EFFECT OF ARBUSCULAR MYCORRHIZAL FUNGI AND PHOSPHATE SOLUBILIZING BACTERIAL INOCULANTS ON GROWTH AND PHOSPHORUS UPTAKE BY ORANGE FLESHED SWEETPOTATOES (Ipomoea batatas (L) Lam).

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2012.
DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

I dedicate this work to my family; my dad Mr Fredrick Kundu and my late mum Mrs Esther Kundu for sacrificing a lot for my education, my lovely daughter Martha K. Kundu who endured my being away for such a long time and my sisters; Linnet, Metrine, Judith, Maureen and Mercy. You are all my inspiration.
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TABLE OF CONTENTS

DECLARATION........................................................................................................... I
DEDICATION ............................................................................................................. II
ACKNOWLEDGEMENT ............................................................................................. III
TABLE OF CONTENTS .............................................................................................. V
LIST OF TABLES ......................................................................................................... VII
LIST OF FIGURES ..................................................................................................... VIII
LIST OF PLATES ........................................................................................................ IX
LIST OF ABBREVIATIONS ....................................................................................... X
ABSTRACT ................................................................................................................ XII
CHAPTER 1 ................................................................................................................... 1
INTRODUCTION ......................................................................................................... 1
  1.1: Background information .................................................................................. 1
  1.2: Problem statement and justification ............................................................... 4
  1.3: Objectives: ....................................................................................................... 7
    1.3.1: Overall objective.......................................................................................... 7
    1.3.2: Specific objectives...................................................................................... 7
  1.4: Hypotheses ....................................................................................................... 7

CHAPTER 2 ................................................................................................................... 8
LITERATURE REVIEW ............................................................................................... 8
  2.1: History of sweetpotatoes ................................................................................ 8
  2.2: Production and utilization of sweetpotatoes .................................................... 8
  2.3: Sweetpotato production constraints ............................................................... 10
  2.4: The soil as a living habitat ............................................................................. 11
  2.5: Arbuscular Mycorrhizal Fungi ....................................................................... 13
    2.5.1: Taxonomy, Description and Distribution of AMF ..................................... 13
    2.5.2: Reproduction and Life cycle of AMF ..................................................... 15
  2.6: Symbiotic benefits of AMF .......................................................................... 19
    2.6.1: Nutrient uptake ........................................................................................ 19
    2.6.2: Drought tolerance .................................................................................... 20
    2.6.3: Tolerance to plant root pathogens ........................................................... 21
    2.6.4: Soil aggregation ...................................................................................... 22
    2.6.5: Tolerance to toxic metals ....................................................................... 22
  2.7: Phosphorus solubilizing Microorganisms ....................................................... 23
  2.8: Mechanism of phosphate solubilization by the phosphate solubilizing bacteria 24
  2.9: Microbial interactions in the rhizosphere ....................................................... 26
  2.10: Effects of agricultural practices on soil microbial populations .................. 27
CHAPTER 3 ________________________________________________________________
MATERIALS AND METHODS .............................................................................
3.1: Site Description ...........................................................................................
3.2: Soil sampling and chemical characterization ..............................................
3.3: Assessment of effective and infective AMF propagules .............................
3.4: Evaluation of AMF and PSB dual inoculants for P uptake and biomass accumulation ......................................................................................
3.5: Field evaluation of AMF inoculants .........................................................
3.6: Data collection and analysis ....................................................................

CHAPTER 4 ________________________________________________________________
RESULTS .............................................................................................................
4.1: Chemical characteristics of soils before experiment ...............................
4.2: Assessment of infective and effective AMF propagules .........................
4.3: Evaluation of AMF and PSB dual inoculation on biomass production and soil P uptake in a greenhouse experiment ........................................
  4.3.1: Effect of dual AMF and PSB inoculation on biomass production ...........
  4.3.2: Effect of dual AMF and PSB inoculation on soil P uptake .......................
4.4: Performance of AMF inoculants and fertilizer application on OFSP in Kakamega ........
  4.4.1: Performance of AMF inoculants in the field .....................................
  4.4.2: Application of fertilizer on OFSP in the field .....................................

CHAPTER 5 5 2
DISCUSSION ........................................................................................................
5.1: Soil chemical characteristics ....................................................................
5.2: Infective and effective AMF propagules ................................................
5.3: Effect of dual AMF and PSB inoculation on biomass production and soil P uptake in a greenhouse experiment ........................................
  5.3.1: Effect of dual AMF and PSB inoculation on biomass production ........
  5.3.2: Effect of dual AMF and PSB inoculation on soil P uptake .....................
5.4: Performance of AMF inoculants and fertilizer in a field experiment ........
  5.4.1: Response of OFSP to AMF inoculants ............................................
  5.4.2: Field application of chemical fertilizer .............................................
5.2 Conclusions and Recommendations .........................................................
  5.2.1: Conclusions ....................................................................................
  5.2.2: Recommendations ...........................................................................

REFERENCES.......................................................................................................
LIST OF TABLES

Table 1: Treatment factors applied in the Greenhouse Experiment .................................................. 35
Table 2: Treatment factors applied in the Field Trial ................................................................. 37
Table 3: Varietal Characteristics of SPK 004 and Kabode .............................................................. 37
Table 4: Selected chemical characteristics of the soil at the study site ........................................ 39
Table 5: Effect of AMF inoculants on sweetpotato root infection sampled at different months ....... 41
Table 6: Mean effect of dual AMF-PSB inoculation on variety vine fresh weight ......................... 42
Table 7: Mean effect of dual AMF-PSB inoculation on variety root fresh weight ............................ 43
Table 8: Effect of dual AMF-PSB inoculation on sweetpotato root length .................................... 43
Table 9: Effect of dual AMF-PSB inoculation variety root infection frequency ............................ 44
Table 10: Effect of dual AMF-PSB inoculation on variety root infection intensity ......................... 45
Table 11: Effect of dual AMF and PSB inoculation on soil available P under two OFSP varieties .... 45
Table 12: Effect of AMF inoculants on variety vine fresh weight in a field experiment .................. 46
Table 13: Effect of AMF inoculation on total and marketable root yield in a field trial .................... 47
Table 14: Sweetpotato root infection by different AMF inoculants in a field trial ............................ 48
Table 15: Effect of AMF soil inoculation on soil available P ......................................................... 48
Table 16: Effect of fertilizer application on sweetpotato vine yield in a field trial ......................... 49
Table 17: Effect of fertilizer application on variety total fresh root yield ....................................... 49
Table 18: Effect of fertilizer application on sweetpotato root marketable quality ........................... 50
Table 19: Effect of fertilizer application rate on sweetpotato root infection by AMF in the field ....... 51
LIST OF FIGURES

Figure 1: Diagrammatic representation of the characteristic structures of AMF as identified in the cortical cell of a host plant when viewed under a microscope ........................................... 14

Figure 2: Life cycle of Arbuscular Mycorrhizal fungi showing the asymbiotic, pre-symbiotic and symbiotic stages of colonization ........................................................................................................ 16

Figure 3: Point measurement scheme sampling layout .................................................................................................................. 31
LIST OF PLATES
Plate 1: Mycorrhization tray (left) and (right) OFSP cuttings in mycorrhization stage. ....... 35
Plate 2: In mycorrhization stage SPK 004 (left) and Kabode (right).................................. 35
Plate 3: Sweetpotato plants in polythene bags after mycorrhization stage. ....................... 36
LIST OF ABBREVIATIONS

AfDB: African Development Bank

Al: Aluminium

AMF: Arbuscular Mycorrhizal Fungi

ANOVA: Analysis of Variance

ASARECA: Association for Strengthening Agricultural Research in East and Central Africa.

a.s.l: above sea level.

Ca: Calcium.

C: Carbon

Cd: Cadmium

CIP: International Potato Centre

Cu: Copper.

DONATA: Dissemination of New Agricultural Technologies in Africa.

ERH: Extraradical hyphae.

FAOSTAT: Online Statistical Database of Food and Agriculture Organization.

FARA: Forum for Agricultural Research in Africa.

Fe: Iron.


HCl: Hydrochloric acid.

H\textsubscript{2}O\textsubscript{2}: Hydrogen peroxide

ICRAF: International Centre for Research in Agro-forestry (World Agroforestry Centre).

IRH: Intraradical hyphae.

JKUAT: Jomo Kenyatta University of Science and Technology.

KARI: Kenya Agricultural Research Institute.

K: Potassium.

KOH: Potassium hydroxide.

Mg: Magnesium.

MoA: Ministry of Agriculture.

Na: Sodium.

N: Nitrogen.

NH₄OH: Ammonium hydroxide.

Ni: Nickel.


OFSP: Orange fleshed sweetpotato.

PGPR: Plant Growth Promoting Rhizobacteria.

PSB: Phosphate Solubilizing Bacteria.

P: Phosphorus.

Pb: Lead

TSBF-CIAT: Tropical Soil Biology and Fertility Institute of International Centre for Tropical Agriculture.

TSP: Triple Super Phosphate.


UoN: University of Nairobi.

Zn: Zinc.
Effect of Arbuscular Mycorrhizal Fungi and Phosphate solubilizing Bacterial Inoculants on growth and Phosphorus uptake by Orange Fleshed Sweetpotatoes (Ipomoea batatas (L.) Lam).

ABSTRACT
Microorganisms and their interactions in the soil play a critical role in nutrient transformations and cycling, and in sustaining soil productivity. Arbuscular mycorrhizal fungi (AMF) play a major role in nutrient cycling. Phosphate solubilizing bacteria (PSB) on the other hand play a role in phosphorus nutrition by enhancing its availability to plants through release from inorganic and organic soil phosphorus pools by solubilization and mineralization. Activity and composition of microorganisms in soil are influenced by management practices such as the choice of crop species and fertilization. Application of AMF in sweetpotato production can contribute to increased growth, increased yields and improved soil nutrition with a reduction in chemical fertilizer input in a more sustainable agriculture. In this study, pot and field experiments were conducted after assessing the dependency of sweetpotatoes to AMF to determine the effects of dual AMF and Phosphate Solubilizing Bacteria (PSB) inoculants with varying rates of chemical phosphorus fertilizer on growth, yield and soil in sweetpotato production. A pot experiment was conducted under greenhouse conditions to evaluate the effects of dual inoculants on Orange Fleshe Sweetpotato (OFSP) growth, yield and nutrition using varieties SPK004 and Kabode as the test crops. The commercial inocula were separate single species of Glomus mosseae, Glomus etunicatum and Glomus intraradices in granular formulation containing spores, root fragments and other propagules. The indigenous inoculum was a single strain of Glomus aggregatum. Local PSB isolates were Azotobacter chroococcum and Pseudomonas fluorescens. Triple super phosphate (TSP) fertilizer was used at varying rates of 0kgP/ha, 20kgP/ha and 40kgP/ha. Varieties responded differently to the different fertilizer rates and AMF inoculation. PSB inoculation did not show any significant effect on the parameters
assessed ($P > 0.05$). SPK004 had better growth and vine yield compared to Kabode and dry matter yield increased with the application of fertilizer at a rate of 40kgP/ha (2.110t/ha and 0.736t/ha) for shoot and root dry matter yield respectively. In terms of AMF root colonization, the mixed inoculum recorded a higher frequency of 30.72% and intensity of 17.36% that was in line with a highest spore count of 5.40. The single species inoculums gave had a spore recovery of 5.02 and 4.45 spores for *Gl. intraradices* and *Gl. mosseae* respectively. Results of the field experiment showed that the varieties differed significantly in growth ($P < 0.05$) with SPK004 giving a vine yield of 29.17t/ha compared to Kabode with 19.38t/ha. However, Kabode had better root yield (14.18t/ha) and SPK004 (12.79t/ha). In terms of AMF colonization, the mixed inoculum gave a 52.22% frequency of colonization that resulted from a higher spore count of 10.94 spores. With the single species inoculants, *Gl. intraradices* out-performed the other single inoculum with a frequency of 42.04% closely followed by *Gl. mosseae* (42.00%). Increased chemical P fertilization inhibited AMF colonization and the benefits associated with it. Mycorrhizal inoculation significantly ($P < 0.05$) influenced root colonization and AMF spore counts recovered in the soil. The highest colonization of 72.78% was in AM inoculated plants in combination with TSP at a rate of 20kgP/ha. The highest spore number of 14.83 was observed in mixed AM inoculated plant with 20kgP/ha fertilization. *Gl. intraradices* was the best performing single species in terms of growth promotion and root colonization followed by *Gl. mosseae*. 
CHAPTER 1

INTRODUCTION

1.1: Background information

Sweetpotato (*Ipomoea batatas*) is an important secondary food crop for many Kenyans whose staple diet is based on cereals, particularly maize (Gakonyo, 1993). In Kenya, sweetpotato growing is mainly concentrated in Western Kenya including Kakamega, Bungoma, Busia, Homa-Bay, Rachuonyo and Kisii districts and to a small extent at the Coast and in Central provinces. There has been a steady increase in the area planted with sweetpotato from about 55,000 Ha in 1988 to about 77,821 Ha in 2009 (FAOSTAT, 2009). Previous work by Mutuura *et al.*, (1992) established that it is an important food security crop especially when maize is in short supply or in years of drought. On the other hand, sweetpotato is more nutritious than cassava, it is more drought tolerant than maize, is a short term crop and improves the yield of maize in crop rotation as compared to continuous maize production (Gakonyo, 1993). Poor soils, pests and diseases have however hampered its production resulting in low yields. Many consumers perceive it as a snack and not as a food, a perception that makes it carry the stigma of being the last resort or a famine food (Gakonyo, 1993). Orange fleshed sweetpotato (*Ipomoea batatas* (L.) *Lam*) varieties have gained popularity in the Western Kenya region in the recent past. They are rich in beta carotene, a precursor of vitamin A hence providing a proper response to vitamin A deficiencies which are on the rise in Kenya (MoA and UNICEF, 1995).

The effects of declining soil fertility on yield and growth are particularly visible in the region. Majority of the small-scale farmers practice low input agriculture that depends on organic matter in the soil to sustain production, hence the need to practice sustainable agricultural practices that produce adequate amounts of high quality food while protecting and repairing the depleted land resource. Farmers in the region grow it traditionally without any chemical
inputs as they would with the other crops like maize (Ndolo et al., 1998). Lack of fertilizer input use is due to the farmers' contention that the use of chemical fertilizer input promotes the vegetative part rather than the tubers (Mutuura, 1990).

Sweetpotato is predominantly grown on small and resource poor farms usually without any purchased inputs. The cropping patterns of sweetpotato producing farms typically embrace a large number of activities including the cultivation of other staple food crops for instance maize and a majority of them are also engaged in some form of livestock keeping. Most of the farmers grow two sweetpotato cycles per year. Sweetpotato is commonly cultivated as a pure crop but sometimes intercropped or relay cropped with maize and more than one sweetpotato variety is planted. It has often offered comparatively better yields in adverse climatic conditions and low in-put regimes. A significant share of the harvest is consumed at home. However, commercialization of sweetpotato has increased substantially in the recent years due to the increase in Kenya’s urbanization.

