sons. New York.

Syers, J. K., Johnston, A. E., and Curtin, D. (2008).Efficiency of Soil and Fertilizer Phosphorus Use. Reconciling Changing Concepts of Soil Phosphorus Behavior with Agronomic Information. In: FAO Fertilizer and Plant Nutrition Bulletin. Food and Agriculture Organization. Rome.

Tan, K. H., Ferguson, L. B., and Carlton, C. (1984). Conversion of Cassava Starch to Biomass, Carbohydrates, and Acids by *Aspergillus niger*. *J. Applied Bioch*. 6: 80-90.

Tavares de Lima, A. A., Xavier, T. F., Pereira de Lima, C. E., Oliveira, J. P., Mergulhåo, A. C. S., and Figueiredo, F. M. V. (2011). Triple Inoculation with *Bradyrhizobium, Glomus* and *Paenibacillus* on Cowpea (*Vigna unguiculata* [L.] walp.) Development. *Brazilian J. Microbiol*. 42: 919-926.

Tetteh, K., and Frimpong, Y. (1991).Root, Tubers, and Plantation Crops. Accelerated Agricultural Growth. 5: 11-15.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D., and Swckhammer, D. (2001).Forecasting Agriculturally Driven Global Environmental Change. *Sci*. 292: 281-284.

Torn, M. S., Vitousek, P. M., and Trunbore, S. S. (2005).The Influence of Nutrient Availability on Soil Organic Matter Turnover Estimated by Incubations and Radiocarbon Modeling. *Ecosystems*. 8: 352-372.

Turner, B. L., and Leytem, A. B. (2004). Phosphorus Compounds in Sequential Extracts of Animal Manures: Chemical Speciation and a Novel Fractionation Procedure. *Environ. Sci. Technol*. 38: 6101-6108.

Uehara, G., and Gillman, G. P. (1981).The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays. Westview Press, Boulder, Co.

Vance, C. P., Uhde-Stone, C., and Allan, D. L. (2003). Phosphorus Acquisition and Use: Critical Adaptations by Plants for Securing a Nonrenewable Resource. *New Phyto*. 157: 423-447.

Vander Zaag, P., Fox, R. L., De La Pena, R. S. and Yost, R. S. (1979). P Nutrition of Cassava, Including Mycorrhizal Effects on P, K, S, Zn, and Cauptake. Department of Agro and Soil Sci, *CTA Field crop Res.*2:253-263.

Von Wandruszka, R. (2006). Phosphorus Retention in Calcareous Soils and the Effect of Organic Matter on its Mobility. *Geochem. Trans*. 7: 6

Vuilleumier, S. (1993).Worldwide Production of High-fructose Syrup and Crystalline Fructose. *American J. Clinical Nutri*. 5: 733S-736S,

Warren, G. (1992). Fertilizer Phosphorus Sorption and Residual Value in Tropical African Soils. *NRI bulletin* 37. *Nat. Res. Inst,* Chatham, England.

Waterer, D. (2001).Impact of High Soil pH on Potato Yields and Grade losses to Common scab.*Dept. Plant Sci*. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Watson, G. W., and Kelsey, P. (2006). The Impact of Soil Compaction on Soil Aeration and Fine Root Density of *Quercus palustris*. *Urban Forestry and Urban Greening*. 4: 69-74

Webster, R. M. (1990). Bioclimate of Natal. KwaZulu-Natal Department of Agriculture, Cedara, South Africa.

Westerman, D. T., and Leyterm, A. B. (2008).Soil Factors Affecting P Availability in Western soils. USDA-ARS. *Northwest Irrigation and Soils Res*.

Williams, C. (2004). The Use of Soil Ameliorants to Improve the Productivity of Established Vineyards on Highly Acid soils. *GWRDC Final Report. RT 02/07*. *Adelaide Hills Wine Region Inc.*

World Bank.(2005).”Promoting Efficient and Sustainable Fertilizer Use in Africa: A Toolkit for Practitioners.” Draft. Africa Region, World Bank, Washington, DC.

World Bank.(2006). “Promoting Increased Fertilizer Use in Africa. Lessons Learned and Good Practice Guidelines.” Economic and Sector Work. Africa Region, World Bank, Washington, DC.

