STUDIES ON THE INFLUENCE OF VESICULAR ARBUSCULAR MYCORRHIZA AND FERTILIZATION ON CHILI PEPPER (*Capsicum annuum* L.) IN DIFFERENT CROPPING SYSTEMS

JAMES AYOOLA ADETUNJI

B. AGRIC. (HONS) UNIFE, M. SC. SOIL SCIENCE (OAU)

Matric number 77374

A thesis in the Department of Botany

Submitted to the Faculty of Science in partial fulfillment of the requirements

for the Degree of

DOCTOR OF PHILOSOPHY

of the

UNIVERSITY OF IBADAN

November, 2011

CERTIFICATION

I hereby certify that this work was carried out by Mr. James Ayoola Adetunji under my supervision in the department of Botany, University of Ibadan.

.....

SUPERVISOR

O.O. OSONUBI,
B. Sc. (Unife), PhD (Lancaster, UK)
Professor in the Department of Botany and Microbiology,
University of Ibadan, Nigeria.

ABBREVIATIONS

AM	Arbuscular Mycorrhiza
AMF	Arbuscular Mycorrhizal Fungi
FMC	Field moisture capacity
LAC	Low activity clay
RCBD	Randomized Complete Block Design
SSP	Single super phosphate
VAMF	Vesicular Arbuscular Mycorrhizal Fungi

ABSTRACT

Investigations were conducted with four pot and two field experiments on the influence of vesicular arbuscular mycorrhiza (VAM), and fertilization on chili pepper, *Capsicum annuum* var. *tatase* (Yoruba) in different cropping systems. All experiments were factorial in a randomized complete block design (RCBD) and each treatment was replicated three times.

The first two pot experiments carried out in the Department of Botany and Microbiology, University of Ibadan under natural solar illumination and daily temperature, consisted of three types of VAM inoculation (*Glomus mosseae, Glomus etunicatum* and control), two levels of cropping systems (sole chili pepper and chili pepper intercropped with cowpea) and two levels of single superphosphate (0kg P/ha and 60kg P/ha) simultaneously in sterile and non-sterile soils. The third pot experiment consisted of three types of VAM inoculation (*Glomus fasciculatum. Glomus mosseae* and control), three levels of cropping systems (sole chili pepper, chili pepper with soybean intercrop and chili pepper with cowpea intercrop) and two levels of rock phosphate supplement (0kg P/ha and 60kg P/ha) in sterile. Finally the fourth pot experiment consisted of three species of VAM (*Glomus mosseae, Glomus etunicatum* and *Glomus fasciculatum*) three levels of organic fertilization (control, soybean intercrop and 5% organic manure) and three levels of rock P (0kg P/ha, 30kg P/ha and 60kg P/ha) also in sterile soil. The latter two pot experiments and the field experiments were located at National Horticultural Research Institute Ibadan, a derived savanna and transition zone between a

tropical rain forest and southern guinea savanna. The first field experiment consisted of three types of VAM inoculation (*Glomus mosseae, Glomus fasciculatum* and control) three levels of cropping systems (sole chili pepper, chili pepper with cowpea intercrop and chili pepper with soya bean intercrop) and two levels of rock P (0kg P/ha and 60kg P/ha). The second field experiment consisted of three species of VAM fungi (*Glomus mosseae, Glomus fasciculatum* and *Glomus etunicatum*), three levels of organic fertilization (control, soya bean intercrop and 5% organic manure) and three levels of rock P (0kg P/ha, 30kg P/ha and 60kg P/ha).

The soil pH (6.5) was significantly ($P<0.05$) reduced with *Glomus mosseae* inoculation while there was significantly ($P<0.05$) higher %C and Ca at 60kg P/ha than 0kg P/ha inorganic P supplement in non-sterile soil. Apart from P, the uptake of N, K, Ca, Mg, Zn and Fe were significantly ($P<0.05$) improved by mycorrhizal inoculation. The dry matter yield of mycorrhizal plant was significantly ($P<0.05$) higher than non-mycorrhizal plant with *Glomus mosseae* performing best in sterile soil. However, there was a significant drop (16%) in dry matter yield with the addition of 60kg P/ha single superphosphate. Mycorrhizal inoculated pepper plants had a twofold increase in fruit weight over uninoculated-mycorrhizal pepper plants. The use of rock P with organic manure in the presence of VAM enhanced fruit yield for chili pepper. There were significant ($P<0.05$) variations in the performance of mycorrhizal species in both pot and field experiments subject to soil environment and cropping systems. The experiment has provided the basis for

the recognition of the fact that mycorrhizal activity is not only a component of plant system but also a soil-plant system improver.

Key words: Vesicular arbuscular mycorrhiza, fertilization, chili pepper, cropping systems

Word count: 480

DEDICATION

This thesis is dedicated to my father, Michael Adesoji Adetunji. He is such a father who cherishes the success of his children. 'Dad, you have always wanted to see me succeed and Iam indeed fortunate that you are alive to see me finish my studies and celebrate my success with that big smile. Now that I have finished and succeeded; my success is your success too. I shall always endeavor to succeed. Wishing you long life to enjoy the fruit of your labour'.

ACKNOWLEDGMENTS

First and foremost I express my gratitude to Almighty God for He has purposed and nobody can thwart it. Thanks to my supervisor Professor O. Osonubi, for everything he has taught me about mycorrhiza, for giving me an opportunity to work on a biological nutrient improver project and for his overall support and guidance throughout the course of this research. I would like to thank the management of National Horticultural Research Institute Ibadan, for providing me an earlier opportunity to work on this program and partial financial support during my study at University of Ibadan.

I would like to thank Professor Oba Fagade and others for serving as my committee members for encouragement and praise, both warranted and otherwise. I would also like to thank Dr. O. Fagbola for his comments and criticisms not against but for the success of this project.

My primary appreciation goes to my wife, Mrs. Anthonia Adenike Adetunji for her help in the execution of this study, as well as for her love and daily support to encourage me to complete the degree. Special thanks to friends mostly in the department for their friendship to make me persevere to the end. Other key inspirations in the development of this study were Mrs. Titilayo Fagade and the leadership of Ibadan BSF (EW) to mention a few. I say thanks to all.

This research would not have been completed without the help of late Professor R.O. Sobulo and his staff in the laboratory procedures. Last and most

definitely not the least, I, and my family, have Professor Wale Adetimirin to thank for his contribution to sanity maintenance. His generosity is paralleled only by his wit and good nature.

TABLE OF CONTENTS

LIST OF TABLES

PAGE

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the developing world, food production by many small-scale farmers is based on intercrop systems. A yield benefit from sole cropping is subject to system stability. Hence farmers intercrop to stabilize productivity, reduce risk of crop failure due to ephemeral factors and spread labour peaks for cost efficiency (Ofori and Stern, 1987; Peoples and Herridge, 1990). Traditional farmers, though ignorant of the process of nitrogen fixation, had earlier noted that the practice of rotating legume cover crop with cereals often result in dramatic yield increases. Even in revolutionized or modern agricultural practice and with the advent of chemical fertilizers, relay or inter-cropping of legume with non-leguminous crop especially as an excellent alternative to optimize cost remains dominant (Alom *et al*., 2009).

Large areas of humid and sub-humid tropical Africa are dominated by low activity clay (LAC) consisting mainly of Alfisols and Ultisols (Kang *et al*., 1990). These soils have major constraints for intensive horticultural and arable crop production. They are characterized by low nutrient status, low to medium phosphorus sorption capacity and high residual effect from applied phosphorus (Sobulo and Osiname, 1985; Kang *et al.*, 1990). The soils in sub-Saharan African have not received adequate nutrient replenishment i.e. have the lowest fertilizer consumption in the world (10kg/ha) in comparison to India – 70kg/ha

and China – 260kg/ha. Phosphorus has been observed as one of the most limiting nutrient elements in tropical soils (Ahn, 1970). Even when P fertilizer is added to supplement its deficiency there is the problem of P fixation by sesquioxide. However in soils where P deficiencies are frequent, Arbuscular mycorrhizal (AM) fungi have been found to play a beneficial role (Sieverding, 1991; Osonubi *et al.*, 1995). The main component of the soil microbiota in most agro ecosystems is the AM fungi. These obligate mutualistic symbionts colonize the roots of vast majority of plants, including most crop plants (Smith, and Read, 1997). By forming an extended, intricate hyphal network, AM fungi efficiently absorb mineral nutrients from the soil and deliver them to their host plants in exchange for carbohydrates. Facilitated nutrient uptakes, particularly with respect to immobile nutrients, such as phosphorus, constitute the main benefit of the mycorrhizal symbiosis for plants (George *et al.*, 1995; Kurle and Pfleger, 1996).