Phosphorus (P) is an essential mineral nutrient for plant growth and development and is the world’s second highest (after nitrogen) chemical input and limiting mineral in agriculture. Soluble P is often the limiting mineral nutrient for biomass production in agricultural ecosystems (Hameeda et al., 2006). Plants utilize fewer amounts of phosphate fertilizers that are applied to the soil while the bulk is converted to insoluble complexes encouraging the farmers to frequently apply fertilizers (Keneni et al., 2010). Microorganisms are important in agriculture because of their role in nutrient cycling which reduces the need for chemical fertilizers (Cakmakci et al., 2006). Phosphate solubilizing microorganisms are considered among the most effective plant assistants that can supply phosphorus at a favourable level (Toro et al., 1997). Other soil organisms that have the ability to supply insoluble P are arbuscular mycorrhizal fungi (AMF) which form symbiotic association with diverse plants
and play an important role in nutrient cycling in natural and agricultural ecosystems (Plenchette et al., 2005).

Mycorrhizal infection has been shown to increase sweetpotato growth and yield in a number of studies, for instance, Paterson et al. (1987), Mulongoy et al. (1988), Khasa et al. (1992), Paula et al. (1992), Dowling et al. (1994) and Floyd et al. (1988) who found that the extent of mycorrhizal infection was positively correlated with yield, and negatively correlated with the crop response to phosphorus fertilizer, over a range of soils in the Highlands of Papua New Guinea (PNG). In other studies however, the effect is greatest under low phosphorus fertility and arbuscular mycorrhizal fungi may have no benefit or even a negative effect on crops which are well supplied with phosphorus (Negeve and Roncadori, 1985). Although sweetpotato may yield relatively well under low phosphorus conditions, phosphorus deficiency is still a very common cause of reduced yields. Goodbody and Humphreys (1986) found significant positive correlations between sweetpotato yield and available phosphorus in each of three soil types surveyed in Simbu province of Papua New Guinea. Floyd et al. (1988) obtained a three-fold increase in yield in response to phosphorus fertilizers in Highland of Papua New Guinea but when potassium was also supplied. Field trials have demonstrated a large positive response of sweetpotato to phosphorus fertilizer on a number of volcanic ash soils in Tonga (Halavatau et al. 1996) and andisols in Papua New Guinea (Dowling et al. 1994). It is clear from such examples that wider use of phosphorus fertilizers will play an important role in improving sweetpotato production as it has for other crops.

Insufficient attention to effective crop nutrition and soil fertility management studies has made it difficult to improve crop yields even when improved clones are made available. Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased outputs and income, especially for low income groups without depleting the natural resource base.
1.2: Problem statement and Justification

Soil fertility decline in sub-Saharan Africa is considered as the major limiting factor to achieving household food sufficiency in the majority of smallholder farming systems (Okalebo et al., 2007). Crop yields have declined in sub-Sahara Africa and up to less than 1 t ha\(^{-1}\) are observed in cereal crops such as maize and beans; this attributed to the loss of soil fertility in smallholder systems (Sanchez et al., 1997). Phosphorus (P) is second to Nitrogen (N) as the most plant limiting nutrient despite it being abundant in soils in both organic and inorganic forms (Gyaneshwar et al., 2002). Its concentration in soluble form in soil is usually very low (Goldstein, 1994). This fixation and precipitation in the soil occur because of the reactivity of the phosphate ions with the numerous soil constituents like calcium (Ca) in calcareous soils and aluminium (Al) or iron (Fe) in acidic soils (Rodriguez and Fraga, 1999; Fernandez et al., 2007). While the use of mineral phosphate fertilizers seems the best means to combat this deficiency, their use in smallholder farming is usually limited by the availability and the high costs incurred (Odendo et al., 2007, Mureithi et al., 2007). In Western Kenya, phosphorus deficiency is one of the most widespread nutritional problems in most agricultural soils. The soils are acidic and infertile representing P deficiencies and farmers practice continuous cropping with little or even none addition of nutrients. Besides crop residues are removed and this has led to the decline in the organic matter and the crop production potential of such soils and as a result there is a reduction in soil biodiversity leading to a loss in ecosystem function, which is further detrimental to sustained productivity. In such a situation, biofertilizers therefore offer a great potential for not only improving soil fertility and organic matter levels but also provide for an efficient use of various inputs and for increasing crop production on sustainable basis. Biofertilizers contain microorganisms which when added to the soil enhance availability of essential nutrients to plants. P is mainly chemically fixed, sorbed to clay or linked with aluminium, iron or calcium in often highly
insoluble compounds or bound in organic complexes making it unavailable to plants (Vance et al., 2003). In such a case, P becomes the least available nutrient in the rhizosphere, thus a deficiency and one of the major limitations in crop production in numerous parts of the world, particularly in the tropics (Hamel and Plenchette, 2007). Crop yields can be increased by adopting proper soil and water management practices, balanced crop nutrition involving the use of all possible sources of nutrients, improved crop production technologies etc. When phosphate fertilizers are incorporated, the major share of phosphorus is fixed thereby making it unavailable to plants (Harikumar and Potty, 2007), and the result has been poor crop yields. Sweetpotato is a high starch human food compared to many cereals and its energy value exceeds that of potato, cassava and any other known tubers (Janssens, 2001). Sweetpotato plants provide the fleshy storage roots and the green tops (vines consisting of stems and leaves), both of which can be used as nutritious food for humans and animals. It also has a number of outstanding nutritional characteristics which make it a valuable tool for combating certain severe and widespread nutritional problems in the developing world (Woolfe, 1992). The major inhibition to sweetpotato production in Western Kenya is poor soil fertility and diseases. The crop is grown mostly for roots which are eaten boiled or can be processed into simple food products like mandazi, juice, crackles, cakes etc for sale. The foliage is an important supplementary feed for livestock. Sweetpotatoes require high doses of potassium, medium doses of phosphorus and low doses of nitrogen especially at planting for optimum storage root yield (Salunke and Kadam, 1998) and there is potential for increasing yields by the introduction of improved clones and more efficient cultivation practices. Studies by Muhamad and Toshiaki, (1990) have indicated high tolerance of sweetpotato to low phosphorus soils compared to cassava. Sweetpotato is tolerant to acidity and is able to perform well in acidic soils and studies in China have shown an increased yield of up to 11% and quality of up to 26%. They grow rapidly and cover the ground within a few weeks of
planning. Orange fleshed sweetpotato (OFSP) varieties provide high amounts of highly bioavailable beta-carotene which is a precursor of vitamin A. In Western Kenya, there has been a steady increase in acreage and consumption levels of OFSP, occupying 10-15% of the region (Tumwegamire et al., 2004). Evaluation and enhancement of microbial associations promoting phosphorus availability to sweetpotato roots seem to be an alternative to the expensive chemical fertilizer input to increase production. Microorganisms are involved in a range of processes that affect the transformation of soil phosphorus and thus form an integral component in the soil phosphorus cycle (Deubel and Merbach, 2005). These organisms are effective in releasing phosphorus from the inorganic phosphorus through solubilization (Richardson, 1994; Narula et al., 2000) This solubilization of P occurs when carboxylic acids are synthesized and released by microorganisms in the soil and also reduce the pH (Puente et al., 2004; Rodriguez et al., 2006). Phosphorus biofertilizers in the form of microorganisms can therefore help in increasing the availability of the fixed phosphates for plant uptake by solubilization (Goldstein, 1986, Kucey et al., 1989).

Plant growth promoting rhizobacteria (PGPR) and mycorrhizal fungi are such soil microorganisms which associate with the plant roots and are said to improve nutrient and water use and also reduce attacks by plant pathogens. The arbuscular mycorrhizal fungi are of considerable interest because of their ability to form symbiotic associations with various crop species. Infection of crop roots with AM fungi can improve the uptake of nutrients particularly phosphorus and increase crop production (Jalaluddin et al., 2008). These endomycorrhizal fungi are obligate symbiotic fungi, the hyphae of which develop mycelia, arbuscules and in most fungal genera vesicles in roots. The hyphae can explore an area around the root which far exceeds that available to the root hairs and have the ability to absorb relatively immobile or fixed elements like phosphorus, zinc and copper in acidic or alkaline soils especially in plants with coarse root system (Allen et al., 1995). Inoculation of
orange fleshed sweetpotato varieties with mycorrhizal fungi and phosphate solubilizing bacteria in the low phosphorus soils would improve soil phosphorus levels and eventually the root yield. Application of inoculants provided from these microorganisms to the soil would enhance an abundant population of active and effective microorganisms to the root zone and thus increase the plant ability to take up more nutrients. This would lead to more accurate fertilizer recommendations, improved yields and minimized environmental pollution.

1.3: Objectives:

1.3.1: Overall objective

To enhance production of orange fleshed sweetpotato in Western Kenya through applications of bio-inoculants.

1.3.2: Specific objectives

1. To assess the presence of effective and infective AMF propagules in sweetpotato growing soils from Western Kenya.

2. To evaluate the performance of dual arbuscular mycorrhizal fungi and phosphorus solubilizing bacterial inoculants on soil P uptake and biomass accumulation by OFSP varieties.

3. To assess the performance of OFSP varieties inoculated with elite AMF in a field trial.

1.4: Hypotheses

1. The sweetpotatoes rhizosphere harbors highly effective AMF symbiosis to meet soil P nutrition requirement of sweetpotato.

2. Mixed (dual) inoculum containing effective AMF and PSB cultures would enhance growth of OFSP and improve soil P nutrition.

3. AMF inoculation increases crop yields and reduces fertilizer requirements.
2.1: History of sweetpotatoes

Sweetpotato (*Ipomoea batatas*) is a dicotyledonous plant that belongs to the family Convolvulaceae. It is large, starchy and has sweet tasting tuberous roots that are economically important. The plant is a herbaceous perennial vine bearing alternate heart-shaped or palmately lobed leaves and medium-sized sympetalus flowers. Sweetpotatoes are native to Central America and are one of the oldest vegetables known to man. They have been consumed since prehistoric times as evidenced by sweetpotato relics dating back 10,000 years that have been discovered in Peruvian caves (Woolfe, 1992).

Christopher Columbus brought sweetpotatoes to Europe after his first voyage to the New World in 1492. By the 16th century, they were brought to the Philippines by Spanish explorers and to Africa, India, Indonesia and southern Asia by the Portuguese. Around this same time, sweetpotatoes began to be cultivated in the southern United States, where they still remain a staple food in the traditional cuisine. In the mid-20th century, the orange-fleshed sweetpotato was introduced to the United States and given the name "yam" to distinguish it from other sweetpotatoes. Sweetpotatoes are a featured food in many Asian and Latin American cultures. Today, the main commercial producers of sweetpotatoes include China, Indonesia, Vietnam, Japan, India and Uganda among other countries (Woolfe, 1992).

2.2: Production and utilization of sweetpotatoes

Sweetpotato is cultivated in over 100 developing countries and ranks among the five most important food crops in over 50 of them. Its production occurs in a wide range of agro-ecological zones in West, East, Central and Southern Africa. However, cultivation is more intense in the highlands of East and Central Africa, in a diverse set of environments located
between 800m and 1900m (Scott and Ewell, 1992). As a crop it has received intense focus globally in an effort to realize its full potential as a source of food, feed, processed products, and income for millions of small farmers and low-income consumers in Africa, Asia, and Latin America. Hence, increasing sweetpotato production and utilization is often considered as a means to improve income and food security among the poorer segments of the rural population (Scott and Ewell, 1993).

In Africa, sweetpotato is the second most important root crop after potato and its production is mainly concentrated in the East African countries around Lake Victoria where it plays significant roles in the farming systems. It has a short growing period; it stores well in the soil, performs well in marginal lands and is therefore recognized as an ideal crop for food security (Kapinga et al., 2007). In Kenya, root and tuber crops are important food crops that have gained increased importance due to their role in food security, ability to withstand drought as well as their potential for commercial processing (GoK/MoA, 2010).

Based on the agro-climatic conditions, the highland districts around Lake Victoria in Western Kenya should be a food surplus area, but in practice, the region is highly dependent on food imports (Ndufa et al., 2005). Sweetpotato as a crop has low input demand and is drought tolerant hence is a food security crop and has high nutritive value (GoK/MoA, 2010). The total area under this crop was about 77,821Ha producing 930,784tonnes in 2009 (FAOSTAT, 2009) with marginal changes in hectares from year to year. However, there has been a steady increase in yields to due to improved cultivars and farming practices (GoK/MoA, 2010).

Sweetpotato cultivars differ from one another in the colour of the root skin (white, cream, brown, yellow, red or purple) or flesh colour (white, cream, yellow, orange or reddish purple); in the size and shape of the roots and leaves, in the depth of rooting, time to maturity, resistance to diseases and in the texture of the cooked roots (Woolfe, 1992). The yellow and orange fleshed sweetpotato varieties are a good source of vitamin A that is frequently lacking
in the diets of most African farming communities (CIP, 1999). The orange fleshed sweetpotato varieties can also be processed into juice or composite flours that can be used in making baked products and weaning foods. The leaves are used as a vegetable and the vines are a high protein fodder source for animals (Ndolo et al., 1997; CIP, 2000; GoK/MoA, 2010). Due to health concerns by the consumers and the subsequent improvement of its food value in some varieties, its utilization as a snack and for breakfast is on the increase especially in urban areas (GoK/MoA, 2010). It also has potential as a raw material for the manufacture of a wide range of industrial products (Woolfe, 1992).

Most producers are small-scale farmers who grow the crop mainly for home consumption and sell the surplus in local markets (Mutuura et al., 1992; Carey et al., 1999). However, a few areas in the Lake Victoria basin and the Kibirigwi irrigation scheme in the Central highlands have specialized in commercial production for sale to distant urban markets (Low, 1996; Carey, 1999). In most cases, sweetpotatoes are planted during the long rainy seasons in March, April and May and in the short rainy seasons in September, October and November (Ngunjiri et al., 1993). In some regions, however, planting is carried out almost continuously throughout the year whenever rain is sufficient (Mutuura et al., 1992; Ngunjiri et al., 1993).

As an important food security crop, sweetpotato can be harvested piecemeal as needed, thus offering a flexible source of food and income to the rural households that are mostly vulnerable to crop failure and fluctuating cash income (Ndolo et al., 1998).