Yaseen, T., Burni, T., and Hussain, F. (2011).Effect of Arbuscular Mycorrhizal Inoculation on Nutrient Uptake, Growth and Productivity of Cowpea (*Vigna unguiculata*) Varieties. *African J. Biotech*. 10:8593-8598.

Zhang, W. H. and Cai, Z. C. (2007). Long-term Effects of Inorganic Fertilizers on Microbial Biomass and Community Functional Diversity in a Paddy Soil derived from Red Clay. *J. Applied Soil Ecol.* 36: 84-91

APPENDIXES

APPENDIX 1

ANOVA tables for (a) Soil Phosphorus. (b) Soil Potassium. (c) Soil Calcium. (d) Soil Magnesium. (e) Soil pH(KCl) at harvest after treatment with Phosphorus, Arbuscular mycorrhiza fungus and Phosphorus plus Arbuscular Mycorrhiza fungus.

(a)

Source of variation	DF	SS[2]	MS[3]	VR[4]	F Probability
Block (Replicate)	3	1805.08	601.69	27.47	
Site	3	3857.21	1285.74	58.7	<0.001
Treatment	3	840.51	280.17	12.79	<0.001
Site x Treatment	9	14.30	1.59	0.07	1.000
Residual	45	985.65	21.9		
Total	63	7502.75			
Coefficient of variation (%)	45				

(b)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	0.2968	0.09883	1.08	
Site	3	7.56064	2.52021	27.54	<0.001
Treatment	3	7.3229	2.44097	26.68	<0.001
Site x Treatment	9	0.88409	0.09823	1.07	0.400
Residual	45	4.11759	0.0915		
Total	63	20.18201			
Coefficient of variation (%)	31.7				

(c)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	26.108	8.703	1.47	
Site	3	996.034	332.011	56.13	<0.001
Treatment	3	55.684	18.561	3.14	0.034

Ste xTreatment	9	9.284	1.032	0.17	0.996
Residual	45	266.157	5.915		
Total	63	1353.267			
Coefficient of variation (%)	27.7				

80

(d)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	97.496	32.499	6.3	
Site	3	81.966	27.322	5.3	0.003
Treatment	3	77.279	25.76	5	0.004
Ste xTreatment	9	12.904	1.434	0.28	0.977
Residual	45	232.062	5.157		
Total	63	501.708			
Coefficient of variation(%)	37.3				

(e)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	3.52852	1.17617	14.37	
Site	3	3.82123	1.27374	15.56	<0.001
Treatment	3	1.73103	0.57701	7.05	<0.001
Ste xTreatment	9	0.57538	0.06393	0.78	0.635
Residual	45	3.68368	0.08186		
Total	63	13.33984			
Coefficient of variation(%)	5.3				

1. DF degree of freedom 2. SS sum of squares

3 MS mean sum of squares 4. VR variance ratio

APPENDIX 2

ANOVA tables for (a) Plant height, (b) yield at harvest as affected by treatment with Phosphorus, Arbuscular mycorrhiza fungus and Phosphorus plus Arbuscular Mycorrhiza fungus.

(a)

Source of variation	DF	SS	MS	VR	F Probability
Block (Replicate)	3	1123.7	374.6	2.49	
Site	3	1721.3	573.8	3.81	0.016
Treatment	3	2994.3	998.1	6.62	<.001
Site x Treatment	9	912.3	101.4	0.67	0.729
Residual	45	0.3	150.7		
Total	63	13533.9			
Coefficient of variation (%)	7.6				

(b)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	1.5148	0.5049	1.26	
Site	3	8.5002	2.8334	7.04	<.001
Treatment	3	9.7462	3.2487	8.08	<.001
Site x Treatment	9	0.5475	0.608	0.15	0.998
Residual	45	18.103	0.4023		
Total	63	38.4116			
Coefficient of variation (%)	19				

1. DF degree of freedom
2. SS sum of squares
3 MS mean sum of squares
4. VR variance ratio

APPENDIX 3

ANOVA tables for (a) Plant leaf Phosphorus. (b) Plant leaf Nitrogen (c) Plant leaf Calcium. (d) Plant leaf Potassium. (e) Plant leaf Magnesium. (f) Plant leaf Zinc during growing period after treatment with Phosphorus, Arbuscular mycorrhiza fungus and Phosphorus plus Arbuscular Mycorrhiza fungus.