AM fungi form symbiotic roots association with the majority of species of land plants (Fitter *et al.*, 2000). As such, AM fungi roots are a normal occurrence in all but some terrestrial ecosystem types e.g. boreal forest and heathlands (Read, 1991) and all but few plant families e.g. Brassicaceae. AM fungi exist naturally in tropical ecosystems (Miller, 1979; Skujins and Allen, 1986). In agricultural systems, legumes are known for their ability to increase soil nitrogen content through symbiotic relationship with N-fixing *Rhizobia* in their root nodules. They are rarely in pure culture but found as catch crops with major staples in traditional farming systems. Leaves pruned or shed increase

soil fertility status. AM fungi extensively colonize many legumes to such extent that some are obligatorily mycorrhizal under natural conditions.

Certain factors affect the growth of plants and also severely hinder biological nitrogen fixation. A common example in many soils in Africa is phosphorus deficiency. The application of P fertilizer to correct such deficiency is usually very expensive, at times non-available and often beyond the reach of peasant farmers. Nitrogen also appears to be the most limiting nutrient element in tropical soils. The potential benefits of the symbiotic interactions among the AM fungi, legumes and non-leguminous plants are well known. These include increasing growth and uptake of P and relatively other immobile nutrients in the host plants (Stribley *et al.*, 1980; Osonubi, 1994; Ali and Saleh, 1997).

There are some biological factors identified as causing rapid decline in productivity. These include weeds, insects, pest and disease infestation, soil degradation and pollution changes in the rhizosphere and microenvironment of the farmland (Agboola, 1987). Rapid decline in soil fertility often accompanies horticultural crop production because of the intensive nature of cultivation. AM fungi have been found capable of alleviating problems resulting from some of these factors (Osonubi, 1999). Also the involvement of a legume component for the improvement of N, and mycorrhiza, for efficient P utilization in the system would in no doubt enhance the sustainability of the system. Thus the triple symbiosis viz; *Rhizobium* – plant – mycorrhiza when

brought into play is found capable of providing N and increasing P utilization particularly in the tropics.

1.2 Objectives of the Study

Experiments were carried out to evaluate the potential of AM fungi – legume – *Rhizobium* tripartite association as a complementary component for sustainable grain legume–pepper cropping systems with different P sources having the following objectives:

1. Study the effect of AM fungi inoculation and P- fertilizer application on soil physico-chemical properties in different cropping systems.

2. Investigate the effect of AM fungi inoculation and P-fertilizer application on uptake and growth of *Capsicum annum* var. Tatase, in different cropping systems.

3. Evaluate the agronomic effectiveness of rock phosphate in combination with organic manure on the performance of *Capsicum annuum* in different cropping systems.

4. Monitor the influence of AM fungi – legume – *Rhizobium* tripartite associations in the presence of soil amendments on growth and nutrient uptake of chili pepper.

CHAPTER 2

LITERATURE REVIEW

2.1 Sustainable food production and its problems in the tropics

The production of adequate food to meet the need of increasing population has become a challenge for many developing countries especially the tropical Africa. Some of the problems identified that limit the growth of food production in sub-Saharan Africa include but not limited to the following;

(a) Low crop yields and limited adoption of new and improved technology.

(b) Degradation of the natural environment because of expansion of cultivated areas, shorter fallow periods, lack of appropriate land conservation practices, increasing farming pressure on fragile land and extension of agriculture into marginal lands.

(c) Inadequate marketing structures and unstable national agricultural policies.

(d) Inadequate and unsatisfactory rural welfare support.

Agricultural production in the past mainly increased by expanding the area for planting crops i.e. cultivation of more land or shifting cultivation. Such practice however has its limitations like shortening the length of fallow periods often results in over exploitation of the fragile lands and gradual depletion of soil nutrients. The possibility of increasing agricultural productivity in the tropics under the present land and population pressure is via aggressive, intensive and continuous cropping of cultivated land. A successful continuous and intensive cropping may be achieved with improved multiple cropping

systems in standard agricultural systems as well as in marginal lands for which pressure is continuously mounting all over the world.

Large parts of the uplands of the humid and sub humid tropics are dominated by Ultisols, Inceptisols, Alfisols and Oxisols. In this area, alternate cropping and bush fallowing characterized by low nutrient input, low yield, short cropping cycles and relatively long fallow periods used to be the traditional form of agricultural practice for food production. A major setback in this system is the shortening or eliminating of the fallow period that form a major ingredient for soil fertility restoration as a result of increasing population and land pressure. Both the Oxisols and Ultisols commonly found in the humid region are highly weathered and leached. The clay mineral is dominated by kaolinite and oxides of iron and aluminum (Juo, 1981). Generally they are characterized by strong acidity, low levels of exchangeable potassium, calcium and magnesium. Deficiencies of nitrogen, phosphorus, potassium, calcium and magnesium are common occurrence (Sanchez, 1981; Kang and Juo, 1983).

Alfisols are less leached, with low surface charge and kaolinitic mineralogy. It is found in the sub-humid tropics. Though it has moderate fertility, deficiencies of nitrogen and phosphorus are common (Kang and Fox 1981). Under intensive and continuous cropping, deficiency of potassium can also emerge. Alfisols derived from acidic soils has low phosphate fixing capacity (Juo and Fox, 1977), low phosphorus requirement for crop production and high residual effect of applied phosphorus (Kang and Osiname, 1979; Sobulo and Osiname 1985; Bationo *et al.*, 1986; Kang *et al.*, 1990).

Nitrogen is the most mobile and most easily exhausted nutrient in the soil. Crop yield levels to a large extent depend on soil nitrogen status since it is recognized as the key element for crop production. Traditional farmers usually depend on fallow periods or use of legumes to restore soil nitrogen status. Also, through the application of intercropping system, the nitrogen status of the soil is improved. The application of mycorrhiza to develop integrated nitrogen management systems capable of full exploits of biologically fixed N_2 in production systems offers an advantage.

2.2 Intercropping

Intercropping is an age-long technique of growing a minimum of two crop species simultaneously in the same plot. Nitrogen - fixing plants especially legume-*Rhizobium* symbiosis usually forms key components of intercropping systems. Legumes are known for their ability to increase soil nitrogen content through symbiotic relationship with N-fixing bacteria in their root nodules. The benefit could be to the succeeding phases of the cropping sequence or effect direct transfer of N to companion plants by sharing some of the fixed N with them (Haynes, 1980).

In traditional agriculture, cassava/maize intercrops are usually combined with low growing crops such as *Citrullus lunatus* (melon), *Abelmoscus esculentus* (okra), *Vigna unguiculata* (cowpea), *Amaranthus spp* (amaranths), *Arachis hypogea* (groundnut) and several leafy vegetables. Companion crops like legumes usually improve the nitrogen economy of the soil. In multiple cropping systems, non-legumes can benefit from inclusions of

legumes in the production system. Intercropping of grain legumes with horticultural crops affords opportunity for the improvement of both protein diets and mineral supplements for the family. Generally, legumes intercropped with other crops, apart from allowing better exploitation of soil and environmental resources for plant growth, have been associated with higher yields, more efficient land use per unit area, and soil fertility improvement (Lal, 1987; Ofori and Stern, 1987; Peoples and Herridge, 1990). Most herbaceous legumes of the Papillionoideae are symbiotic with both nodules forming *Rhizobium* and AM fungi. The movement of nutrients and water between the root zones of associated plants is enhanced by AM fungi, whose hyphae colonize and connect the roots of adjacent plants (Francis and Read, 1984; Van Kessel *et al.*, 1985).

2.3 Arbuscular mycorrhizal (AM) fungi

Five types of endomycorrhizae can be recognized of which arbuscular mycorrhiza (AM) is the most widespread. They were formerly classified into the order Endogonales but now belong to the order Glomales (Morton and Benny, 1990).