2.3: Sweetpotato production constraints

Sweetpotato productivity is limited by both abiotic and biotic constraints that lead to poor yields at farm level. These include low soil fertility and drought, shortage of improved varieties, shortage of planting materials, pests and diseases particularly viruses, post-harvest problems such as storages and market availability and demand as well as low socio-economic
status in some communities (Kapinga et al., 2007). About 95% of the increase in the global human population takes place in the tropics, in sub-Saharan Africa. This has put pressure on the agricultural land leading to a faster rate of decline in soil fertility in the region (Hartemink, 2003). Declining soil fertility may result in nutrient deficiencies because of nutrient depletion and imbalances or an increase in some toxic substances e.g. aluminium due to severe soil acidification (Hartemink, 2003). This greatly affects the productivity of a land use system and dwindling crop yield is the most noticeable result. Diseases e.g. the sweetpotato virus disease results in losses of between 20-80% (Gichuki et al., 2001). Insect pests are also a problem in sweetpotato production and the most important one is the sweetpotato weevil.

Most rural households in Africa are dependent on agriculture for an important part of their livelihood. However, land degradation and soil fertility depletion in smallholder farms are serious threats- the fundamental biophysical root cause of declining per capita food production (Sanchez et al., 1997) and a major cause of poverty among rural households (Krishna et al., 1994). Neither phosphorus nor nitrogen levels are sufficient for even moderate agricultural performance (Shepherd and Soule, 1998) therefore intensifying and diversifying land use with high value products is one of the basic requirements for increasing per capita agricultural production (Sanchez et al., 1997).

2.4: The Soil as a living habitat

Soil is a reservoir of biodiversity, particularly with respect to the diversity of microbial communities. These microorganisms are essential in the functioning and sustainability of all natural ecosystems but unfortunately they are frequently ignored because of their small size and the difficult methodologies involved in studying them (Prosser, 2002) These soil microbial populations are involved in interactions that are known to affect plant fitness and
soil quality, thus ensuring the stability and productivity of both agricultural and natural ecosystems (Barea et al., 2005). Soil is a storehouse of nutrients and energy for organisms living in soil including plants. Transformations of nutrients in forms that can be used by plants are carried out by a diverse group of soil organisms including nematodes, protozoa, springtails, mites, earthworms, millipedes, fungi, bacteria and cyanobacteria. Plant life is the primary energy source that drives terrestrial soil ecosystems. Plant residues and roots release various organic materials into the rhizosphere and these carbon-containing substances act as a fuel for the growth of the microbial community (Nayyar, 2009). Plants thus play an important role in influencing the number, diversity and activity of microorganisms and the interactions among these, plant root and the soil. The microbial community in the vicinity of roots can ultimately influence health, vigour and productivity of the plant (Nayyar, 2009).

Rhizosphere microbial communities can influence ecological processes such as nutrient acquisition and fitness of plants through interaction with each other. Mycorrhizal fungi and Plant Growth Promoting Rhizobacteria (PGPR) are typical beneficial organisms that are capable of influencing changes in rhizosphere functioning (Barea et al., 2002b; Suresh and Bagyaraj, 2002; Azcón-Aguilar and Barea, 1992). It is well known that a considerable number of bacterial species most of which are associated with the plant rhizosphere are able to exercise a beneficial effect upon plant growth (Rodriguez et al., 2006). This group of bacteria are termed plant growth promoting rhizobacteria (PGPR) and there are several strains from genera such as Pseudomonas, Bacillus, etc (Bashan and Holgrin, 1998).

Mycorrhizal fungi provide an essential link between plants and the soil environments and are therefore critical to any rhizosphere studies (Timonen and Marschner, 2005). Mycorrhizae formation modifies the root system metabolism by changing the chemical and mineral composition of root exudates that are released into the soil (Timonen and Marschner, 2005; Azcón-Aguilar and Barea, 1992). This mycorrhizal-induced change can affect microbial
populations in the rhizosphere or rhizoplane (Barea et al., 2002b; Azcón-Aguilar and Barea, 1992). Söderberg et al., (2002) stated that the effect of mycorrhizal fungi on rhizosphere bacterial population varied with different plant species because of differential plant exudation patterns in the soil. Hence mycorrhizal fungi form a unique part of the rhizosphere and contribute to rhizodeposition dynamics (Fillion et al., 1999). Thus the microbial community in the vicinity of roots can ultimately influence health, vigour and productivity of the plant (Nayyar, 2009). Beneficial microorganisms such as soil born-symbionts arbuscular mycorrhizal fungi provide minerals to plants and are directly implicated in crop production. They colonize the root cortex biotrophically then develop an external mycelium which is a bridge connecting the root with the surrounding soil microhabitats. Mycorrhizal symbioses can be found in almost all ecosystems worldwide to improve plant fitness and quality through key ecological processes (Barea et al., 2005).

2.5: Arbuscular Mycorrhizal Fungi

2.5.1: Taxonomy, Description and Distribution of AMF

Arbuscular mycorrhizal fungi are obligate symbiotic fungi and endosymbionts of a variety of plants within the Angiosperms, Gymnosperms and Pteridophytes (Steinberg and Rillig, 2003; Smith and Read, 1997) belonging to the Division Glomeromycota (Schüßler et al., 2001). Their evolution dates back 460 million years ago from fossil records of the Ordovician age which suggest that they played a crucial role in colonization of most terrestrial plants (Brundrett, 2002; Redecker et al., 2000; Smith and Read; 1997). The taxonomy of AM fungi has been based on morphological and anatomical characteristics of their spores. However, other modern techniques such as serology, isozyme variation revealed by electrophoresis (Hepper et al., 1988), fatty acid variation (Bentivenga and Morton, 1994) and DNA based methods (Helgason et al., 1999, Schüßler et al., 2001, Morton and Redecker, 2001) have aided in a clearer phylogenetic analysis than was possible using morphological and
microscopic identification. AM fungi have three major components: the root itself which provides carbon in the form of sugars to the fungus, fungal structures within cortical cells of plant root that provide contact between fungus and the plant cytoplasm and the extraradical hyphae that aid uptake of nutrients and water (Smith and Read, 1997). Arbuscular mycorrhizal fungi are so named because they produce fine tree-like hyphal structures (Figure 1) termed “arbuscules” that occur within the root cortical cells of plants. They are responsible for the exchange of carbon needed for energy and nutrients after close contact is made with the host cell (Hodge, 2000). Vesicles (Figure 1) serve as carbon storage compartments for the fungi and are rich in lipids.

Figure 1: Diagrammatic representation of the characteristic structures of AMF as identified in the cortical cell of a host plant when viewed under a microscope (Adapted from Ike-Izundu, 2007).

The development of vesicles depends on environmental conditions such as high or low P levels (Smith and Read, 1997). Other important structures of AM fungi involved in the colonization of roots are intraradical hyphae (IRH) extraradical hyphae (ERH) and extraradical auxiliary cells. The distribution of AMF is worldwide in almost every terrestrial ecosystem and is affected by several environmental factors (Rillig, 2004a). They have since become a subject of interest for many scientists and with the realization that members of this
group are the most common soil fungi that can be obtained from any soil type (Koide and Mosse, 2004; Smith and Read, 1997).

2.5.2: Reproduction and Life cycle of AMF

Arbuscular mycorrhizal fungi propagate in soil as spores, hyphae or colonized root fragments. The spores of AMF are unique from other fungal spores and are able to perform differential functional roles such as mitosis of rich nuclei (Maria-Laura, 2002). Reproduction in AM fungal spores is solely asexual as there is no evidence to prove that it reproduces sexually (Pawlowska and Taylor, 2004; Smith and Read, 1997). Spores of AMF under favourable environmental conditions germinate and undergo a sequence of steps that are based on structural morphogenesis though poorly understood biochemically (Barker et al., 1998). These stages have been categorized into the asymbiotic, pre-symbiotic and the symbiotic stages (Bago and Becard, 2002). In the asymbiotic stage, sometimes referred to as the resting stage, the AM fungal spores are produced in the soil naturally by the extraradical hyphae after symbiotic association with the host plant (Bago and Becard, 2002; Nagahashi, 2000). These dormant spores (Figure 2) may remain alive in the soil for one or even two years and dormancy periods of spores differ between species and genera (Giovannetti, 2000).
For instance spores of *Gigaspora margarita*, when collected from sand dunes, showed no dormancy and were able to germinate after 3-5 days incubation on water agar or on any media without storage preservative. The differences between genera are characterized by changes in cellular events such as cytoplasm activity and biochemical changes in the fungus metabolism. This results in varying modes of germination, which may be through the spore wall or from a germination shield (Giovannetti, 2000). Factors such as pH, temperature, moisture, carbon dioxide and organic nutrients are likely triggers that relieve spore dormancy. The resting stage has been reported to be host independent as AM fungal spores contain energy reserves (stored lipids and carbohydrates) and are not only carriers of genetic material (Giovannetti, 2000; Bago and Becard, 2002; Smith and Read, 1997). These energy reserves, which occur in the form of lipid droplets and trehalose, are put into action during spore germination to sustain the initial growth of the germ tube (Smith and Read, 1997). In case the presence of a host is delayed, germination ceases rapidly before the energy reserves are
depleted or the cytoplasm is retracted within the spore (Redecker, 2005; Bago and Becard, 2002). In the second stage, germinated spores grow toward the host root by producing hyphal branches. This occurs before the formation of structures such as appressoria that occur on the host root epidermal cell walls (Nagahashi, 2000; Giovanetti, 2000). An appressorium is a hyphal tip enlargement that attaches to the root surface of the host (Nagahashi and Douds, 1997). This stage is referred to as pre-symbiotic because a one-on-one contact between the root and fungus is not required for stimulation of hyphal branches, but rather, the influence of some root exudates such as organic acids, amino acids, carbohydrate monomers, phenolics, or volatiles compounds (Jones et al., 2004). Plant hormones such as auxins are thought to play a vital role at this developmental stage of mycorrhizal colonization because auxins are found in high concentrations during appressoria formation (Ludwig-Müller, 2000). The third stage, the symbiotic stage, refers to the penetration and development of the IRH and the formation of arbuscules in the cortex of roots (Figure 2). The ERH growth arises after arbuscules formation and is characterized by the release of spores into the soil. Though the AM fungal hyphae are involved in different synthesis and phases, it is at this stage that there is a bidirectional exchange of carbon (C) and nutrients between the fungus and the plant (Saito, 2000; Nagahashi, 2000). In the IRH phase, the intraradical hyphae are surrounded by the host plasma membrane and have specificity for hexose (carbon source) uptake that is transported from the plants to the fungus. While in the ERH phase, the hyphae develop within the soil substrate and facilitate the uptake of phosphorus (P) and other nutrients. Lipid synthesis carried out in the internal hyphae are metabolized and transported to the ERH phase, where they will be utilized and stored in newly formed spores (Bago et al., 2000; Douds et al., 2000). These new spores, when mature germinate and use stored C as an energy source to re-initiate the AM fungal life cycle (Figure 2). However, when there is a non-existent carbon metabolism due to the absence of a host for a long period of time, the fungus fails to
complete the cycle and enters a sporulation phase where reproduction is carried out asexually pending favourable germination conditions and maturity (Azcón-Aguilar et al., 1999; Bago and Becard, 2002). It is the root colonization that brings about the symbiotic interaction; but the benefits of root colonization are dependent on the survival of the AM fungal propagules particularly, the spores (Xavier and Germida, 2003). Two types of AM colonization as described by Gallaud in 1905 based on the structures of the intraradical hyphae are identified i.e. the Paris-type and the Arum-type (Brundrett, 2004; Brundrett et al., 1996). In the Arum-type of colonization, intercellular hyphae run along longitudinal channels between cortical cells in a linear form before entering the cortical cells to form arbuscules. In the Paris-type of colonization, the intracellular hyphae grow as coils within cortical cells. It has been suggested that these morphological types of AM structures, though they have similar percentage root colonization, differ in the sites where metabolic activity is carried out. In the Arum type of colonization, the arbuscules are the main sites for nutrient release while in the Paris-type both hyphal coils and arbuscules may be involved (Van Aarle et al., 2005). AMF species are non-specific in their relations with the host plants. However, different species can colonize a vast range of both herbaceous and woody plants but not all of these species have the same effect (Smith and Read, 1997). Specificity, infectivity and effectivity are the three major parameters in determining root colonization. Specificity refers to the ability of the fungus to colonize root cells of particular plant species, infectivity, the amount of colonization and effectivity, the plant’s response to colonization (Sylvia et al., 1998).
2.6: Symbiotic benefits of AMF

Approximately 80% of plant families from all phyla of land plants except those belonging to the Cruciferae and Chenopodiaceae are identified as hosts of AMF which colonize their roots by forming intercellular and intracellular hyphae and intracellular arbuscules (Smith and Read 1997). Demonstration that AMF are capable of increasing productivity in mycorrhizal plants compared to non-mycorrhizal plants has created much interest in AMF symbioses in agriculture, forestry and rehabilitation of environments where practices have altered the soils’ native state (Friberg, 2001; Cuenca et al., 1998). The major benefits of AMF to host plants include:

2.6.1: Nutrient uptake

Plants require macro- and micronutrients for growth in varying amounts. Micronutrients are usually required in moderate quantities and are likely to result in toxicity disorders when present in high levels or deficiencies when present in very low levels (Ashman and Puri, 2002). Various levels of micronutrients have been reported to affect the yield of crops such as rice, wheat and legumes (Johnson et al., 2005). AMF are known to enhance mainly the uptake of the macronutrient phosphorus (P) from the soil, which is then translocated to the host plant through the hyphal networks in the soil. Their ability to take up other micronutrients such as Copper (Cu), Zinc (Zn), Nickel (Ni), Lead (Pb) and Iron (Fe) etc; has been demonstrated by researchers using different host plants and soil type management (Ike-Izundu, 2007). They also have the ability to sequester these nutrients and minimize their transfer to the plant roots when nutrients are in high concentrations though the mechanism has not been proved (Turnau et al., 1993). The solubility and mobility of phosphorus in the soil is low, making it difficult for plants to readily utilize it in either organic or complex inorganic forms (Schachtman et al., 1998). In such cases, AMF intervene to enhance nutrient
uptake through the spread of their extraradical hyphae into the surrounding soil and hydrolyzing any unavailable sources of P with the aid of secreted enzymes such as phosphatases (Carlile et al., 2001; Koide and Kabir, 2000; Amaranthus, 1999). Liu et al., (2000) showed that the uptake of copper, zinc, manganese and iron by AMF in maize was significantly influenced by the soil P nutrition and as such the use of AM inoculum instead of some chemical fertilizers for plant productivity, growth and restoration of polluted soils or in revegetation has been suggested (Cardoso and Kuyper, 2006; Khan, 2006; Quilambo, 2003).