(a)

Source of variation	DF	SS	MS	VR	F Probability
Block (Replicate)	3	0.067743	0.022581	10.78	
Site	3	0.065853	0.021951	10.48	<0.001
Treatment	3	0.569353	0.189784	90.61	<0.001
Time (MAP)	4	0.264673	0.066168	31.59	<0.001
Ste x Treatment	9	0.02056	0.002284	1.09	0.370
Site x MAP	12	0.041419	0.003452	1.65	0.080
Treatment x MAP	12	0.016932	0.001411	0.67	0.776
Site x Treatment x MAP	36	0.023856	0.000663	0.32	1.000
Residual	237	0.496407	0.002095		
Total	319	1.566795			
Coefficient of variation(%)	9.6				

(b)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	6.1569	2.0523	7.47	
Site	3	38.7613	12.9204	47.05	<0.001
Treatment	3	19.4095	6.4698	23.56	<0.001
Time (MAP)	4	29.5031	7.3758	26.86	<0.001
Ste x Treatment	9	2.5337	0.2815	1.03	0.420
Site x MAP	12	13.1498	1.0958	3.99	<0.001
Treatment x MAP	12	2.308	0.1923	0.7	0.750
Site x Treatment x MAP	36	4.5821	0.1273	0.46	0.996
Residual	237	65.0771	0.2746		
Total	319	181.4814			
Coefficient of variation(%)	11.6				

(c)

SOV	DF	SS	MS	VR	F Probability
Block (Replicate)	3	2.76908	0.92303	33.85	
Site	3	0.68362	0.22787	8.35	<0.001
Treatment	3	2.11704	0.70568	25.88	<0.001
Time (MAP)	4	3.65092	0.91273	33.47	<0.001
Ste x Treatment	9	1.39156	0.15462	5.67	<0.001
Site x MAP	12	0.5381	0.08782	3.22	<0.001
Treatment x MAP	12	0.50636	0.0422	1.66	0.108
Site x Treatment x MAP	36	1.29818	0.03606	1.32	0.115
Residual	237	6.46209	0.02727		
Total	319	19.93266			
Coefficient of variation(%)	13.6				

(d)

Source of variation	DF	SS	MS	VR	F Probability
Block (Replicate)	3	0.96163	0.32054	7.62	
Site	3	1.48403	0.49498	11.76	<0.001
Treatment	3	8.27476	2.75825	65.54	<0.001
Time (MAP)	4	4.20333	1.05083	24.97	<0.001
Ste x Treatment	9	1.28266	0.14252	3.39	<0.001
Site x MAP	12	0.95261	0.07938	1.89	0.037
Treatment x MAP	12	0.71219	0.05935	1.41	0.162
Site x Treatment x MAP	36	0.7072	0.01964	0.47	0.996
Residual	237	9.97389	0.04208		
Total	319	28.5532			
Coefficient of variation (%)	10.9				

(e)

Source of variation	DF	SS	MS	VR	F Probability
Block (Replicate)	3	0.12969	0.04323	1.1	
Site	3	0.02073	0.00591	0.18	0.912
Treatment	3	0.33088	0.11029	2.81	0.4
Time (MAP)	4	0.63599	0.159	4,06	0.003
Ste x Treatment	9	0.27226	0.03025	0.77	0.643
Site x MAP	12	0.45837	0.0382	0.97	0.474
Treatment x MAP	12	0.52948	0.04412	1.13	0.34
Site x Treatment x MAP	36	1.37149	0.0381	0.97	0.52
Residual	237	9.29263	0.03921		
Total	319	13.04154			
Coefficient of variation (%)	46.3				

(f)

Source of variation	DF	SS	MS	VR	F Probability
Block (Replicate)	3	1330.5	443.5	11.9	
Site	3	7264.33	2421.44	64.96	<0.001
Treatment	3	3261.83	1087.28	29.17	<0.001
Time (MAP)	4	15966.41	3991.6	107.09	<0.001
Ste x Treatment	9	929.1	103.23	2.77	0.004
Site x MAP	12	3491.39	290.95	7.81	<0.001
Treatment x MAP	12	429.27	35.77	0.96	0.488
Site x Treatment x MAP	36	2829.93	78.61	2.11	<0.001
Residual	237	8834	37.27		
Total	319	44336.75			
Coefficient of variation (%)	8.6				

1. DF degree of freedom
2. SS sum of squares
3 MS mean sum of squares
4. VR variance ratio