Arbuscular mycorrhizal fungi (AMF) are ubiquitous but species abundance and diversity differ among soils (Harley and Smith, 1983; Abbott and Robson, 1989). Although, plant host may be facultative or obligate in their relationship to mycorrhiza fungus, the AM fungi being obligate biotrophs do not grow on synthetic media. The fungi form an obligate symbiosis with host

plant i.e. the host plant provides carbon for AM growth in return for plant nutrients especially phosphorus provided by AM fungi from the labile pool (Mosse, 1973; Ross and Harper, 1976; Harley and Smith 1983).

Over one hundred and fifty species have been described and are all grouped in a single family - the Endogonaceae. The six genera that constitute the family apart from *Endogone* (which forms zygospores but not known to produce AM fungi) are *Glomus*, *Gigaspora*, *Acaulospora*, *Sclerocystis*, *Entrophospora* and *Scutellospora* (Morton, 1988; Sieverding, 1991).

AM fungi type predominates in the roots and soils of agricultural crop and weed plants (Hayman, 1980; Trappe, 1987). In more recent times, Vesicular arbuscular mycorrhiza (VAM) have been referred to as arbuscular mycorrhizae (AM) because many non-mycorrhizal fungi contain vesicles but without arbuscules (Morton and Bentivenga, 1994; Bonfante and Perotto, 1995) while the two genera *Scutellospora* and *Gigaspora* do not form vesicles (Morton 1990). The AM fungi are geographically ubiquitous occurring in arctic, temperate and tropical plants (Powell and Bagyaraji, 1984). Arbuscular mycorrhizae are not individual organisms but rather symbiotic interactions among soil, plant and fungi. Agriculture overtly manages all these three components of mycorrhizal systems.

They constitute an important group of soil-borne microorganisms that contribute immensely to the productivity and durability of cultivated ecosystems (Harley and Smith, 1983). These fungi are non-septate. They are peculiarly specialized that they cause little or no damage to their hosts.

Arbuscular mycorrhizal association in plants is a necessary mutualistic one for the survival of both symbionts.

The AM symbiosis begins with germination of large spores or some other forms of inoculum propagules such as infected root pieces. Infection processes by AM are basically in two stages:

(i) The extraradical or external soil phase with extramatrical hyphae and external vesicle or spores scattered in the surrounding soil; and

(ii) The intraradical phase with intercellular unbranched hyphae and branched intercellular hyphae (arbuscules) and vesicles. The arbuscules serve as the preferential site for fungus/plant metabolite exchange (Cox *et al*., 1975; Scannerini and Bonfate-Fasolo, 1983). The major structures used to identifying AM infection in roots are hyphae, arbuscules and sometimes vesicles.

A natural infection of host plants by AM fungi is usually initiated through the germination of spores present in the soil into a germ tube (Sanders and Sheikh, 1983). Within a period of three weeks to six months depending on the species, arbuscular mycorrhizal fungi form resting spores on the external mycelium. These spores are capable of survival for several years in the soil. In virtually all cases of mycorrhizal associations, the symbionts are heterotrophic and obtain their carbon and energy supply from the host plant (Ho and Trappe, 1973; Cox *et al*., 1975; Bethlenfalvay, 1982; Harley and Smith, 1983; Finlay and Soderstrom, 1992). The host plant in return obtains inorganic nutrients and water supply drawn from the surrounding soil via the extensive hyphae network (Gianinazzi-Pearson *et al*., 1981; Bledsoe and Zasoski, 1983; Sanders

and Sheikh, 1983; George *et al*., 1992). The germ tube develops into a hypha that penetrates the epidermal surface of the roots via the formation of the appressorium, usually between or through sub-epidermal cells where hyphal coils may result. The hyphae grow longitudinally in the inner layers of the cortex in a bi-directional way along the intercellular spaces and sometimes pass from cell to cell forming specialized haustoria-like structures within the cells called arbuscules within 2-3 days (Mosse, 1981; Sanders and Sheikh, 1983). Metabolite exchanges between fungus and host cytoplasm normally take place within the arbuscules. Characteristic sac-like swellings known as vesicles may also form in the cortical cells and function as nutrient storage organs or as propagules in root fragments (Mosse, 1981; Harley and Smith, 1983; Sanders and Sheikh, 1983; Jackson and Mason, 1984). At the onset of infection by AM fungi, the host plant cells appear similar to that of a healthy plant cell reacting to an invading pathogenic fungus (Readhead, 1975). Thus the anatomical observation of cells at this stage normally reveals structures similar to a parasitic invasion.

The production of pure AM inoculum normally starts from a single spore and the source of inoculum for starter cultures is the rhizosphere of endomycorrhizal plants in the field. Spores are obtained by wet sieving method followed by decanting rhizosphere soil samples taken from 0-15cm depths. The spores are screened on soil sieves of various mesh sizes (Gerdemann and Nicolson, 1963). After species identification, spores can be isolated from soil by density gradient centrifugation, surface disinfested (Tommerup and Kidby,

1980) and used in a sterilized soil by placing them near the root (Menge and Timmer, 1982). These spores can be used for the establishment of new pot cultures with the inoculum placed in close contact with actively growing roots and where seeds are sown in pots, inoculum has to be layered 2-3cm below the seed. Monocots have proved better than the dicots for the propagation of AM (Strubble and Skipper, 1988) however, some AM species cannot be multiplied using monocots as host. Different mechanisms stimulate the formation of AM spores and the root plays an inductive role by supplying nutrients (root exudates) and also maintaining gas balance in which carbon dioxide (CO_2) appears to play a key role before, during and after colonization, (Becard *et al*., 1989).

Differences in AM fungi response to the environment and vis-a-vis the host–plant response to the AM fungi are influenced by intraspecific variability within the endophyte. Quite a large number of fungal species can associate with a single plant species, however, the possibility of preferential associations of host fungus species in different ecological set ups exist (Abbot and Robson, 1985). This often results in differential compatibility of mycorrhizal associations. Selectivity or preference between symbionts may be due to ecological and physiological interactions between fungi and host. Companion plants for example, can influence whether neighbouring plants form AM, the degree of AM colonization and competitive interactions (Miller, 1987). Also, the interaction between AM and other symbionts in the rhizophere, e.g. Rhizobium strains and AM species on legumes (Azcón *et al.*, 1991), may

influence functional compatibility of the symbiosis. The term ecological specificity, a term coined by Harley and Smith (1983) expressed the aspect of competition in different field conditions capable of altering significantly the results of mycorrhizal associations induced in the laboratory experiments.

Other biotic and abiotic factors that affect the ability of plants to form or alter functional mycorrhizal associations include the interactions between roots and fungal propagules, between fungi that restrict or enhance growth or restrict certain associations and rhizosphere microorganisms that influence differential host-fungus associations (Molina *et al*., 1992). Quite often, there is differential effectiveness in host nutrition enhancement by these associations. Development of infection is also influenced by some other factors. For example, the raising of partial pressure of oxygen from zero to 21% result in the increase on the level of infection and the development of vesicles (Saif, 1981). Hall and Armstrong (1979) traced the occurrence of mycorrhizae under waterlogged conditions to satisfactory pathways for gaseous oxygen transfer through tissues. Soil P level is yet another important factor. High P level in the soil will hinder effective colonization. Soil with low P is usually preferred (Mosse, 1973; Jasper *et al*., 1989). Other factors that have to be monitored for effective propagation of inoculum include adequate moisture (Saif, 1981), pruning or defoliation of the host plant (Daft and El-Giahmi, 1978) and chemical applications (Chandreshekara *et al*., 1995).

Colonization can be characterized in various ways. The quantitative model of AM fungal colonization establishes a relationship between propagule

density and colonization unit and not the rate of fungal growth within the roots. This implies that there may be differences in colonization unit established by different propagules in an ecosystem however, the rate of growth has no bearing with the colonization unit. Somehow, research finding is yet to ascertain which of the two is more important in promoting the symbiotic relationship between the fungi and the hosts. Bayne and Bethlenfalvay (1987) defined infectivity as the capability of a given set of propagules (adjudged to be viable) to establish a certain level of infection within a given length of time. This also is dependent on the type of inoculum applied as spores which are found to produce higher infection than hyphal fragments. The medium of storage and condition of inoculum (Abbott and Robson, 1989), quantity of inoculum as well as temperature (Schenck *et al*., 1975) equally affect the level of infection produced. Another major factor suggested to regulate AM formation is membrane permeability. AM formation usually increase with increase in root exudates (Graham *et al*., 1981) however, soluble sugar exudates have been found to be weakly associated with the host response, giving that not all the root exudates are important to AM colonization (Azcón and Ocampo, 1981).