2.6.2: Drought tolerance

Studies by Augé, (2001) and Davies et al., (1993) showed that along with accessing soil nutrients, the AMF hyphal network allows greater access to water through mechanisms like stomatal regulations, increased root hydraulic conductivity, osmotic adjustments and maintenance of cellular water pressure and cell wall elasticity changes. Amerian and Stewart (2001) observed that mycorrhizal infection of maize with *Glomus mosseae* and *Glomus intraradices* helped the plant to maintain higher leaf water potential compared to non-mycorrhizal plants. Goicoechea et al., (1997) while working with *Glomus fasciculatum* and *Rhizobium* to investigate relationships between nutrient content and water in alfalfa observed that plants inoculated with AMF had the highest leaf nutrient maintenance under drought stress. Other studies have also shown the capability of AMF to influence plant growth, crop quality and adaptability to stress conditions (Mena-Violante et al., 2006; Fagbola et al., 2001, Tobar et al., 1994).
2.6.3: Tolerance to plant root pathogens

The colonization of plant roots by AMF has been suggested to increase plants tolerance to pathogens thereby acting as biocontrol agents (Azcón-Aguilar and Barea, 1996). A biocontrol agent is a biologically friendly resource from the ecosystem that is capable of protecting plants against pathogens (Azcón-Aguilar et al., 2002; Azcón-Aguilar and Barea, 1996). There are several mechanisms or combination of them accounting for bio protection of plants by AMF. Primarily, the ability of AMF to enhance plant vigour due to increased nutrient uptake enables it to resist pathogen infection. Such pathogens can be root-infecting fungi that are antagonistic and capable of feeding on their host as necrotrophs. Wilt pathogens such as Fusarium oxysporum, or root rotting pathogens like Phytophthora and Rhizoctonia that are common soil borne pathogens (Smith, 1988). This interaction of AMF with the soil root pathogens and with the enhanced nutritional uptake of P and other nutrients increases the plant's tolerance to pathogens through mechanisms such as alteration of root exudates, increased root growth and function and competition for space or infection sites (Smith, 1998). AMF increased the nutritional status of plants and thus increase tolerance to root pathogens but there was no effect observed on the development of leaf diseases in maize caused by Helminthosporium maydis and Acremonium kiliense (Chhabra et al., 1992). Microbial and anatomical changes in the mycorrhizosphere induced by AMF formation may bring about stimulation of specific functional groups in the micro biota that are antagonistic towards pathogens (Azcón-Aguilar et al., 2002; Sylvia et al., 1998; Azcón Aguilar and Barea, 1996; Linderman, 1994). Mukasa-Mugerwa (2005) studied biocontrol potential of AMF inoculant on Fusarium using different maize cultivars and showed an increased tolerance to the pathogen. Lignifications caused by AMF colonization involve the thickening of the exodermis and cortical root cell walls making penetration of pathogenic hyphae difficult because of the anatomical changes in the root structure (Cordier et al., 1996; Dumas-Gaudot
et al., 2000). Accumulation of phenols from AMF colonization has been reported to cause both localized and systemic resistance to some pathogens. Zhu and Yao (2004) examined the inhibition of *Ralstonia solanacearum* by *Glomus versiforme* when both were inoculated in tomato roots. Soluble phenol contents in the tomato roots were increased whereas the population of *Ralstonia solanacearum* in the rhizosphere and in the xylem tissues decreased. In another study, Pozo et al., (2002b) used tomato plants and observed that *Glomus mosseae* reduced the infection of the pathogen *Phytophthora parasitica* in tomato roots.

### 2.6.4: Soil aggregation

AM fungi secrete a glue-like proteinaceous water soluble and heat stable substance from their hyphae called glomalin that improves soil structure (Steinberg and Rillig, 2003). Glomalin aids in soil aggregation by binding soil particles together thereby influencing soil porosity, which promotes aeration and water movement, essential for good root growth, root development and microbial activity (Amaranthus, 1999). The positive correlation between glomalin, land-use and soil carbon-nitrogen ratio gives it a benefit in assessing the changes in soil carbon under various land-use types, hence regarded as an indicator for soil aggregation and stability (Rillig et al., 2003). Glomalin can be easily assayed and cannot be produced from uncolonized plant roots as it is AM fungal specific thus can be used to determine AMF hyphal growth and activity in the soil (Lovelock et al., 2004a; Rillig et al., 2001; Wright and Upadhyaya, 1998).

### 2.6.5: Tolerance to toxic metals

The toxicity of metals depends on the concentrations in which they are present in the soil (Smith and Read, 1997). These metals can arise from a variety of sources in the form of acid rain, dust containing these metals, wash waters from polluted soils or from atmospheric
factors produced as a result of mining, smelting, burning of fossil fuels, industrial or
ground-level activities and incineration of municipal waste (Gaur and Adholeya, 2004). The
level at which heavy metals such as zinc (Zn), cadmium (Cd), aluminium (Al), copper (Cu)
and lead (Pb) affect plants and mycorrhizal fungi varies and is usually dependent on their
concentration, oxidation state in the soil, soil pH, organic matter content, cation exchange
capacity and redox potential (Entry et al., 2002). AMF alleviate plant stunting caused by
toxic metals by binding to these metals in the root zone with the aid of the extraradical
mycelium and altering the plant cells ability to capture the metals through the production of
polyphosphates (Smith and Read, 1997; Turnau et al., 1993). Khan (2003) reported the
potential use of AMF in detoxification of heavy metal polluted environments and in
phytoremediation. However in such processes, selection of AMF species with appropriate
phytobionts is of great importance (Entry et al., 2002).

2.7: Phosphorus solubilizing Microorganisms

Phosphorus solubilizing microorganisms refer to a group of soil microorganisms that as
components of the phosphorus cycle are able to release it from insoluble sources by different
mechanisms (Salehrastin, 1999). Soil microbial populations are immersed in a framework of
interactions in the rhizosphere where they are known to affect plant fitness and soil quality.
Through their activities, they ensure the stability and productivity of both agricultural
systems and natural ecosystems (Barea et al., 2005). A considerable number of bacterial
species mostly associated with the rhizosphere are able to exert beneficial effects on plant
growth and as such, their use as inoculants or control agents in agricultural improvement has
been of great focus (Rodriguez et al., 2006). This group of bacteria is collectively termed
plant growth promoting rhizobacteria (PGPR) (Bashan and Holgrin, 1998) and there are
several strains derived from different genera such as Pseudomonas, Bacillus, Erwinia and
In the soil, there are several microorganisms which can solubilize the cheaper sources of P. These organisms solubilize the bound P and make it available to the plant resulting in improved growth and yield of crops (Diriba, 2007). Phosphate solubilizing microorganisms solubilize insoluble phosphates in the rhizosphere and thus enhance nutrient availability to the plants (Richardson, 2001; Rodriguez et al., 2006). These organisms secrete organic acids and phosphatases that convert insoluble phosphates into soluble monobasic (\(H_2PO_4^-\)) and dibasic (\(HPO_4^{2-}\)) ions, the forms which plants take up (Vessey, 2003; Vance et al., 2003). Phosphorus solubilizing bacteria are such soil organisms that play a major role in phosphorus nutrition by enhancing its availability to plants through release from the soil pools by solubilization and mineralization. Bacteria are more effective in phosphorus solubilization than fungi (Alam et al., 2002). Among the soil bacterial communities, ectorrhizospheric strains from Pseudomonas and Bacillus, and endosymbiotic rhizobia have been effective in phosphorus solubilization (Igual et al., 2001). According to Whitelaw (2000), strains from the bacterial genera Pseudomonas, Bacillus, Rhizobium and Enterobacter along with Penicillium and Aspergillus fungi are the most powerful solubilizers.

2.8: Mechanism of phosphate solubilization by the phosphate solubilizing bacteria

The involvements of microorganisms in solubilization of inorganic phosphates dates back as early as 1903, and in general, P solubilizing bacteria commonly out-number P solubilizing fungi (Kucey et al., 1989). Some bacterial species have mineralization and solubilization potential for organic and inorganic phosphorus, respectively (Hilda and Fraga, 2000; Khiari and Parent, 2005). Phosphorus solubilization is carried out by a large number of saprophytic bacteria and fungi acting on sparingly soluble soil phosphates, mainly by chelation-mediated mechanisms (Whitelaw, 2000). Phosphorus solubilizing activity is determined by the ability of microbes to release metabolites such as organic acids, which through their hydroxyl and
carboxyl groups chelate the cation bound to phosphate, the latter being converted to soluble forms (Sagoe et al., 1998). Solubilization of insoluble phosphates in the rhizosphere is one of the most common mode of action of bacteria. Phosphate solubilizing bacteria (PSB) secrete organic acids and phosphatases that convert insoluble phosphates into soluble monobasic ($H_2PO_4^-$) and dibasic ($HPO_4^{2-}$) ions in the process termed solubilization (Taurian et al., 2010). Phosphorus solubilization ability of PSB has direct correlation with pH of the medium. Release of root exudates such as organic ligands can also alter the concentration of P in the soil solution (Hinsinger, 2001). Organic acids produced by PSB solubilize insoluble phosphates by lowering the pH, chelation of cations and competing with phosphate for adsorption sites in the soil (Nahas, 1996). In certain cases phosphate solubilization is induced by phosphate starvation (Gyaneshwar et al., 1999). Solubilization of iron (Fe) and aluminium (Al) occurs via proton release by PSB thus decreasing the negative charge of adsorbing surfaces to facilitate the sorption of negatively charged P ions. Proton release can also decrease P sorption upon acidification which increases $H_2PO_4^-$ in relation to $HPO_4^{2-}$ having higher affinity to reactive soil surfaces (Whitelaw, 2000). Carboxylic acids mainly solubilize Al-P and Fe-P (Henri et al., 2008; Khan et al., 2007) through direct dissolution of mineral phosphate as a result of anion exchange of $PO_4^{3-}$ by acid anion, or by chelation of both Fe and Al ions associated with phosphate (Omar, 1998). Moreover, carboxylic anions replace phosphate from sorption complexes by ligand exchange (Whitelaw, 2000) and chelate both Fe and Al ions associated with phosphate, releasing phosphate available for plant uptake after transformation. Ability of organic acids to chelate metal cations is greatly influenced by its molecular structure, particularly by the number of carboxyl and hydroxyl groups. The type and position of the ligand in addition to acid strength determine its effectiveness in the solubilization process (Kpomblekou and Tabatabai, 1994).
Beneficial plant-microbe interactions in the rhizosphere are the primary determinants of plant health and soil fertility (Jeffries et al., 2002). The rhizosphere of mycorrhizal plants (mycorrhizosphere) harbours a great array of microbial activities responsible for several key ecosystem processes (Barea et al., 2002). Within the mycorrhizosphere, AMF interact positively with various types of rhizobacterial communities that have proven agronomic and/or ecological significance including symbiotic free-living nitrogen fixing bacteria, PSB, heavy metal detoxifying bacteria, microbial control agents and microbes that are involved in soil aggregate formation. Mycorrhizal formation changes several aspects of plant physiology and some nutritional and physical properties of the rhizospheric soil (Barea et al., 2002) resulting in alteration of the microbial composition of the rhizosphere (Hodge and Campbell, 2001). The extraradical hyphae of mycorrhizal fungi act as root extensions and draw phosphorus from soil to supply it to plants (Zapata et al., 2009). There is vast evidence reporting an increase in phosphorus concentration in mycorrhizal plants (Smith and Read, 1997; Pasqualini et al., 2007; Yao et al., 2008). However, growth and/or yield responses to mycorrhizal fungi could range from negative to positive depending on the development stage and the availability of phosphorus in the soil (Li et al., 2005). In the rhizospheric soil, the AMF develop a hyphal network that serves as a fundamental link between the soil, nutrient reservoir and the plant. When a nutrient is deficient in soil solution, the critical root parameter controlling its uptake is surface area. Hyphae of mycorrhizal fungi have the potential to greatly increase the absorbing surface area of the root, thus the hyphal network is more efficient for ion uptake than the root hairs (Dorneless et al., 2001). Exploration of large soil volume, faster movement of phosphorus into hyphae and solubilization of the relatively immobile phosphorus sources (Hetrick, 1989) are reported as the mechanism for increased phosphorus uptake by mycorrhizal plants. Mycorrhizal fungal hyphae contribute to
absorption and translocation of phosphorus from sites in the soil that are not accessible to plant roots. In phosphorus fixing soils, phosphorus deficiency is mainly caused by strong adsorption of \( \text{H}_2\text{PO}_4 \) to aluminium (Al) and iron (Fe) oxide or hydroxides, which turn large proportions of total phosphorus into forms that are unavailable to plants. This synergistic interaction between the mycorrhizal fungi and phosphorus solubilizing bacteria play a major role in phosphorus availability to mycorrhizal plants.

2.10: Effects of agricultural practices on Soil microbial populations

Different agricultural and management practices, such as fallowing, affect AM fungi in their native state, which in turn affects the establishment and improvement of AM fungal inoculum for sustainable crop production. Such practices remove potential host roots where the fungus derives its energy thereby decreasing root colonization of the subsequent host crop (Thompson, 1994a). Crop rotation practices are also to be considered in that the colonization potential of AM fungi in the soil will depend on the previous crops. If previous crops are non-mycorrhizal for example canola, or produce non-mycorrhizal toxic compounds as a result of root structure and physiology, this can lead to a reduction in AM fungal infective propagule density (Kling and Jakobsen, 1998).

Soil disturbances such as tillage and harrowing are also known to have an effect on AM fungal propagules and the extraradical hyphae. These methods involve stirring, leveling, or breaking of soil clumps in preparation for growing plants. Because AM fungal propagules, such as spores and active hyphae, are predominantly found in the topsoil, this activity hinders the ability of these propagules to germinate and colonize new host roots, which in turn affects the production and transport of nutrients to the plant at an early developmental stage (Kabir, 2005; Kling and Jakobsen, 1998). Studies by Jansa et al., (2002) showed that there is indeed a deleterious effect of tillage on the population and diversity of AM fungi compared to non-till
Therefore, the reduction in intense tillage favours AM fungal management in soils (Thompson, 1994a) thereby enhancing colonization potential of plants and subsequent environmental benefits. Soil tillage affects the distribution of mycorrhizal fungi propagules in the soil thus reducing root colonization and early plant phosphorus uptake as the hyphal network remaining from the previous crop is disrupted (Evans and Miller, 1990). However, with a high inoculum density soil disturbance has no effect on mycorrhizal fungi colonization of plants. Mineral and organic phosphorus fertilizers decrease colonization and soil infectivity of mycorrhizal fungi (Planchette et al., 2005). The fate of organic or inorganic phosphate fertilizers when applied to soil is reported to be determined by biogeochemical processes. These include immobilization, solubility and adsorption (Compton and Cole, 2001) that may be dependent on the soil pH and soil type (Rodriguez and Fraga, 1999). Immobilization is the conversion of inorganic phosphates that are available to plants into an unavailable organic form by biochemical or microbial processes, while the reverse is termed mineralization. P fertilizers are mainly applied to increase P levels when deficient in soils or to maximize plant growth (Xu et al., 2000). Fertilizers when applied, undergo precipitation-dissociation reactions, which are then solubilized into the soil mineral solutions. These solutions bind to the soil particles which become readily available and absorbed by plant tissues. If not present in soil as solutions, it can be in the active or fixed pool P (Busman et al., 2002). The active P in soil is usually in the solid phase and can easily be released into soil solution. It replenishes P in the solution pool based on crop utilization, while the fixed pool contains organic and inorganic forms of P that are insoluble and resistant to mineralization (Busman et al., 2002). Owing to the high influence of host P demand on AM fungi, application of fertilizers has a great impact on the plant-fungus relationship (Gosling et al., 2006). The effect of fertilizers on AM fungi has been well studied using pot trials (Xu et al., 2000, Braunberger et al., 1991). These studies have shown that the increasing use of P
fertilizer led to the high P pool in soils. These high P levels affect AM fungi root colonization and minimize growth performance by decreasing the nutrient acquisition role of AM fungi. Azcón et al., (2003) showed that increased P fertilization reduced the fraction root length containing arbuscules, which was due to inhibition of intraradical hyphae development. Similar results were obtained by Martensson and Calgren (1994) in a field experiment, who observed a 50% decrease over five years in spore numbers of AM fungi even when P fertilizers were applied in moderate amounts of 45 kg ha⁻¹ year⁻¹. However, when P fertilization was excluded, spore density doubled within 5-14 years and was three times the amount after 28 years of experimental establishment. A meta-analysis study which involves statistical analysis of fertilizer effects from various studies was conducted by Treseder (2004). The results on the effect of P fertilizers such as super-phosphate (Ca(H₂PO₄)₂) and N fertilizers (containing NaNO₃, NH₄NO₃ and NH₄NO₃ mixed urea) on AM fungi, reported a reduction in mycorrhizal abundance (percentage colonization, spore counts, hyphal length) by an average of 32% and 15% respectively (Treseder, 2004). This percentage response varied with the initial soil nutrients present resulting in inconsistencies of N and P fertilizer effect. Conversely, studies by Podeszinski et al., (2002) reported that some species of AM fungi such as Gl. magarita and Scutellospora calospora are able to survive high or low P levels. This could mean that fertilization can lead to selective AM species that may be of little benefit to the host in terms of effective nutrient uptake (Gosling et al., 2006). Organic sources of fertilizers such as farmyard manure, compost and animal faeces have been reported to have no negative effect on AM fungal colonization (Kabir et al., 1998). Studies by Douds et al., (1997) observed an increase in spore population of two AM fungal species, Gl. etunicatum and Gl. mosseae using chicken or litter compost when applied alone. In another study, Harinikumar and Bagyaraj

29
(1989) observed that the co-application of farm yard manure with varying levels of N, P or K fertilizers reduced AM fungal propagules. These varying results led to the conclusion that the use of organic manure solely or together with inorganic fertilizers is dependent on manure source, addition rate and perhaps the rate of decomposition of fertilizers (Kurle and Pfleger, 1994). Soil water conditions also affect mycorrhizal fungi development and phosphorus uptake. Jayachandran and Shetty (2003) studied the impact of mycorrhizal fungi on growth and phosphorus uptake of wet prairie saw grass (*Cladium jamaicense* Crantz). They observed that root and shoot growth and phosphorus uptake were increased in mycorrhizal plants as compared to control plants, and decreasing water content were conducive to mycorrhizal fungi development. Neumann and George (2004) found out that total plant phosphorus content was similar in mycorrhizal and non-mycorrhizal plants under well-watered conditions but phosphorus uptake was twice as high in mycorrhizal plants as compared to non-mycorrhizal plants when the soil is dry. The factors that affect mycorrhizal development directly therefore arise from agricultural practices. They include plant modifications such as breeding, pesticides, growth regulators and seed coating with fungicides. Soil modifications such as fertilization, pesticides tillage and fallow also affect mycorrhizal development (Plenchette et al., 2005). Mycorrhizal dependency not only varies among crops but also among plant varieties. The effects of pesticides particularly fungicides are deleterious on mycorrhizal fungi, although this varies depending on the active ingredient present and the rate at which it is applied (Schreiner and Bethlenfalvy, 1997). Fungicides applied as a seed coating are probably more detrimental to mycorrhizal fungi development than those applied when plants are already mycorrhizal (Plenchette and Perinn, 1992).
CHAPTER 3
MATERIALS AND METHODS

3.1: Site description
The experimental site was KARI-Kakamega Research station, south-east of Kakamega town located on longitude 34° 47' E and latitude 00° 17' N at an altitude of 1585m above sea level. The station is within the Upper Midland one (UM1) agro-ecological zone with well drained deep friable red clays (nitosols) developed on a tertiary or older basic igneous rock. It receives a bimodal rainfall ranging between 1600mm and 2000mm with long rains occurring between April and May and short rains between September and October. It has a mean temperature of 18.5° - 21°C. The experimental plot had a history of cassava cultivation without any chemical fertilization.

3.2: Soil Sampling and Chemical Characterization
Soil samples were taken from KARI-Kakamega Research Station where the field trial was conducted. The plot of approximately two acres was subdivided into four quarters and using an auger, the surface 0-30cm soil was taken from each of the four plots using the point measurement scheme layout (Figure 3).

![Figure 3: Point measurement scheme sampling layout.](image)

Key: • Sampling points (Core). → 3m radius (Inner circle)
                 6m radius (Outer circle)
The soil was homogeneously mixed and a composite sample of approximately one kilogram of soil was taken, placed in plastic sampling bags, labelled appropriately, sealed, and kept in a cool box. The samples were delivered to the University of Nairobi, Department of Land Resource Management and Agricultural Technology (LARMAT), Soil Microbiology laboratory and kept at room temperature. Part of the sample was sieved and analysed for pH, organic carbon, available phosphorus, exchangeable cations, total nitrogen and particle size analysis as outlined in Okalebo et al. (2002). Soil pH was determined by the 1:1.5 ratio of water using six grams of air dried soil sieved through a 2mm sieve. Soil available phosphorus was determined by the double acid method developed by Mehlich (1953) using five grams of air dried soil. Percentage organic carbon was determined by the Walkley-Black (1934) oxidation method. For the cation exchange capacity, the Metson (1961) method was used; the Parkinson and Allen (1975) method was used in the determination of soil total nitrogen and the hydrometer method for the determination of the percentage sand, silt and clay.

Spores were extracted by the Ingleby and Mason (1973) wet sieving and enumerated by counting healthy spores under a dissecting microscope, Leica Zoom 2000. Different morphotypes were recorded depending on colour, size, shape and presence or absence of hyphal attachments. Spores were recorded as representatives of AM fungal species present in 50g of soil sample. In order to describe and identify the AMF species, permanent slides of the extracted spores were prepared following the process developed by Ingleby and Mason (1973). Each of the slides was labelled appropriately and the mounting date stated. The slides were examined under a compound microscope, Leica EC3 at x 400 magnification for wall layers, hyphal features, properties, ornamentation, development features i.e. saccule/scar, germination shield and reaction with Melzer's reagent. Photographs of the spores were also taken on a Leica Application Suite LAS EZ.
3.3: Assessment of effective and infective AMF propagules

To assess the dependency of sweetpotato on mycorrhizae, trapping was done in the greenhouse at the World Agroforestry Centre (ICRAF) to assess the effectivity and infectivity of AMF propagules in the soil sample. Two OFSP varieties Kabode and SPK004 were used as a trap crop and mini cuttings were obtained from the Root and Tuber program at KARI-Kakamega. The mini cuttings were planted in pots filled with 1kg of field soil with six AMF inoculation treatments (no inoculation, *Glomus aggregatum*, *Glomus mosseae*, *Glomus etunicatum*, *Glomus intraradices* and a mixed inoculum containing *Glomus mosseae*, *Glomus etunicatum* and *Glomus intraradices*). The inoculum used comprised of commercial *Glomus* species (*Glomus mosseae*, *Glomus etunicatum*, and *Glomus intraradices*) that was previously sourced from Dudutech by TSBF COMPRO project and *Glomus aggregatum*, an indigenous inoculum sourced from the National Museums of Kenya Mycology Laboratory. AMF inoculation was done at 2g per pot. The pots were grown for five months under greenhouse conditions. Watering was done twice daily using distilled water up to four months and the watering frequency reduced in the fifth month. Fine roots and soil were sampled from each treatment pot at one, two, three and four months for AMF colonization assessment and spore counts. At the end of five months, destructive sampling was done in each treatment pot where root samples and soil was taken for colonization assessment and spore extraction.

The roots were cleared with 2.5% KOH (25g KOH in 1000ml water) by heating in an oven at 70°C for one hour and then rinsed with tap water. To remove phenolic substances, alkaline hydrogen peroxide (60ml of 28-30% NH₄OH, 90ml of 30% H₂O₂ and 840ml distilled water) was added and roots left standing in a hood for twenty minutes. The roots were thereafter rinsed with tap water and acidified with 1% HCl and left for 30 minutes. The HCl was decanted and without rinsing the roots, a staining reagent 0.05% trypan blue in acid glycerol (500ml glycerol, 450ml water, 50ml of 1% HCl and 0.5 g trypan blue) was added and roots
placed in the oven for 1 hour at 70°C. The stain was decanted and a de-staining solution comprising of acid glycerol (500 ml glycerol, 450 ml water, and 50 ml of 1% HCl) was added. Fine root segments were cut into approximately 1 cm-long pieces and 30 pieces randomly picked, mounted on slides and observed under a compound microscope to assess the frequency and intensity of AMF colonization. The presence of arbuscules, vesicles, internal and external hyphae was examined. The frequency of AMF was recorded as the number of root fragments infected with AMF while the intensity of AMF colonization was recorded as percentage cover of AMF infective propagules in each 1 cm root fragment.

3.4: Evaluation of AMF and PSB dual inoculants for P uptake and biomass accumulation

To evaluate the performance of AMF and PSB dual inoculants on P uptake and biomass accumulation in OFSP, a greenhouse experiment was conducted at the World Agroforestry Centre (ICRAF) on pasteurized field soil. AMF inoculants comprised of commercial inoculum obtained from Dudutech Naivasha and indigenous inoculum that was sourced from the National Museums of Kenya (NMK) mycology laboratory. The commercial inoculums were separate single species of *Glomus mosseae*, *Glomus etunicatum* and *Glomus intraradices* in granular formulation containing spores, root fragments and other propagules. The indigenous inoculum was a single strain of *Glomus aggregatum*. The PSB bacterial isolates used were *Azotobacter chrooccocum* and *Pseudomonas fluorescens* obtained from CIP/USAID. Cuttings of two OFSP varieties: Kabode and SPK 004 were obtained from the Roots and Tuber program of KARI-Kakamega and were raised in sterile medium in a greenhouse. A 2 x 3 x 2 x 6 factorial experiment with six treatment levels of AMF, three triple super phosphate (TSP) fertilizer levels, two PSB isolates and two varieties of OFSP (Table 1) was used. This gave a total of 72 treatments that were replicated five times.
### Table 1: Treatment factors applied in the Greenhouse Experiment

<table>
<thead>
<tr>
<th>OFSP varieties</th>
<th>Fertilizer levels</th>
<th>PSB isolates</th>
<th>AMF inoculants</th>
</tr>
</thead>
<tbody>
<tr>
<td>V₁ - SPK 004</td>
<td>F₁ - 0kg/ha</td>
<td>P₁ - Azotobacter chroococcum</td>
<td>I₁ - No inoculation</td>
</tr>
<tr>
<td>V₂ - Kabode</td>
<td>F₂ - 20kg/ha</td>
<td>P₂ - Pseudomonas fluorescens</td>
<td>I₂ - Glomus aggregatum</td>
</tr>
<tr>
<td></td>
<td>F₃ - 40kg/ha</td>
<td></td>
<td>I₃ - Glomus mosseae</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I₄ - Glomus etunicatum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I₅ - Glomus intraradices</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I₆ - I₃ + I₄ + I₅</td>
</tr>
</tbody>
</table>

Field soil collected from KARI-Kakamega was autoclaved at 70°C twice at an interval of 24 hours and allowed to cool. Planting trays (Plates 1 and 2) with dimensions of 27cm by 47cm containing 66 cells, where each cell had a 37.68 cm² volume were used for mycorrhization of the cuttings.

Plate 1: Mycorrhization tray (left) and (right) OFSP cuttings in mycorrhization stage.

Plate 2: In mycorrhization stage SPK 004 (left) and Kabode (right)
AMF inoculation was done at the rate of 66kg/ha (0.059gAMF/cell). The inoculum was mixed with the pasteurized soil and placed in the cells. The inoculum-soil mixture was moistened with distilled water and holes made in readiness for putting the mini cuttings. A total of 360 OFSP cuttings were planted in 10 trays for 8 weeks one cutting in each cell for eight weeks before transferring in bigger pots. Misting using distilled water was done regularly to maintain the humidity. After 8 weeks, the cuttings were transferred into 5 x 9 x 10 cm green polythene bags (Plate 3) of gauge 200 filled with two kilograms of pasteurized soil for another 8 weeks. Watering was done twice daily in the morning and evening using distilled water. The greenhouse had a temperature range of 14.3°C - 28.3°C with a mean relative humidity of 40.7-87.3%.

Plate 3: Sweetpotato plants in polythene bags after mycorrhization stage.

3.5: Field Evaluation of AMF inoculants

A field trial was set up at KARI-Kakamega in a plot where cassava and maize had been grown previously. Land was ploughed before the onset of 2011 long rains and harrowed. AMF inoculants comprised of commercial inoculum obtained from Dudutech Naivasha and indigenous inoculum that was sourced from the National Museums of Kenya (NMK) mycology laboratory. The commercial inocula were single species of *Glomus mosseae*, *Glomus etunicatum* and *Glomus intraradices* in granular formulation containing spores, root
fragments and other propagules. The indigenous inoculum was a single strain of *Glomus aggregatum*. Clean cuttings, free from disease and virus attack of two OFSP varieties: Kabode and SPK 004 were obtained from the Roots and Tuber program of KARI-Kakamega.

A 2 x 3 x 6 factorial experiment with six treatment levels of AMF, three triple super phosphate (TSP) fertilizer levels and two varieties of OFSP (Table 2) was laid in a split-split design with the OFSP varieties in the whole plot, fertilizer in sub-plots and AMF inoculum in sub-sub plot.

Table 2: Treatment factors applied in the Field Trial.