AM ability to increase plant growth has been attributed primarily to increased phosphorus uptake (Jakobsen, 1992). Improved phosphate uptake via the mycorrhizal hyphae also forms the basis for enhanced growth and yield in mycorrhizal plants (Gianinazzi-Pearson and Gianinazzi, 1983). Many soils are P deficient (Jeffries, 1987), and P depletion zones rapidly develop in the

immediate vicinity of the roots (Nye and Tinker, 1977; Mosse, 1981). The low mobility of phosphate ions in the soil however limits replenishment. AM hyphae extend and exploit beyond the root zones to absorb and transport phosphorus to the host roots (Cooper and Tinker, 1981; Sieverding, 1991). Also quite a large proportion of the soil P is bound as ester phosphate in complex organic compounds (Anderson, 1980). Such organic P needs be hydrolysed to inorganic P before being utilized by plants and AM fungi have been implicated in the production of acid and alkaline phosphatases at the arbuscules for hydrolysis of P delivered by the hyphae (Tarafdar and Marschner, 1994). The efficient mediation of P input by AM fungi to the symbiotic association is dependent on the greatly improved exploitation of bulk soil by the soil mycelium (Abbott and Robson, 1985). That also depicts its ability to deplete P from more dilute solutions than is possible for non-AM roots (Thompson *et al*., 1990).

In addition to P uptake, AM association has been found to improve nutrient uptake and nutritional status of host plants for the following elements; N (Nielsen and Jensen, 1983; Ames *et al*., 1983), K (Nielsen and Jensen, 1983; Sieverding and Toro, 1988; Osonubi *et al*., 1995), Mg (Sieverding, 1991), Zn and Cu (Benson and Covey, 1976; Cooper and Tinker, 1981), S (Rhodes and Gerdemann, 1978; Buwalda *et al.*, 1983), Bo and Mo (Sieverding, 1991), Fe, Mn and Cl (Buwalda *et al.*, 1983). There have been reported cases, where VAM did not increase the uptake of some of these elements (Krikun and Levy, 1980; Nielsen and Jensen, 1983). Whenever there is enhanced uptake, it has

been attributed to increased soil exploration by the extramatrical hyphae (Jenny, 1961).

There are also secondary influences (Rhodes and Gerdemann, 1978) by which AM symbiosis may affect plant nutrition. This includes altered stomata response and xylem transport (Allen and Allen, 1986), changes in concentrations of growth regulating compounds such as auxin, cytokinins and gibberellins (Allen *et al*., 1980), which may affect nutrient mobilization and uptake (Singh *et al*., 1986). There is increased root exudate that may affect chelation of soil nutrients and changes in root: shoot ratios that may affect rooting density (Hunt *et al*., 1975).

Another widely demonstrated benefit of AM association to the host plant is improved resistance to drought (Huang *et al*., 1985; Puppi and Brass, 1990; Osonubi, 1994). AM plants are observed to be less sensitive to temporary periods of water stress than non-mycorrhizal ones. Increase in hydraulic conductivity of host plants reported by Hardie and Leyton, (1981), has been attributed to greater length and diameter of the roots induced by AM. The occurrence of higher hydraulic conductivity or lower resistance per unit length of mycorrhizal root has been traced to improved host nutritional status during stress (Bolgiano *et al*., 1983; Fitter, 1988). Some other attributes of AM association capable of improving drought tolerance include changes in leaf elasticity (Auge *et al*., 1987a), improved leaf water and turgor potentials and maintenance of stomatal opening and transpiration (Auge *et al*., 1987b).

Also applicable is increased rooting length and depth (Ellis *et al*., 1985; Kothari *et al*., 1990).

The role of AM association in soil conservation forms an important aspect of sustainable agriculture. The extraradical or external soil phase of the AM association is an important contributor to the process of establishing a stable soil aggregate structure (Tisdall and Oades, 1982; Bethlenfalvay *et al*., 1988; Miller and Jastrow, 1990). The process of packaging soil particles into stable aggregates helps soils to accrue organic matter as organic residues are protected from the actions of microbes when encapsulated by clays and silts during aggregate formation (Oades, 1984; Elliot and Coleman, 1988). Arbuscular mycorrhizal fungi improved plant growth in marginal soils (Espinoza *et al*., 1993). They are referred to as biological fertilizers due to their effects on plant P nutrition (Azcón-Aguilar *et al*., 1979). For this reason, it is imperative to apply AM association's role in plant productivity to sustainable food production in a resource poor oriented agro-ecological zone in the tropics.

AM fungi influence the transfer of nutrients between the root zones of associated plants with the hyphae colonizing and connecting the roots of adjacent plants (Francis and Read, 1984; Ritz and Newman, 1984; van Kessel *et al*., 1985). Their broad host range nature (Chanway, *et al*., 1991) permits them to form underground networks of external hyphae that link together roots of different plants growing within the same area (Hamel *et al*., 1991). AM association is involved in interspecific nitrogen transfer as well as other

nutrients (Newman, 1988). The potential of AM fungi to mediate nutrient fluxes between plants is of particular importance in legume-non-legume relationships (van Kessel *et al*., 1985). Legumes serve as a provider of biologically fixed N to non-legumes (Haynes, 1980). They are also important in absorbing and translocating nutrients from dying plants to living plants through this same network (Newman and Eason, 1989).

Other benefits from AM association include increase in chlorophyll concentration (Allen *et al*., 1981) and promotion of nitrogen fixation by symbiotic or associating nitrogen fixing bacteria (Smith *et al*., 1979; Pacovsky *et al*., 1986; Barea *et al*., 1992) and increased resistance to pathogens (Graham, 1983; Fitter and Garbaye 1994). Reports on AM performance on the severity of diseases caused by root pathogenic fungi, bacteria, and nematodes varied. AM fungi appear to decrease plant susceptibility or buildup tolerance against the attack of root pathogens. Inoculation with AM has resulted in the reduction of the diseases or its impact on the productivity of the plant even when the symptom was not reduced. The suggested mechanisms of AM prophylaxis include improved nutrient uptake capable of enhancing plant resistance by a more balanced nutritional status, and induced physiological changes in the plant that deter the pathogen or compete with it for colonization/infection site (Newsham *et al*., 1995; Dodd, 2000). *Glomus mosseae* in particular, induced local and systemic resistance to P. *parasitica* and was effective in reducing symptoms produced by this pathogen (Pozo *et al*., 2002). In some other instances, mycorrhizal plants were found to be more

susceptible to root pathogens than the non-mycorrhizal plants (Larsen and Bodker,2001; Ryan *et al.*,2002). Viral infection was also found to have increased titre in mycorrhizal plants than in non-mycorrhizal plants (Daft and Okusanya, 1973). There are other instances where there is no correlation between the disease incidence and mycorrhizal infection (Weaver and Wehnut, 1975).

2.4 Mycorrhiza integration for sustainable food production

The interdependence of a healthy plant-soil system that forms the base of a sustainable agricultural system is dependent on a myriad of microorganism that inhabits the rhizosphere (interface between plant and soil). An identified organism, mycorrhiza, capable of penetrating the living cells of plants with little or no harm stands out among the host of microbes in this regard. The roots of most flowering plants live associated in a form of mutual symbiosis with mycorrhiza. In 1885, Frank coined the word mycorrhiza (myco-fungus, rhiza-root) with the description of a symbiotic association between plant roots and fungi (Powell and Bagyaraj, 1984). Mycorrhizae are peculiarly specialized that they cause morphologically no damage to their host.