<table>
<thead>
<tr>
<th>OFSP varieties</th>
<th>Fertilizer levels</th>
<th>AMF Inoculants</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1- SPK004</td>
<td>F₁ - 0kg/ha</td>
<td>I₁ - No inoculation</td>
</tr>
<tr>
<td>V2- Kabode</td>
<td>F₂ - 20kg/ha</td>
<td>I₂- <em>Glomus aggregatum</em></td>
</tr>
<tr>
<td></td>
<td>F₃ - 40kg/ha</td>
<td>I₃- <em>Glomus mosseae</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I₄- <em>Glomus etunicatum</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I₅- <em>Glomus intraradices</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I₆- I₃+I₄+I₅</td>
</tr>
</tbody>
</table>

This gave a total of 36 treatments that were replicated three times. Mycorrhization at 66kg/ha (79.2gAMF/plot) and fertilization was done at planting. Each plot consisted of two ridges 6m long spaced at 1m apart. Characteristics of the varieties evaluated are indicated in Table 3.

The cuttings were planted at 0.3m interval on each ridge. Weeding was done three times to maintain a clean field up-to harvesting at 4 months.

Table 3: Varietal Characteristics of SPK 004 and Kabode

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>SPK 004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plant/canopy type</td>
<td>Spreading/creeping</td>
<td>Non-twining, semi erect</td>
</tr>
<tr>
<td>2. Leaf colour</td>
<td>Green</td>
<td>Slightly purple then green</td>
</tr>
<tr>
<td>3. Stem/vine colour</td>
<td>Green</td>
<td>Green with purple tips</td>
</tr>
<tr>
<td>4. Leaf Lobing</td>
<td>Very deep lobes</td>
<td>Moderately deep lobes</td>
</tr>
<tr>
<td>5. Root skin colour</td>
<td>Purple red</td>
<td>Purple red</td>
</tr>
<tr>
<td>6. Root flesh colour</td>
<td>Orange</td>
<td>Deep orange</td>
</tr>
<tr>
<td>7. Stem/vine length</td>
<td>Thin vines, long</td>
<td>Moderately thick vines, short</td>
</tr>
<tr>
<td>8. Root shape</td>
<td>Long, moderately regular</td>
<td>Moderately long, irregular</td>
</tr>
<tr>
<td>9. Maturity</td>
<td>4 months</td>
<td>4 months</td>
</tr>
</tbody>
</table>
3.6: Data collection and Analysis

Data on AMF root colonization and spore counts at various growth stages and various plant growth parameters was collected at different stages during the growth period. In the greenhouse, the plant vine length was taken for each plant at three and four months after planting using a metre rule during each round of data taking. At the end of the growth period i.e. at four months after planting, the shoots were cut at the soil level, the fresh weights taken and oven dried at 60°C for two days and dry weights taken. The roots of each plant were harvested fresh weights taken and the roots divided into two portions; one part was weighed then placed in the oven to dry while the second part was cleaned and preserved in 70% ethanol for AMF colonization assessment. The soil from each treatment was sampled for spore extraction, pH and available P analysis.

In the field experiment, ten plants in each treatment plot were tagged for data collection where the vine lengths and number of internodes were taken at one, two, three and four months after planting using a metre rule during each round of data taking. At four months after planting, the vines were cut at the soil level, fresh weights taken and recorded. The roots of each plot were dug out, counted, weighed and graded into marketable and non-marketable roots by looking at the sizes and the presence of any deformities and weighed. Fine root samples were taken and preserved in 70% ethanol for AMF colonization assessment. The soil in each treatment plot was sampled for spore extraction, pH and available P analysis. The data collected was subjected to analysis of variance (ANOVA) to determine significant effects of time on spore abundance and root colonization and the effects of AMF soil inoculation on OFSP plant survival, biomass production, root yield, spore count, soil pH, soil available P and root colonization. The treatment means were compared using the least significant difference (LSD) test at a significant level of 0.05. The analyses were performed using GENSTAT software version 14 for windows.
CHAPTER 4

RESULTS

4.1: Chemical characteristics of soils before experiment

Results of initial chemical and physical soil characterization on selected parameters are presented in Table 4. The results indicate that the soils from Kakamega Research Centre are moderately acidic with a pH (water) of 5.50. The exchangeable bases are low except for Na (2.61g/kg) and Ca (1.64g/kg) which are relatively high when compared to the other bases. The cation exchange capacity was very low at 1.4mg/kg. The soil total nitrogen was low at 0.122% and organic carbon moderate at 2.4% C. Soil available phosphorus was moderate at 8.64mg/kg and the soil texture was Sandy clay.

Table 4: Selected chemical characteristics of the soil at the study site.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (water)</td>
<td>5.50</td>
</tr>
<tr>
<td>Available P (mg/kg)</td>
<td>8.64</td>
</tr>
<tr>
<td>Soil organic matter (%)</td>
<td>2.40</td>
</tr>
<tr>
<td>Total N (%)</td>
<td>0.12</td>
</tr>
<tr>
<td>Exchangeable K (g/kg)</td>
<td>0.23</td>
</tr>
<tr>
<td>Exchangeable Ca (g/kg)</td>
<td>1.64</td>
</tr>
<tr>
<td>Exchangeable Mg (g/kg)</td>
<td>0.15</td>
</tr>
<tr>
<td>Exchangeable Na (g/kg)</td>
<td>2.61</td>
</tr>
<tr>
<td>Exchangeable acidity (mg/kg)</td>
<td>1.40</td>
</tr>
<tr>
<td>Texture</td>
<td>Sandy clay</td>
</tr>
</tbody>
</table>

4.2: Assessment of infective and effective AMF propagules

The soils contained infective AMF propagules though in low numbers and the AMF inoculants used were effective. The results obtained after trapping indicated that AMF colonization frequency, intensity and soil spore count varied at different times of sampling and also with the different AMF inoculants used. The frequency of root colonization differed...
significantly (P<.001) between the two varieties. SPK004 roots were more colonized (29.33%) than the Kabode roots (23.56%). Significant differences (P<.001) between AMF inocula were observed in root infection rates. The mixed inocula recorded a spore count of 14 spores/25g soil with 33.67% frequency and intensity of 16.50%. With the single species inoculants, *Glomus mosseae* outperformed the other species recording a spore count of 11.50 with a frequency of 29.66% and intensity of 13.93%. Time of sampling had a significant effect (P<.001) on the root infection rates and spore count. The highest frequency of 44.45% was observed in the roots sampled in the fourth month after planting. The highest spore count of 26.42 spore/25g soil was recorded in the fifth month after planting. The inocula infected roots at varying rates and significant differences (P<.001) were seen in colonization rates at the different sampling months. High infection rates were observed from the mixed inocula in roots sampled in the fourth month after planting (Table 5).
Table 5: Effect of AMF inoculants on sweetpotato root infection sampled at different months

<table>
<thead>
<tr>
<th>Variable/Parameter</th>
<th>Frequency (%)</th>
<th>Intensity (%)</th>
<th>Spore count</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFSP variety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPK004</td>
<td>29.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.30&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Kabode</td>
<td>23.56&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.66&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.63&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>0.17</td>
<td>0.42</td>
</tr>
<tr>
<td>s.e.d</td>
<td>0.73</td>
<td>0.45</td>
<td>0.41</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;(0.05)&lt;/sub&gt;</td>
<td>1.52</td>
<td>0.95</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter in a column are not significant at p=0.05

AMF inoculants

<table>
<thead>
<tr>
<th>AMF inoculants</th>
<th>Frequency (%)</th>
<th>Intensity (%)</th>
<th>Spore count</th>
</tr>
</thead>
<tbody>
<tr>
<td>No inoculation</td>
<td>21.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.00&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. aggregatum</td>
<td>21.67&lt;sup&gt;dc&lt;/sup&gt;</td>
<td>5.22&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.50&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. mosseae</td>
<td>29.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.93&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.50&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. etunicatum</td>
<td>25.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.89&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.70&lt;sup&gt;ed&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. intraradices</td>
<td>26.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.22&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.10&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculant</td>
<td>33.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>s.e.d</td>
<td>1.26</td>
<td>0.79</td>
<td>0.71</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;(0.05)&lt;/sub&gt;</td>
<td>2.64</td>
<td>1.64</td>
<td>1.48</td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter in a column are not significant at p=0.05

Months after planting

<table>
<thead>
<tr>
<th>Months after planting</th>
<th>Frequency (%)</th>
<th>Intensity (%)</th>
<th>Spore count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.93&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.75&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>15.28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.78&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.05&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>26.39&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.08&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>44.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.00&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>39.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.42&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>s.e.d</td>
<td>1.15</td>
<td>0.72</td>
<td>0.65</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;(0.05)&lt;/sub&gt;</td>
<td>2.41</td>
<td>1.50</td>
<td>1.35</td>
</tr>
<tr>
<td>CV (%)</td>
<td>10.7</td>
<td>17.6</td>
<td>16.7</td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter in a column are not significant at p=0.05

4.3: Evaluation of AMF and PSB dual inoculation on biomass production and soil P uptake in a greenhouse experiment

4.3.1: Effect of dual AMF and PSB inoculation on biomass production

Inoculation of AM fungi and PSB increased the growth of sweetpotato plants compared to control treatment. Plant height as well as the vine yield was increased in dual inoculation compared to individual biofertilizer inoculation. The highest fresh vine yield of 15.33t/ha was observed in the variety SPK004 inoculated with G. mosseae and A. chroococcum. The least
yield was observed in the mixed inoculum and *P. fluorescens* treated plants. On the variety Kabode, the highest vine yield of 11.90t/ha was recorded for *G. intraradices* and *P. fluorescens* treatments and the least vine yield from *G. etunicatum* and *P. fluorescens* treated plants (Table 6).

**Table 6: Mean effect of dual AMF-PSB inoculation on variety vine fresh weight**

<table>
<thead>
<tr>
<th></th>
<th>SPK 004</th>
<th></th>
<th>Kabode</th>
<th></th>
<th>P. fluorescens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. chroococcum</td>
<td><em>P. fluorescens</em></td>
<td>A. chroococcum</td>
<td><em>P. fluorescens</em></td>
<td></td>
</tr>
<tr>
<td>No inoculation</td>
<td>13.36&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>14.24&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>11.49&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>8.78&lt;sup&gt;cd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>G. aggregatum</em></td>
<td>12.54&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>12.74&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>11.76&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>9.05&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>G. mosseae</em></td>
<td>15.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.74&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>11.69&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>12.90&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>G. etunicatum</em></td>
<td>12.72&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>12.99&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>10.40&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>7.51&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>G. intraradices</em></td>
<td>11.97&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>14.10&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>10.31&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>11.90&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>12.18&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>10.52&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>11.53&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>12.23&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

P-value: 0.45  
s.e.d: 2.77  
LSD<sub>(0.05)</sub>: 5.44  
CV (%): 22.6

Means followed by the same superscript letter are not significant at p=0.05

Bioinoculants AMF and PSB inoculation had an effect on the variety root yield at the end of four months. It was observed that Kabode had the maximum fresh root yield of 10.19t/ha with a *G. mosseae* and *P. fluorescens* combination. The second best combination was *G. intraradices* and *P. fluorescens* followed by the mixed inoculant and *A. chroococcum*. The least root yield of 4.84t/ha was in *G. etunicatum* and *P. fluorescens* combination. For the variety SPK004, the highest root yield of 9.24t/ha was recorded in the AMF un-inoculated but *P. fluorescens* treated plants. The second best yielding combination was *G. aggregatum* and *P. fluorescens* followed by *G. intraradices* in combination with *P. fluorescens*. The mixed inoculant when combined with *P. fluorescens* gave the least root yield (Table 7).
Table 7: Mean effect of dual AMF-PSB inoculation on variety root fresh weight.

<table>
<thead>
<tr>
<th>SPK 004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. chroococcum</td>
</tr>
<tr>
<td>No inoculation</td>
<td>8.19&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. aggregatum</td>
<td>8.14&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. mossea</td>
<td>8.31&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. etunicatum</td>
<td>7.29&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. intraradices</td>
<td>6.26&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>6.78&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P-value: 0.74
s.e.d: 2.00
LSD<sub>(0.05)</sub>: 3.94
CV (%): 29.4

Means followed by the same superscript letter are not significant at p=0.05

4.3.2: Effect of dual AMF and PSB inoculation on soil P uptake

The results obtained indicated that dual inoculation of AMF and PSB did not have any significant (P>0.05) effect on soil P. However, the two varieties responded differently to dual AMF and PSB inoculation. Inoculation of Kabode with G. mossea and P. fluorescens greatly enhanced root length compared to the control. The least root length was recorded in AMF un-inoculated and P. fluorescens treated plants. SPK004 root length was high in AMF un-inoculated but P. fluorescens treated plants and lowest in mixed AMF inoculated with A. chroococcum inoculated plants (Table 8).

Table 8: Effect of dual AMF-PSB inoculation on sweetpotato root length.

<table>
<thead>
<tr>
<th>SPK 004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. chroococcum</td>
</tr>
<tr>
<td>No inoculation</td>
<td>1660&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. aggregatum</td>
<td>1839&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. mossea</td>
<td>1798&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. etunicatum</td>
<td>1774&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. intraradices</td>
<td>1673&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>1538&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P-value: 0.63
s.e.d: 402.60
LSD<sub>(0.05)</sub>: 792.5
CV (%): 24.1
After four months of inoculation, the number of root fragments infected with AMF increased in all dual AMF and PSB treated plants over control. Overall, maximum percent root colonization frequency was observed in combination of mixed inoculant and *A. chroococcum* for both varieties. The single AMF inoculants responded differently in combination with the PSB isolates. *G. intraradices* in combination with *P. fluorescens* was the second best performing combination followed by *G. mosseae* and *A. chroococcum* in SPK004 root infection frequency. For Kabode, a combination of *G. intraradices* and *P. fluorescens* was the second best followed by *G. mosseae* and *P. fluorescens* in AMF root infection frequency (Table 9).

<table>
<thead>
<tr>
<th></th>
<th>SPK 004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>A. chroococcum</em></td>
<td><em>P. fluorescens</em></td>
</tr>
<tr>
<td>No inoculation</td>
<td>1.17&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.44&lt;sup&gt;cdef&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G. aggregatum</em></td>
<td>14.44&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13.56&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G. mosseae</em></td>
<td>21.56&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.33&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G. etunicatum</em></td>
<td>20.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19.78&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G. intraradices</em></td>
<td>21.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>23.56&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>32.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.78&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>P-value</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>s.e.d</td>
<td>5.16</td>
<td></td>
</tr>
<tr>
<td>LSD&lt;sub&gt;(0.05)&lt;/sub&gt;</td>
<td>10.15</td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td>18.2</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter are in a column are not significant at p=0.05.

The percentage of mycorrhizal root colonization increased in all the treated plants as compared with the control. The amount of AMF infective propagules in the two varieties varied with the dual AMF-PSB combinations. The best overall combination was mixed inoculant with *A. chroococcum* in both varieties. The mixed AMF inoculant and *P. fluorescens* was the second best combination in root infection intensity for the varieties. *G. intraradices* with *A. chroococcum* was third best combination for SPK004 and *G. intraradices* and *P. fluorescens* for Kabode (Table 10).
Table 10: Effect of dual AMF-PSB inoculation on variety root infection intensity

<table>
<thead>
<tr>
<th></th>
<th>SPK 004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. chroococcum</td>
<td>P. fluorescens</td>
</tr>
<tr>
<td>No inoculation</td>
<td>0.29&lt;sup&gt;de&lt;/sup&gt;</td>
<td>1.89&lt;sup&gt;dec&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. aggregatum</td>
<td>6.00&lt;sup&gt;bce&lt;/sup&gt;</td>
<td>7.13&lt;sup&gt;be&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. mosseae</td>
<td>9.58&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>10.60&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. etunicatum</td>
<td>11.98&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>9.67&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. intraradices</td>
<td>12.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.16&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>15.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.89&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P-value          | 0.84             |                   |

s.e.d            | 3.12             |                   |

LSD<sub>(0.05)</sub> | 6.15             |                   |

CV (%)            | 23.2             |                   |

Means followed by the same letter in a column are not significant at p=0.05

Dual AMF-PSB inoculation did not show any significant results on soil available P (P>0.05).

The different biofertilizer combinations recorded different amount of soil available P at the end of the growth period. In the soil, maximum available P was observed in P. fluorescens and AMF un-inoculated and G. mosseae and A. chroococcum inoculated soils. The lowest soil available P was observed in G. etunicatum and P. fluorescens treated soil (Table 11).

Table 11: Effect of dual AMF and PSB inoculation on soil available P under two OFSP varieties

<table>
<thead>
<tr>
<th></th>
<th>SPK 004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. chroococcum</td>
<td>P. fluorescens</td>
</tr>
<tr>
<td>No inoculation</td>
<td>8.94&lt;sup&gt;ace&lt;/sup&gt;</td>
<td>10.43&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. aggregatum</td>
<td>8.19&lt;sup&gt;ace&lt;/sup&gt;</td>
<td>8.94&lt;sup&gt;ace&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. mosseae</td>
<td>10.43&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.94&lt;sup&gt;ace&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. etunicatum</td>
<td>8.94&lt;sup&gt;ace&lt;/sup&gt;</td>
<td>8.20&lt;sup&gt;ace&lt;/sup&gt;</td>
</tr>
<tr>
<td>G. intraradices</td>
<td>8.94&lt;sup&gt;ace&lt;/sup&gt;</td>
<td>8.20&lt;sup&gt;ace&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>8.94&lt;sup&gt;ace&lt;/sup&gt;</td>
<td>8.20&lt;sup&gt;ace&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P-value          | 0.62             |                   |

s.e.d            | 1.71             |                   |

LSD<sub>(0.05)</sub> | 3.36             |                   |

CV (%)            | 13.0             |                   |

Means followed by the same letter are not significantly different at p=0.05
AMF inoculation had significant effects on vine growth, vine and root yield, soil spore counts and root infection. Highly significant differences (P<0.001) in vine lengths, vine weights and root yield were recorded with both SPK004 and Kabode varieties. The varieties showed differences in their vine growth as recorded at the sampling stages. In the first month of growth, *G. mosseae* was highly infective for SPK004 while *G. aggregatum* for Kabode as evidenced in the vine lengths and number of internodes recorded. Generally, inoculation of varieties with AMF enhanced vine yield and the two varieties responded differently to the different AMF inoculants. The mixed inoculant that comprised of *G. mosseae, G. etunicatum* and *G. intraradices* gave the highest vine yield of 21.39t/ha for Kabode. Un-inoculated plants were second best followed by those that were inoculated with *G. aggregatum*. For SPK004, *G. etunicatum* was the most effective inoculant in enhancing vine yield. *G. aggregatum* was second followed by the un-inoculated plants (Table 12).

### Table 12: Effect of AMF inoculants on variety vine fresh weight in a field experiment

<table>
<thead>
<tr>
<th></th>
<th>Vine fresh weight (t/ha) SPK004</th>
<th>Vine fresh weight (t/ha) Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>No inoculation</td>
<td>26.66*</td>
<td>20.88*</td>
</tr>
<tr>
<td><em>G. aggregatum</em></td>
<td>30.59*</td>
<td>20.46*</td>
</tr>
<tr>
<td><em>G. mosseae</em></td>
<td>27.78*</td>
<td>16.85*</td>
</tr>
<tr>
<td><em>G. etunicatum</em></td>
<td>31.76*</td>
<td>19.02*</td>
</tr>
<tr>
<td><em>G. intraradices</em></td>
<td>28.19*</td>
<td>17.68*</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>28.06*</td>
<td>21.39*</td>
</tr>
<tr>
<td>P value</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>s.e.d</td>
<td>2.80</td>
<td></td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>5.59</td>
<td></td>
</tr>
<tr>
<td>C.V (%)</td>
<td>24.5</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter are not significant at p=0.05.

At harvesting time, there were differences in the variety root yield with different AMF inoculants. Field inoculation with mixed AMF inoculant enhanced total and marketable root
yield of Kabode compared to the un-inoculated plants. *G. aggregatum* was the second best yielding inoculant followed by *G. mosseae*. With SPK004, un-inoculated plants recorded the highest yield. *G. etunicatum* was the second best followed by the mixed inoculant (Table 13).

**Table 13**: Effect of AMF inoculation on total and marketable root yield in a field trial.

<table>
<thead>
<tr>
<th>AMF Inoculant</th>
<th>Total root fresh weight (t/ha)</th>
<th>Marketable root weight (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPK004</td>
<td>Kabode</td>
</tr>
<tr>
<td>No inoculation</td>
<td>14.32*</td>
<td>14.10* b</td>
</tr>
<tr>
<td><em>G. aggregatum</em></td>
<td>11.69*</td>
<td>15.09* ab</td>
</tr>
<tr>
<td><em>G. mosseae</em></td>
<td>11.92*</td>
<td>14.81* ab</td>
</tr>
<tr>
<td><em>G. etunicatum</em></td>
<td>13.43*</td>
<td>13.66* ab</td>
</tr>
<tr>
<td><em>G. intraradices</em></td>
<td>12.04*</td>
<td>11.81* b</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>13.32*</td>
<td>15.60* a</td>
</tr>
</tbody>
</table>

**P value**

<table>
<thead>
<tr>
<th></th>
<th>SPK004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>P value</td>
<td>0.49</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**s.e.d**

<table>
<thead>
<tr>
<th></th>
<th>SPK004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>s.e.d</td>
<td>1.74</td>
<td>1.61</td>
</tr>
</tbody>
</table>

**LSD (0.05)**

<table>
<thead>
<tr>
<th></th>
<th>SPK004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSD (0.05)</td>
<td>3.47</td>
<td>3.22</td>
</tr>
</tbody>
</table>

**C.V (%)**

<table>
<thead>
<tr>
<th></th>
<th>SPK004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.V (%)</td>
<td>27.4</td>
<td>30.7</td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter in a column are not significant at p=0.05

All the inoculation treatments formed mycorrhizal structures within the roots of the evaluated OFSP varieties. Root infection rates of the AMF inoculants varied widely in terms of frequency and intensity. The mixed inoculant showed greater root infection rates than the single isolates. However in terms of root infection frequency, *G. intraradices* was the most infective inoculant followed by *G. mosseae* for both SPK004 and Kabode varieties. On intensity of root infection, it was observed that *G. etunicatum* showed high colonization intensity on SPK004 roots followed by *G. mosseae*. On Kabode roots, the highest root infection intensity was recorded on *G. aggregatum* inoculated plants followed by *G. intraradices* (Table 14).
Table 14: Sweetpotato root infection by different AMF inoculants in a field trial

<table>
<thead>
<tr>
<th>Infection frequency (%)</th>
<th>Infection intensity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPK004</td>
</tr>
<tr>
<td>No inoculation</td>
<td>29.63&lt;sup&gt;cdef&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>aggregatum</em></td>
<td>38.15&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>mosseae</em></td>
<td>40.00&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>etunicatum</em></td>
<td>38.52&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>intraradices</em></td>
<td>42.96&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>52.22&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P value 0.99 0.33
s.e.d 4.13 2.90
LSD (<sub>0.05</sub>) 8.23 5.79
C.V (%) 22.0 37.1

Means followed by the same superscript letter in a column are not significantly different at p=0.05

AMF inoculants had an effect on soil available P. Un-inoculated soils recorded high soil available P compared to the AMF inoculated soils. The highest soil available P was recorded in the un-inoculated SPK004 plants (Table 15).

Table 15: Effect of AMF soil inoculation on soil available P

<table>
<thead>
<tr>
<th>Soil available P (mg/kg)</th>
<th>SPK004</th>
<th>Kabode</th>
</tr>
</thead>
<tbody>
<tr>
<td>No inoculation</td>
<td>11.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>aggregatum</em></td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>mosseae</em></td>
<td>11.19&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>etunicatum</em></td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>G</em>. <em>intraradices</em></td>
<td>11.19&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.19&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>11.19&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P value 0.04
s.e.d 0.01
LSD (<sub>0.05</sub>) 0.01
C.V (%) 0.1

Means followed by the same superscript letter are not significant at p=0.05
4.4.2: Application of fertilizer on OFSP in the field

Application of TSP on OFSP varieties greatly enhanced vine growth. Data obtained from the field indicated that all growth parameters of sweetpotato plants were significantly increased with increasing P rate from 0kgP/ha to 40kgP/ha. SPK004 recorded longer vine lengths than Kabode and the maximum vine lengths were observed in plants that were supplied with TSP at the rate of 40kgP/ha. At harvesting time, sweetpotato plants that received 40kgP/ha recorded the highest vine yield compared to the other application rates (Table 16).

Table 16: Effect of fertilizer application on sweetpotato vine yield in a field trial.

<table>
<thead>
<tr>
<th>OkgP/ha</th>
<th>0kgP/ha</th>
<th>20kgP/ha</th>
<th>40kgP/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPK004</td>
<td>26.71b</td>
<td>28.75ab</td>
<td>32.06a</td>
</tr>
<tr>
<td>Kabode</td>
<td>18.52d</td>
<td>19.12d</td>
<td>20.50cd</td>
</tr>
</tbody>
</table>

P value 0.16  
\text{s.e.d} 1.98  
LSD (0.05) 3.95  
CV (%) 24.5

Means followed by the same superscript letter are not significant at p=0.05

In terms of root fresh weight, the variety Kabode yielded more than SPK004. However, with application of TSP at a reduced rate of 20kgP/ha improved root yield in both varieties; Kabode 15.39t/ha and SPK004 13.85t/ha as compared to a high TSP application rate of 40kgP/ha (Table 17).

Table 17: Effect of fertilizer application on variety total fresh root yield

<table>
<thead>
<tr>
<th>OkgP/ha</th>
<th>0kgP/ha</th>
<th>20kgP/ha</th>
<th>40kgP/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPK004</td>
<td>12.77b</td>
<td>13.85ab</td>
<td>11.73b</td>
</tr>
<tr>
<td>Kabode</td>
<td>14.13ab</td>
<td>15.39a</td>
<td>13.01ab</td>
</tr>
</tbody>
</table>

P value 0.09  
\text{s.e.d} 1.23  
LSD (0.05) 2.46  
CV (%) 27.4

Means followed by the same superscript letter are not significantly different at p=0.05
High fertilizer rate of 40kgP/ha reduced the quality of roots as seen in the high non-marketable root yield for the varieties evaluated. SPK004 was more affected by the high fertilizer rate as it gave more non marketable yield compared to Kabode (Table 18).

Table 18: Effect of fertilizer application on sweetpotato root marketable quality

<table>
<thead>
<tr>
<th>Marketable yield</th>
<th>Non-marketable yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0kgP/ha 20kgP/ha 40kgP/ha</td>
</tr>
<tr>
<td>SPK004</td>
<td>10.44&lt;sup&gt;b&lt;/sup&gt; 10.97&lt;sup&gt;b&lt;/sup&gt; 9.38&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Kabode</td>
<td>12.06&lt;sup&gt;a&lt;/sup&gt; 12.80&lt;sup&gt;a&lt;/sup&gt; 11.09&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>s.e.d</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD&lt;sub&gt;(0.05)&lt;/sub&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CV (%)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter are not significant at p=0.05

Application of chemical P fertilizer had a significant effect (P=0.003) on sweetpotato root infection frequency by the AMF. An increase in P application rate from 0kgP/ha to 20kgP/ha enhanced sweetpotato root infection rates. At high P rate of 40kgP/ha, the AMF root infection was slowed down. Mixed inoculant was the best in root infection at a P rate of 20kgP/ha. The single species AMF inoculum responded differently to varying TSP rates. *G. intraradices* out-performed the other single species in no P treatment (0kgP/ha) with a frequency of 42.78% and 56.67% at a reduced P rate of 20kgP/ha followed by *G. mosseae* at the same fertilizer rate. At a high P rate of 40kgP/ha, *G. aggregatum* and mixed inoculum recorded a frequency of 35.00% while the rest of the species had a lower root colonization frequency. In terms of root infection intensity, *G. intraradices* was the best single inoculant at 20kgP/ha followed by *G. mosseae*. At 0kgP/ha and 40kgP/ha, *G. aggregatum* was the best single inoculant followed by *G. etunicatum* (Table 19).
Table 19: Effect of fertilizer application rate on sweetpotato root infection by AMF in the field.

<table>
<thead>
<tr>
<th></th>
<th>Frequency of infection (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Intensity of infection (%)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0kgP/ha</td>
<td>20kgP/ha</td>
<td>40kgP/ha</td>
<td>0kgP/ha</td>
<td>20kgP/ha</td>
<td>40kgP/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No inoculation</td>
<td>27.22&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>21.66&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>13.38a</td>
<td>18.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>G. aggregatum</em></td>
<td>34.45&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>43.89&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>35.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>G. mosseae</em></td>
<td>36.11&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>55.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.89&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>14.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>G. etunicatum</em></td>
<td>34.45&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>47.78&lt;sup&gt;bd&lt;/sup&gt;</td>
<td>28.33&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>16.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.95&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>G. intraradices</em></td>
<td>42.78&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>56.67&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.67&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>15.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed inoculum</td>
<td>48.89&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td>0.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.e.d</td>
<td>5.05</td>
<td></td>
<td></td>
<td></td>
<td>3.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD&lt;sub&gt;0.05&lt;/sub&gt;</td>
<td>10.08</td>
<td></td>
<td></td>
<td></td>
<td>7.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td>22.00</td>
<td></td>
<td></td>
<td></td>
<td>37.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same superscript letter in a column are not significant at p=0.05
5.1: Soil chemical characteristics

Soil is a limited resource and therefore its health is crucial for any sustainable development. The soils of the study site are low in plant nutrients such as N, P and basic cations and this could be associated with continuous cropping coupled with non-application of fertilizer. Another reason could be due to the previous crop grown and in this case, cassava which is a heavy feeder and derives most soil nutrients from the soil. Burning of crop residues or removal of the residues from the farm which is also a common practice during land preparation reduces the organic resources that should otherwise be returned to soil to improve on the soil resource base (Karanja et al., 2006; Achieng et al., 2010). The practice reduces the soil organic matter thus affecting available soil nutrients such as N and P since soil organic matter is important in releasing nutrient stocks through mineralization hence offset nutrient deficiency in crops. This is likely to result also in a reduction of water and nutrient retention capacity which negatively impacts on fertilizer use efficiency and generally affecting provision of ecosystem services (Bationo et al., 2006). This condition could be reversed by appropriate management of agricultural lands and efficient recycling of organic resources (Bationo and Buerkert, 2001).