Mycorrhizal fungi are divided into four very different types namely ectomycorrhiza, arbuscular mycorrhiza (AM mycorrhiza), ericaceous mycorrhiza, and orchidaceous mycorrhiza. As indicated by their names, ericaceous mycorrhiza and orchidaceous mycorrhiza are associated with ericaceous plants (blueberries, cranberries, azaleas.) and orchidaceous plants

(orchids), respectively. The fungus biotrophically colonizes the root epidermis and cortex, becoming an integral part of these organs with the development of an extrametrical (soil) mycelium, which the plants utilize to acquire mineral nutrients from the soil.

Some hyphae grow out of the root and the rhizosphere into the soil to form external mycelium. This young root-like external mycelium is non-septate and consists of dichotomously branched, coarse, principal hyphae, 5-20 mm in diameter and thin, secondary hyphae, 1-5 mm in diameter (Friese and Allen, 1991). The external mycelium forms the primary channel for taking elemental nutrient to the root. The hyphae also range deep into the bulk soil with ability of establishing intimate contact with the microbiota of soil aggregates and microsites. Mycorrhizae have impact on both crop production and soil conservation in sustainable agriculture. They are recognized as playing a key role in plant survival and nutrient recycling in the ecosystem.

Based on fungal hyphae arrangement in relation to host root tissues, mycorrhizae have been classified into two basic groups viz; ectotrophic or ectomycorrhiza and endotrophic or endomycorrhiza. In the case of the ectomycorrhizae, the fungal hyphae form a dense network around the roots penetrating the host cells to a limited extent whereas in endomycorrhizae, a loose network of hyphae appears on the root surface while there is an extensive development within the root cortex (Harley and Smith, 1983; Jackson and Mason, 1984).

The presence of mycorrhiza in plants has become as a rule, a normal occurrence while the absence is viewed as unusual in plants (Jackson and Mason, 1984). These unusual species consist of the families of Cruciferae, Chenopodiaceae, Caryophyllaceae and Cyperaceae (Hirrel *et al.*, 1978), Resedaceae (Jackson and Mason, 1984), Amaranthaceae, Sapotaceae, Commelinaceae, Lecythidaceae, Portulacaceae and Proteaceae (Sieverding, 1991) where only few species have been found to be mycorrhizal (Davidson and Christensen, 1977; Allen, 1983). The physiology of the plant is greatly affected by the presence of the fungal symbionts (Harley and Smith, 1983; Smith and Gianinazzi-Pearson, 1988).

The study of mycorrhiza in the past traditionally focused on the potential of mycorrhizal fungi to improve crop yield and minimize the use of fertilizers (Bagyaraj and Verma, 1995). Minimal attention was paid to the association of mycorrhizal fungi with soil (Hayman, 1982; Sylvia, 1992) and its impact on soil structure has only recently been articulated (Miller and Jastrow, 1992; Gianinazzi *et al*., 2005). However Chanway *et al.*, (1991) reviewed extensively the activities of rhizosphere microorganisms and the positive effects on plant productivity through improved plant nutrition.

Mycorrhiza is a symbiotic association between plant roots and fungi performing in a way of improving soil texture, providing adequate nutrition and uptake of essential nutrients especially phosphorus (Mosse, 1977; Newbould and Rangeley, 1984). The low phosphorus requirement for crop productivity on Alfisols may be traced to abundance of mycorrhizal infections

that enhance phosphorus uptake by the crops grown on the Alfisols (Ayanaba and Sanders, 1981). The importance of mycorrhizal fungi in sustainable food production is based on their role as a link between plant and soil. The recognition of the critical importance of soil in sustainable food production (Reganold *et al*., 1990) avails a new outlook on the study and application of mycorrhizal fungi (Sieverding, 1991).

When plants become mycorrhizal, changes occur in concentrations of growth regulating compounds such as auxins, cytokinins and gibberellins. The photosynthetic rates increase and partitioning of photosyntate to roots and shoots changes. It is apparent that almost all legumes with Rhizobium nodules grow better if mycorrhizal (Barea and Azcón-Aguilar, 1985; Linderman, 1991).

2.5 Host Plant

Most plants are mycorrhizal and about 95% of these are believed to be of the Arbuscular type (Meyer, 1973) with the exception of Cruciferae and Chenopodiacea families. The AM fungi are cross compatible between major crop families such as the Gramineae, Leguminosae, Solanaceae, and Rosaceae. The acquisition of plant nutrient and growth response to AMF colonization, are dependent on several inherent morphological and physiological characteristics of the plant (Azcón and Ocampo, 1981; Hetrick *et al.*, 1988; Koide *et al*, 1988; Manjunath and Habte, 1990; Bryla and Koide, 1990). Furthermore, various reports have indicated that host-plant genotype is an important criterion to be

considered when screening or selecting for efficient AM symbiosis in any specific soil or climatic condition (Krishna *et al*., 1985; Rao *et al*., 1990). According to Mercy *et al*., (1990), this host-dependent mycorrhizal colonization is heritable. This is a good advantage in that once a strain that has efficient infection is obtained, it can be propagated and made use of continuously.

The host plant benefits immensely from the symbiotic association in the areas of nutrient and water uptake. The external mycelia of the fungi extend up to 7-8cm from the root surface (Rhodes and Gerdemann, 1975; Owusu-Bennoah and Wild, 1979; Sieverding, 1991). The extension increases the rhizophere of the host plant and enables the roots to explore the soil far beyond the zone the root hairs could have explored (Mosse, 1981). The arbuscular mycorrhizal plants thus have the advantage of enhanced nutrient and water uptake over non-mycorrhizal plants.

It is accepted that AM plants draw most of their phosphate from the soluble pool although more efficiently than non-mycorrhizal plants. Plants benefit most from AMF symbiosis under nutrient poor conditions particularly when P is limiting in soil (Smith, 1980; Cooper, 1984; Barea, 1991) and also respond even at high soil tested P levels (Khalil *et al.*, 1992). Extraradical hyphae of AM fungi often help to increase host's efficiency of nutrient uptake and water absorption from the soil even beyond the root zone.

2.6 Chili pepper

Chili pepper (*Capsicum annuum*) is a popular vegetable valued around the world for the color, flavor, spice, and nutritional value it contributes to many meals. Early voyagers to the Americas, including Central America, Mexico, Peru, and Chile, found many forms of peppers, including them the hot ones. Most of the varieties of pepper referred to as chili peppers belong to *C. annuum* L. However, some varieties with "chili" included in their name are actually *C. frutescens* L. Precise categorization of this particular type of pepper is difficult because of the large number of varieties, and the constant creation of new ones by hybridization. Forms sold or grown by one name in certain areas of the country may not be the same elsewhere, even though the names are the same. Chili constitutes one of the three main commercial types of hot-fleshed (pungent) peppers. The other two are cayenne and tabasco. In Spain the hot peppers are called chili, meaning from Chile, while in the United States, certain varieties of the hot peppers are called chili peppers. However in India, peppers in general are called chilies.

The most popular chili varieties range from 7.5-16 cm long and have a maximum diameter of 2.5-5 cm. Other varieties of chili peppers range from cherry size to conical forms.

2.6 .1 Types

There are many different types of peppers grown in Nigeria. Peppers grown commercially belong to two species; *Capsicum annuum* which includes

all sweet peppers and hot chili peppers, and *Capsicum frutescens*. When the Portuguese first arrived in Nigeria in the late 15th century, it was Oyo empire that controlled trade with them, first in goods such as peppers, which were secured from the northern interior lands and transferred to the southern coast, and later in slaves. Among the pepper varieties of wide acceptance in Nigeria is 'Tatase'.

2.6 .2 Usage

Consequent upon their extreme pungency, chili pepper pods usually are not eaten alone, but are used for flavoring other foods. They may be picked red ripe and dehydrated (dried), or picked green (or red) for fresh use (cooking or canning). Drying can be accomplished by sunlight or in one of the many home dehydrating units on the market. Also, they are quite often pickled. Pungency is due to the presence of capsaicin, a colourless, odourless alkaloid that is concentrated in the placental tissue. Peppers can be classified based on their relative hotness. Scoville Heat unit is a measure of pepper pungency. Pure capsaicin is approximately 16,000,000 Scoville units.