Many tropical soils are fragile and have characteristics that constrain crop production. Such characteristics are low nutrient capital, low pH, high P fixation and loss of soil biodiversity (Sanchez et al., 2003). Studies by Jama et al., (2000), Okalebo et al., (2003 and 2007) and Achieng et al., (2010) have shown that phosphorus is one of the most limiting nutrients in Western Kenya and its deficiency in soil is often accompanied by very low crop yields. In many acid soils, when phosphate fertilizers are incorporated in the soil, the major share of P is fixed thereby making it unavailable to plants. Most of it is fixed into pools with very
availability (Janssen, 2006). In such cases, soil P can be replenished by addition of inorganic fertilizers or organic matter. However, application of chemical fertilizers alone in acid soils is uneconomical due to high costs and low use efficiencies due to high P fixation.

5.2: Infective and effective AMF propagules

Data on AMF root infection frequency in sweetpotato ranged from 21.33% in the un-inoculated and 33.67% for the inoculated. Slightly more root infection rates by AMF were observed in inoculated soils and more numbers of AM fungal spores caused the root infection rates though they were low. Spore counts and root infection rates by AM fungi varied in the OFSP varieties studied. The highest number of AM fungal spores was observed in Kabode, in the mixed inoculum and at five months of growth period. In terms of root infections: the variety SKP004 and mixed inoculum recorded a high colonization in the fourth month of growth. Many anthropogenic practices have resulted in degradation of agricultural soils and there has been progressive loss of soil fertility. AMF are essential components of soil biota: they can be found in nearly all ecological situations, both in natural ecosystems, particularly in those supporting plant communities with high species diversity, and also in normal cropping systems, especially if managed with sustainable practices (Gianinazzi and Schüepp, 1994). Doran and Linn, (1994) reported that the quality of soil depends not only on its physical or chemical properties, but also on the diversity and activity of its biota, thus the soils under study are not of good quality because of the low abundance of AMF propagules and inherent soil nutrients. The abundance and diversity of AMF has significant ecological consequences because individual AMF isolates vary in their potential to promote plant growth and adaptation to biotic and abiotic factors. Thus, the composition and population dynamics of AMF have an impact on the structure and diversity of the associated plant communities, both in natural and agricultural ecosystems (Grime et al. 1987; Gange et al.
According to Gosling et al., (2006), arbuscular mycorrhizal fungi are the largest component of the soil fungal community. They facilitate plant uptake of mineral nutrients, especially immobile nutrients such as P, Cu, Zn (Ryan et al., 2008), besides their effects on plant nutrition, they also play an important role in modulation of plant resistance to pathogens (Elsen et al., 2008), water and salt stress (Miransari et al., 2008) and in improving soil structure through exudation of glomalin (Wu et al., 2008). Root colonization assessed by the traditional Trypan blue root staining revealed that sweetpotato is capable of forming a symbiotic relationship with AMF as reported by O'Keefe and Sylvia, (1993) and Harikumar and Potty, (2002a) and there was varying colonization patterns by all the AMF inoculants used. The AMF varied in development, including length of lag period, slope of the rapid growth phase and peak values of percentage colonization. Although they have evolved as beneficial to host plants, AMF functionality may be influenced by changes in the soil environment related to soil fertility management. The hypothesis that sweetpotato rhizosphere harbours infective AMF propagules was proven in this study and the acidic soils favoured the growth and establishment of Glomale AMF. These organisms can therefore be exploited to enhance the production of sweetpotato.

5.3: Effect of dual AMF and PSB inoculation on biomass production and soil P uptake in a greenhouse experiment

5.3.1: Effect of dual AMF and PSB inoculation on biomass production

In this study, dual PSB-AMF inoculation did not show any significant benefits with OFSP varieties. Contrary to the PSB effect, inoculation with AMF showed tendencies to enhance OFSP growth as AMF inoculation increased shoot and root weight. Kahiluoto et al., (2000) observed that the benefits of arbuscular mycorrhizal fungi are often related to the rate and
extent of mycorrhizal formation. Root colonization, hyphal density and spore density, along with plant P uptake and biomass production are usually chosen as the parameters to assess efficient isolates. It has been reported by Barea et al. (2004) that interactions between AMF and PSB occur naturally since they share common habitats; the root surface. It is well known from the many studies cited that these interactions increase plant growth through several synergistic mechanisms carried out by both the AMF and the bacteria (Barea et al., 1997; Kim et al., 1998; Antoun and Prevost, 2005; Miransari, 2011). In combination this interaction has a beneficial effect on plant growth and health. In this study, mycorrhizal inoculation alone resulted in an increase in plant biomass. However, the AMF isolates had different efficiencies and intraspecific differences were observed; with Glomus mosseae and Glomus intraradices showing the most mycorrhizal effectiveness in promoting plant above ground and below ground biomass respectively. The other AMF isolates lagged behind and produced less biomass.

In investigating the interactions between AMF and PSB dual inoculation on biomass production, it was observed that addition of PSB to AMF inoculated plants increased vine and root production compared to either AMF or PSB in isolation. Fresh vine weight was high in plants inoculated with Glomus mosseae and Azotobacter chroococcum. Co-inoculation of Glomus intraradices and Pseudomonas fluorescent however increased the production of root fresh weight compared to individual inoculation of AMF or PSB after five months of planting. The observations observed in this study could be explained by Germida and Walley, (1996) who observed that plant host species affect the performance and interaction of PSB. In studies by Vikram et al., (2007), it was reported that phosphate solubilizing microorganisms isolated elsewhere have not been very consistent in their performance everywhere owing to their poor adaptability to the changing soil and agronomic conditions. The PSB used in the study were isolated from potato growing soils and this could
be the reason why they did not show any significant effect on sweetpotato growth. Another possible reason could be that the PSB could have produced hydrolytic enzymes which caused the cortical cells to dilate, providing a larger intercellular surface area with which the AMF can penetrate and colonise more easily thereby providing more nutrients to the plant and enhance growth (Mamatha et al., 2002) or the increase in P element activated photosynthesis and metabolic processes of organic compounds in the plant that increased the plant growth (Purekar et al., 1992). An increase in plant P increases plant length, leaf area, total chlorophyll and canopy dry weight thus increased biomass production as observed by Hassan et al., (2005).

5.3.2: Effect of dual AMF and PSB inoculation on P uptake

Dual AMF-PSB inoculation did not give any significant added benefit to P uptake. The advantages of mycorrhizal inoculation of plants are often related to the increased exploitation of the soil volume beyond the root-nutrient-depletion zone and enhanced uptake and assimilation of nutrients with low mobility and solubility such as P (Smith and Read, 1997; Bethlenfalvay and Linderman, 1992). In this study it is reported that soil inoculation with Glomus mosseae and Azotobacter chroococcum enhanced soil available P and with no added phosphorus fertilization. This could be attributed to the fact that phosphate solubilizing bacteria release phosphate ions into the soil which are then transferred by the AMF hyphae to the plant especially in P deficient soils as reported by Artursson et al., (2006). It has been reported by Andrade et al., (1997) and Artursson et al., (2006) that some bacterial species respond to the presence of certain AMF indicating that there is a high degree of specificity between bacteria associated with AM fungi and this is attributed to species-specific exudates produced by the fungi.
In terms of AMF root infection, the sweetpotato plants varied in their response to inoculation with different mycorrhizal fungi. It has been observed by Barea et al. (2005) that many P solubilizing microorganisms increase the mycorrhizal root colonization by producing specific metabolites such as vitamins, amino acids and hormones in addition to P solubilization.

There was an increase in root infection rates from the mixed inoculum and *A. chroococcum* inoculated plants. In terms of root proliferation, combined inoculation of *G. intraradices* with *P. fluorescent* showed extensive root proliferation compared to the other combinations. Increase in root infection by the mixed inoculant confirms work done by Koide (2000) and Alkan et al. (2006) who observed that the greater the diversity of AMF in the soil, the more the benefits conferred to the host crop i.e. sweetpotato in this study. This is because the mycorrhizal communities tend to offer a broader range of functions, so if a plant is colonized by AMF species that are complementary in their functions, they may prove to be more beneficial for the plant as a mixture than any of the species separately. However, increased root proliferation in AMF inoculated could have resulted in faster removal of P from the soil around the root system into the plant tissues thus a decrease in soil available P as seen in this study. Jacobsen et al., (1992) and Liu et al., (2003) have reported in their studies that increased external hyphal growth in the soil enhances soil P depletion around the root zone resulting in low soil available P.

5.4: Performance of AMF inoculants and fertilizer in a field experiment

5.4.1: Response of OFSP to AMF inoculants

AMF inoculants enhanced growth of sweetpotato in the field compared to un-inoculated plants. According to Smith and Read, (1997) and Barea et al., (2005), the main contributions of AMF to plant physiology are to modify the plant root to explore the soil for nutrients that are otherwise unavailable for plant uptake. However, AMF do not have equal capabilities to
perform these beneficial roles as observed by George et al., (1995). In field application, fungal propagules including extraradical mycelium and spores are considered because they are important for the persistence of AM fungi in roots and soils. In this study, the AMF inoculants responded differently to the two OFSP varieties. Studies by Johnson et al., (1992, 1997) and Jansa et al., (2002) have shown that individual species of AMF and even fungal isolates in one species, differ in their ability to promote plant growth, and that promotion of plant growth depend on the particular matching of plant and fungal species. When tested on a single plant species, the fungal isolates can increase, decrease, or have little effect on plant growth and as such these inter- and intraspecific variations make it essential to screen for efficient AM fungi for particular host-plant species. There was wide variation in the degree of functional compatibility between sweetpotato and the AM fungal isolates tested. In this study, *Gl. aggregatum* and *Gl. etunicatum* were the most and effective inoculants for Kabode and SPK004 respectively in the first thirty days of growth. At harvesting, it was observed that *Gl. etunicatum* recorded the highest vine yield. The mixed inoculum was however the best overall in terms of root infection but *Gl. intraradices* recorded much root infection as a single species than the other species indicating that it was the most efficient in terms of sweetpotato root infection. The mixed inoculum which comprised of *Gl. mosseae, Gl. etunicatum* and *Gl. intraradices* provided the greatest benefit to sweetpotato plants as evidenced in the root infection and overall root yield. This may be attributed to the complementary functions of different species as reported by Koide (2000), Alkan et al., (2006) and Gai et al., (2006) thus the greater the diversity of AMF in the soil, the more the benefits conferred to the host crop.
5.4.2: Field application of chemical fertilizer

Application of TSP enhanced vine growth and vine yield. In this study, application of TSP at a reduced rate enhanced root yield and vine yield at an increased rate. Studies by Were et al., 2003 have reported favourable response to P fertilizers by sweetpotatoes. In this study, plants which received 40kgP/ha had significant increases in vegetative growth traits compared to the other rates. This increase in vegetative growth may be due to the beneficial effect of P-element on the activation of photosynthesis and metabolic processes of organic compounds in plants and hence increasing plant growth as observed by Purekar et al., (1992). Similar observations have been made by EI-Gamal and Abdel-Nasser (1996), EI-Morsy et al., (2002) and Hassan et al., (2005) who found out that increasing P rate to sweetpotato plants significantly increased plant length and plant leaf area. In terms of root yield, increase in P rate reduced root yield and the marketable quality. This is contrary to studies by Hameda et al., (2011) who observed an increase in sweetpotato root yield with an increasing P rate up to 45kgP/ha and EI-Morsy et al., (2002) and Hassan et al., (2005) that increased P fertilization caused significant increase in total and marketable root yield.

Field application of TSP fertilizer had significant effect on AMF root infection that ranged from positive to negative. In this study it was observed that lower concentration of P enhanced AMF root infection. Lower concentration of TSP at 20kgP/ha showed higher mycorrhizal root colonization and spore number as compared to high concentration of 40kgP/ha. Similar observations were made by Kahiluoto et al., (2001), Harwani (2006) and Johansson et al., (2004) who found that increased chemical fertilizer application reduced AMF development. Azcon-Aguilar and Barea, (1996) in their study observed that the overall level of AM colonization and spore number decreases with increasing availability of soluble P. Studies by Hu et al., (2009) have shown that high P may be detrimental to mycorrhizal colonization and a reduction in spore production which ultimately reduce the phosphatase
secretion responsible for the conversion of bound P into available form and hence lesser P-uptake.

With root proliferation, the extraradical hyphae of AMF intercept soil volume that contains the orthophosphate ions which are taken up by the hyphae and with their high surface-to-volume ratio and the high turnover rate, the hyphae efficiently increase the volume of the soil that is exploited during plant development. These hyphae take up the orthophosphate ions and translocate this P to their host plant (Liu et al., 2007) thus improving P nutrition. The advantages of mycorrhizal inoculation of plants are often related to the increased exploitation of the soil volume beyond the root-nutrient-depletion zone, enhanced uptake and assimilation of nutrients with low mobility and solubility such as P and the improved usage of chemical fertilizers when applied in low doses in plant production systems (Smith and Read, 1997; Bethlenfalvay and Linderman, 1992). The observations from this study indicate that application of P fertilizers influence plant-AMF interactions concurring with studies by Covacevich et al., (2007), Liu et al., (2000); Bohrer et al. (2001), van der Heijden, (2010) and Treseder, (2004) that high P levels in soil negatively impact on the abundance of AMF.
5.2 Conclusions and recommendations

5.2.1: Conclusions

1. The soils collected from the study site had viable AMF spores though in low numbers.
2. In this study, dual AMF and PSB interaction effect influenced growth and mixed inoculation of the *Glomus spp.* had beneficial effects.
3. Application of TSP fertilizer at 40kgP/ha negatively affected AMF development and root infection.
4. Inoculation of sweetpotato with *Glomus spp.* and adapted P solubilizing bacteria might be a promising strategy in enhancing production and soil P in P deficient soils.
5. Inoculation of soil with mixed AMF species in general, has a simulative impact upon growth and productivity of sweetpotato plants than single AMF species.

5.2.2: Recommendations

- Isolating and evaluating plant growth promoting bacteria from sweetpotato growing soils of Western Kenya.
- Isolating and testing indigenous AMF isolates from sweetpotato soils should be done to search for any excellent isolates for use in sweetpotato inoculation.
REFERENCES


79