2.6 .3 Agronomy

Chili pepper grows best in a loam or silt loam soil with good water-holding capacity, but can tolerate many soil types, as long as the soil is well drained. Chili peppers require moderate to high rates of fertilization. Pre-plant phosphorus application of 60 to 200 kg/ha is common. Relay or intercropping

also may provide extra income from the same piece of land, and reduce insect and disease problems. It takes about 55–60 days after flowering for fruits to fully form. Chili peppers can be harvested either at the green immature or red mature stage.

2.7 Legumes

The family leguminosae forms the third largest family of flowering plants and contains 650 genera and 18,000 species (Polhill and Paul, 1981) showing variation in sizes from large trees to small herbaceous ephemera. They are of great importance in standard agricultural systems as well as in marginal lands for which pressure is continuously mounting all over the world. Most herbaceous legumes of the Papillionoideae are symbiotic with both nodules forming *Rhizobium* and AM fungi. The mycorrhizal nitrogen-fixing legumes of importance in both temperate and tropical climate include clover, lucerne, beans (*Phaseolus* and *Vicia*), peas, soybeans, cowpea, pigeon pea, chickpea, groundnut, *Stylosanthes*, *Pueraria and Centrosema*. These forages and grain legumes form endomycorrhiza of the arbuscular mycorrhizal type.

The AM fungi do not fix atmospheric N_2 but definitely enhance N fixation by nodule producing bacteria. Colonization of roots by AM fungi favours nodulation by *Rhizobium* (Osonubi *et al.*, 1992; Smith *et al*., 1979). Inoculation of lablab bean and soybean with AM fungi (*Glomus mosseae*) both in the field and pot experiments enhanced nodulation, dry matter yield, tissue N, and phosphorus content (Mahdi and Atabani, 1992). Some soybean

cultivars inoculated with *Bradyrhizobium japonicum* in combination with soil inoculated *Glomus fasciculatum* exhibited increased root colonization, nodulation, shoot P and N concentration and seed yield (Screenivasa *et al*., 1995).

Most legumes that grow in natural soils are symbiotic with both Rhizobium and AM fungi. Plants with both symbiosis generally grow better than plants with either alone (Linderman, 1991). Literature further indicates that nitrogen fixation by Rhizobium nodules is greatly enhanced by the presence of compatible strains of AMF (Barea and Azcón-Aguilar, 1985), while incompatible strains may have little or no effect on nodulation (Bethlenfalvay *et al.*, 1985; Bayne and Bethlenfalvay 1987).

Legumes have a high phosphorus requirement for their optimum growth and nodulation (Van Schreven, 1958). The greater benefit of mycorrhiza to the P nutrition of some legumes compared to other plant species can affect plant competition and survival in mixed plantings (Crush, 1974). Tarafdar and Rao (1997) in a field study conducted to determine the effect of AM fungi on growth and nutrient uptake of the drought hardy legumes observed that concentrations of N, P, Cu and Zn in shoot were significantly higher in inoculated plants. However, K, Ca, Mg, Na, Fe and Mn remained unaffected. Ali and Saleh (1997) also observed that AMF could enhance the dry matter, uptake of P, Zn and Fe and N_2 - fixation by *B. japonicum*. AM - inoculated *Capsicum annum* dry weight and mean P concentration in the five

youngest matured leaves were greater than in uninoculated plants (Olsen *et al*., 1996).

2.8 Arbuscular mycorrhizal interaction in the Rhizosphere

AM fungi formation of symbiotic association with the host plant occurs within and external to the root thus providing an opportunity to have interactions with other soil organisms. Various levels of interactions have been reported between rhizosphere organisms and mycorrhizal fungi. Among the notable of all the interactions between AM fungi and rhizosphere microbes is that between AM and nitrogen-fixing bacteria. According to various reports (Crush, 1974; Mosse, 1977; Redente and Reeves, 1981), nodulating plants have their growth strongly stimulated by AM and Rhizobium.

Some soil and rhizosphere bacteria have been found to produce phosphatase enzymes that solubilize phosphorus from mineral sources (Barea *et al*., 1975). Positive interactions between phosphate solubilizing bacteria (PSB) and AM fungi on plants have been reported (Lindahl and Olsson, 2004; Toljander *et al*., 2005,). However, it is yet to be resolved whether the increase plant growth is due to hormonal secretion by PSB rather than P solubilization (Barea *et al*., 1976; Baya *et al*., 1981). The co-inoculation of these bacteria with AM fungi has resulted in plant growth enhancement. AM fungi however, do not produce phosphatase enzymes but enzyme levels are elevated in their presence (Dodd *et al*., 1987). Sequel to say that AM fungi do not add phosphate to the soil but only improve its availability to the plants. AM fungi

are obligate symbionts and depend solely on the host plant for their carbon needs (Fitter and Merryweather, 1992).

2.9 The tripartite relationship of Host-Rhizobium-AM

All strains of Rhizobium or strains or species of AM fungi neither affect their host plant in the same manner nor to the same degree. Suggestion was made (Bayne and Bethlenfalvay, 1987) from some studies that inter endophyte compatibility may play a role in the combined effect on plant role.

A study (Bethlenfalvay *et* al., 1985) has shown that advance formation of AM inhibited nodulation, which may be due to competition. However, when AM fungi have not significantly increased number of nodules, the size and N_2 fixing activity has been shown to increase (Pacovsky *et al*., 1986).

Mycorrhizal infection usually causes increased translocation of carbon to the infected roots due to irreversible conversion of plant assimilates to fungal-specific carbohydrates (Lewis and Harley, 1965). This reaction creates a fungal sink (Finlay and Soderstrom, 1992) of which demand in turn raises the photosynthetic rate. The photosynthates of the host plant are absorbed by the AM fungi in the root system for development, functional activity and spore formation (Sieverding, 1991) leading to growth depression of the host plant (Buwalda and Goh, 1982).

2.10 AM and the rhizosphere

Earlier studies focused on mycorrhiza as a component of only the plant system, whereas the production base is a healthy plant - soil system (Hayman, 1982; Sylvia, 1992). It is now recognized that the unity and interdependence of this system including its health and resilience, in the face of natural and cultural stresses, is based to a large but little known and appreciated extent on a myriad of microorganisms. These microorganisms inhabit the interface between plant and soil i.e. the rhizosphere. AM fungi become unique among this myriad of microbes and have been identified as both agents of plant nutrition as well as soil nutrition (Reid, 1984; Elliot and Coleman, 1988; Bethlenfalvay and Newton, 1991).

AM fungi optimize the successful coupling of plants with rhizosphere microbial processes. The AM fungi form a symbiotic relationship with plant roots, which becomes a major interface between the soil and the plant (Bagyaraj and Menge, 1978; Ames *et al*., 1984; Linderman, 1988). The germination of spores or other forms of inoculum propagule results in specialized haustoria-like structures within the cells termed arbuscules where metabolite exchanges take place between fungus and host cytoplasm. Vesicles also form in the cortical cells functioning as nutrient storage organs or as propagules in root fragments. Mycorrhizal plants are found capable of increasing photosynthetic rates, altering nutritional status levels of growth–regulating substances and patterns of root exudation due to changes in membrane permeability. The above physiological changes in addition to

physical and chemical presence of external hyphae of the AM fungi significantly affect the chemical, physical, and microbiological composition of the Rhizosphere soil (Meyer and Linderman, 1986; Schisler and Linderman, 1989). Mycorrhizal fungi release powerful chemicals into the soil that dissolve hard to capture nutrients such as P, Fe and other tightly bound soil nutrients (Lester, 2009).

2.11 Soils and Fertilizer Input

The more environmentally conservative traditional forms of agriculture practiced in the past are no longer sustainable because of increased population densities and developmental pressures on land. The last four decades have witnessed great interest in the development of farming systems characterized by a relatively inexpensive level of input, a high efficiency of internal resource use and hence more sustainable production in both economic and ecological terms. Soil P nutrient status is a key factor in plant response to mycorrhiza (Hayman, 1983; Uyanoz *et al*., 2007), however the amount of root infection is not indicative of endophyte's ability to enhance plant growth. Species and strains of AM fungi although capable of infecting a wide range of legumes and non legumes vary greatly in their infective potential and symbiotic effectiveness as they exhibit preferences for particular soils and host plants (Ross and Ruthencutter, 1977; Schenck and Smith, 1982; Ollivier *et al*., 1983).

Studies with low cost partially acidulated rock phosphate sources have given inconsistent results and no obvious advantage over conventional sources (Bationo *et al.,* 1986). Owing to low phosphate fixing capacity of Alfisols derived from acidic rocks (Juo and Fox, 1977), phosphorus placement is only advantageous at very low rates of phosphorus application i.e. initial dressing of 30kgP/ha followed by maintenance dressing of 15 - 20kgP/ha. Slightly higher dressing is required on soils derived from basic rocks. Sanchez (1981) suggested the use of cheaper phosphorus sources as one of the ways to overcome the phosphorus problem.

Studies have shown that cultural practices influence the presence of AM fungi both quantitatively and qualitatively (Evans and Miller, 1990; Jasper *et al*., 1991; Land *et al*., 1993). The negative effect of fertilizer input on AM in crops is well known, however, AM fungi vary in their sensitivity to fertilizer application. Examples are N (Porter and Beute, 1972; Hayman, 1975; Chambers *et al*., 1980; Wang and Hayman, 1982) and P (Sanders, 1975; Crush, 1974; Porter *et al*., 1978; Hayman, 1984).

The amount of P fertilizer applied annually is second only to the amount of nitrogen. Phosphorus plays a major role in all plant life, functions as part of the energy reactions ATP and ADP (Westheimer, 1987). It is required by plant in large amount (Hayman, 1975; Tinker, 1980). Despite high levels of phosphorus in the soil, most of it is stored within the soil and not available for plant use. P fertilizers when added to most tropical soils (Oxisols and Ultisols) are rendered unavailable because of the high P-fixing power of these soils.

Even though an expensive agricultural input, its use efficiency by crops may be as low as 10-25% (Bahl and Singh, 1986). Both mycorrhizal and non-mycorrhizal roots take up phosphate ions from the same soil fraction. However, mycorrhizal roots possess by virtue of external mycellium a larger and better-distributed absorbing surface. Improved P nutrition has been shown to increase in both infertile and P-fixing soils of the tropics (Dodd, 2000).

The soils mostly used for agriculture in Nigeria include the well drained upland Alfisols and Ultisols. Major upland soils in the humid and subhumid zones particularly in West Africa consist of low activity clays (LAC) – Alfisols, Ultisols and Oxisols. Alfisols that are less leached, slightly acidic and derived from pre-cambrian crystalline basement complex rock (Harpstead, 1973) have a high base saturation and are predominant in the subhumid zone. The Ultisols and Oxisols are more prevalent in the humid zone. Low nutrient status, low phosphorus sorption capacity and high residual effects from applied P characterize the Alfisols and associated soils. The LAC soils are defined as soils with effective cation exchange capacity (ECEC) of < 16meq/100g clay in the subsoil (Juo and Adams, 1986). Observations in West Africa have shown that the majority of LAC soils have ECEC < 8meq/100g. The clay fraction consists mainly of kaolinite and halloysite, with oxides and hydrous oxides of Fe and Al.

After N, phosphorus is apparently the most limiting plant nutrient in most agricultural soils of Nigeria. The savanna soils are inherently deficient in P, which limits crop production to a great extent. The organic P constitutes

about 20-50% of the total P in soils. The savanna values range from 20-40% while higher values 30-54% have been reported for forest soils (Olaitan and Lombin, 1985). For soils all over Nigeria, Enwezor and Moore (1966) found a range of 17-72% organic P and Adepetu (1970) also observed total soil P contained 47% organic P in forest soils and 57% in savanna soils.

Fertilizer consumption in Nigeria is in the increase since 1990. The price per bag has also increased for more than six folds (from N200 to N1, 200 – N1, 500 per 50kg bag) due to deregulation of fertilizer market. Nigeria imports about 200,000 tonnes of SSP and about 600,000 – 8,000,000 tonnes compound fertilizers containing P are used annually. This translates to about N16 billion including transportation. This high cost of phosphate source has initiated investigation into local alternative – Sokoto rock phosphate and Ogun rock phosphate (Nehikhare, 1987; Sobulo, 1990). In Nigeria, phosphate deposits were found in Sokoto, Ifo and Oja Odan in Ogun State and part of Bendel State. Sokoto deposit was put at about 10million tonnes while about half a million tonne P_2O_5 were estimated for Ogun State. Rock phosphate can be used on unlimed acid soil as an inexpensive and efficient way of supplying P to acid tolerant crops (Juo and Kang, 1979; Srivastava *et al*., 2009).

Acid soils of the tropics are usually deficient in available P as a result of low P reserves and the dominance of occluded and organic forms over more active forms of P. The roots of non-acid tolerant species can only explore a limited volume of soil, thereby contributing to inefficient or limited use by such plants of P reserves in acid soils. The Alfisols and associated soils have

low P fixation and high residual effects from applied P. AMF are inhabitants of tropical ecosystems (Miller 1979; Skujins and Allen, 1986). The potential benefits of these obligate symbionts in increasing growth and uptake of P and other relatively immobile nutrients in the host plants are well known (Stribley *et al.*, 1980; Hardie and Leyton, 1981; Nelsen and Safir, 1982; Harley and Smith, 1983; Hayman, 1986; Osonubi *et al*., 1991; Linderman, 1992) particularly in low P soils. However, more attention has been focused on inorganic source of P and its uptake. It has also been suggested that one of the major functions of AM fungi is to lower the P requirements and increase P uptake in soils low in available P (Harley and Smith, 1983; Sieverding, 1991). The chief phosphorus containing rock mineral is apatite, the most soluble of which is fluorapatite $3[Ca_3(PO_4)_2]CaF_2$. The apatites are generally insoluble as to be of little immediate agricultural importance but do decompose with time to simpler and more soluble forms such as tricalcium phosphate $Ca_3(PO_4)_2$ and its derivatives. Organic matter has been shown to increase phosphate availability by the mechanism of solubilization (Webley *et al.*, 1960; Bromfield, 1959; Gerretson, 1948; Srivastava *et al*., 2009) and chelation (Nagarajah *et al.*, 1979).

Phosphate rocks are non-renewable resource but capable of meeting the requirement of slow growing crops like oil palm, rubber, cocoa etc. In Malaysia, it is a major source of P for rubber and tree crops. In West African countries e.g. Burkina Faso and Niger, it is a feasible farming fertilizer practice (Nehikhare, 1987; Sobulo, 1990; Adediran and Sobulo, 1995). However, for

rapid growing arable legumes and vegetables, a promising strategy to achieve maximum efficiency in their use is through research into appropriate combination with mycorrhiza and organic manure for rapid solubilization and plant uptake.

2.12 Farming Systems

Modern-day farms in the tropics seem to be moving away from their integrated pasts. In the past, farms raised a number of diversified products ranging from vegetables to grains to livestock. These integrated systems enabled farmers to make complete use of their diversified resources. Rather than purchase fertilizers, farmers used cover crops and the manure from their livestock to fertilize their fields. The use of crop rotations and companion planting serve to minimize pest damage instead of applying pesticide. In addition, rather than raise just one product, farmers raise a variety of crops to help meet the homestead's needs as well as the needs of the marketplace. All these techniques have been, for the most part, lost to the current generation of farmer. In the current farming system, farmers purchase chemical fertilizers and pesticides and focus their production on monoculture. This monoculture production may be efficient in the short run, with regards to revenue generation for the farmer, but it leaves much to be desired in terms of a healthy farm community (Barea and Jeffries, 1995) and a healthy farm ecosystem.

CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1 Soil Sample collection and sterilization

Surface soil samples (0-15cm) of Alfisols (Iwo series) were collected from undisturbed plot (over twenty years) except for annual removal of underbrush behind Botany and Microbiology Department, University of Ibadan. The bulked sample was air-dried, pulverized and passed through a 2mm sieve and was divided into two equal halves. The first half was then steam sterilized at 100 °C for 48 hours, allowed to cool before being bagged and made ready for use for the experiments that required sterilized soil. The other half remained unsterilized. These two different categories of soil samples served as growing media for the first two pot experiments.

The same sterilization procedure was followed for another set of soil samples collected at the National Horticultural Research Institute, Ibadan vegetable plots where the field experiments were sited. The samples that were collected here served for two additional sets of pot experiments.

3.2 Production of arbuscular mycorrhiza inoculum

Soil inoculum consisting of external hyphae, mycorrhizal root fragments and spores of *Glomus mosseae*, *Glomus etunicatum* or *Glomus fasciculatum* each obtained from the Department of Botany, University of Ibadan was used for propagation. Soil inoculum is considered to be more

infective than spore inoculum. Fifteen-liter size plastic buckets already perforated at the bottom were each filled with 10kg of sterilized soil. Two seeds each of maize (trap plants) were sown in the sterilized soil contained in the plastic buckets with 50g-soil inoculum carefully layered 2-3cm below the seeds. After emergence, seedlings were thinned out to one per pot and allowed to grow under greenhouse management conditions for three months. During this period the seedlings were adequately watered routinely. The maize plant was disallowed from fruiting as the stamens were carefully removed prior to fertilization process. After two months, the plants were drought-stressed and aerial part of the plant cut off. The dried soils with the infected maize roots cut into small bits were thoroughly mixed together and stored in sterilized plastic bags for use as mycorrhizal inoculum.

3.3 Seed preparation

Seeds of *Vigna unguiculata* var. Ife Brown (cowpea), *Glycine max* (soybean), *Cajanus cajan* (pigeon pea) and *Capsicum annuum* var. "Tatase" (chili pepper) were surface sterilized for five minutes with 65ml of 70% (v/v) ethanol plus 1.2% (w/v) sodium hypochlorite solution and subsequently washed with distilled water several times. Seeds of chili pepper were germinated in plastic trays containing sieved sterilized soil and then transplanted after four weeks. The cowpea, soybean and pigeon pea seeds were directly sown in experimental pots for greenhouse studies or field plots.

3.4 Soil Physical and Chemical Analysis

3.4.1 Moisture content determination

A sub sample of the air-dried, sieved soil (100g) was measured into moisture cans of known tare weights. The sub sample in duplicate was oven dried at 105^0C to constant weights. Moisture content was calculated thus:

$$\text{Moisture content (\%)} = \frac{\text{wt of air dry soil - wt of oven dry soil}}{\text{wt of oven dry soil}} \times 100$$

3.4.2. Field Moisture Capacity (FMC)

Air-dry soil sample of known moisture content was filled up to the 1000ml mark of a graduated cylinder. A capillary tube was inserted for exhaustion of air. Added to the soil was 150ml H_2O after which the cylinder was plugged with cotton wool to prevent loss of water through evaporation. After the stoppage of water movement, an average reading was taken at the wetting front to calculate the field moisture capacity.

$$\text{FMC} = \text{ml } \frac{H_2O \text{ added + ml of } H_2O \text{ already in soil}}{\text{Oven-dry weight of wetted soil}} \times 100$$

3.4.3. Particle size analysis

Particle size analysis was determined according to the hydrometer method (Bouyoucos, 1962). Air-dry soil (51g) sample was transferred into a milkshake mix cup. Sodium hexametaphosphate (5.0%) was added along with 100ml distilled H_2O.The sample was mixed with a stirring rod and allowed to

set for 30mins.The soil suspension was then stirred for 15mins with multimix machine and transferred to a glass cylinder. With the hydrometer in the suspension, distilled H_2O was added to the lower blue line (1130ml). The first reading was taken at 40secs and subsequent reading at 3hrs.

3.4.4. pH

Soil pH was determined potentiometrically with soil solution ratio of 1:1 in H_2O. Using the standard scoop (10ml), one level scoop of soil sample was transferred into extraction cups and 10ml distilled water added. It was allowed to stand for 15mins and stirred for 5mins. After stirring, it was allowed to stand for another 10mins. The pH was read on the pH meter standardized with buffer solution of pH 4.0 and 7.0.

3.4.5 Organic carbon

This was by the chromic acid digestion method of Walkley and Black (1934). Air-dried soil (1.00g) sample was weighed in a weighing boat and transferred to the bottom of a clean and dry 250ml conical flask. The procedure was followed using the reagents; Potassium Dichromate solution and concentrated Sulfuric acid. The solution was filtered (No 2 Whatman filter paper) into 50ml vials. Readings were taken on the Brinkman probe colorimeter.

3.4.6 Exchangeable cations

Exchangeable cations were extracted using neutral ammonium acetate solution (IN NH_4OAC). Potassium and Sodium were determined using a flame photometer. Calcium, Magnesium and Manganese were read using Perkin Elmer Atomic Absorption Spectrophotometer. The determination of Zn and Cu in soil was also by atomic absorption spectrophotometry while that of Fe in soil extracts was by orthophenanthroline method.

3.4.7 Total Nitrogen in soil

The quantitative determination of total nitrogen in soil involved the digestion of organic matter using the Tecator Digestor followed by measurement of ammonium produced. The ammonium was determined colorimetrically using the Berthelot reaction following the procedure of Technicon autoanalyzer (AA11).

3.4.8 Available P in soil

Available P in soils was determined by Bray No.1 method. Ammonium molybdate reacts in an acid medium to form molybdophosphoric acid that is reduced to the molybdenum blue complex read on colorimeter by reaction with ascorbic acid.

3.5 Plant tissue analysis

3.5.1 Total Nitrogen in plant tissue

The quantitative determination of total nitrogen in plant involved the digestion of organic matter using the Tecator Digestor followed by measurement of ammonium produced as obtained in soil.

3.5.2 Total P in plant tissue

The colorimetric determination of P in plant tissue followed that of Vanado-molybdate method. The practice of colorimetry operates on two basic principles that when a ray of monochromic light enters an absorbing medium, its intensity decreases exponentially with an increase in the thickness/concentration of the medium traversed. The complex is measured colorimetrically at 420nm.

3.5.3 Total Cations in plant material

The determination of total cations in plant material was preceded by digesting plant material using Tecator Digestor and reading concentration with Perkin Elmer Atomic absorption Spectrometer.

3.6. Pot experiments

3.6.1 Experiment 1: Effect of AM fungi, different cropping systems and P-fertilization on chili pepper in non-sterilized soil

This experiment was performed within the premises of Botany and Microbiology Department University of Ibadan under natural solar illumination and daily temperature (25 – 28^{0}C).

Six-kilogram (6kg) portions of sieved soil were weighed into plastic buckets (15L size) with perforated bottom but plugged with cotton wool. 4kg soil and 100g of mixed inoculums consisting of infected roots, spores and mycelium were spread over and finally topped with additional 2kg soil. Each plastic bucket (totaling fifty-four in number) containing the soil sample and the mixed inoculum was well watered before introducing the test crops. Roots of *Capsicum annuum* var. Tatase, germinated in sterilized soil contained in flat nursery trays (about 5cm deep) were rinsed thoroughly in distilled water. Four seedlings per pot were transplanted. These were later thinned down to two plants per pot. The cowpea seeds (two per pot) were planted directly into experimental pots where required. The treatments were arranged on raised platform (to break contact with the ground) in a 3x2x2 factorial experiment with randomized complete block design. The treatments consisted of AM inoculation (*Glomus mosseae, Glomus etunicatum* and un-inoculated control); cropping systems (sole pepper, and mixture); and P-fertilization (0kg Pha^{-1} and 60kg Pha^{-1} single super phosphate). Each treatment was replicated thrice. The treatment combinations were as shown in Table 3.1. Routine cultural

operations and observations were carried out during experimentation. These included the maintenance of adequate soil moisture and weekly data record of growth parameters such as height, stem diameter, number of leaves and number of branches.

3.6.2 Experiment 2: Effect of AM fungi, different cropping systems and P-fertilization on chili pepper on sterilized soil.

The experiment was also performed within the premises of Botany and Microbiology Department, University of Ibadan under similar natural solar illumination and daily temperatures as with non-sterilized soil.

Six-kilogram (6kg) portions of sieved sterilized soil were weighed into plastic buckets (15L size) with perforated bottom and same treatments as obtained with non-sterilized soil applied. This second experiment was different from the previous pot experiment because of the reduction or removal of indigenous microbes through sterilization procedure.

Table 3.1. Treatment combinations 3x2x2 applied to chili pepper with mycorrhiza, cropping system and P-fertilization on non-sterilized soil.

Mycorrhiza	P-fertilization	Cropping systems	
		Sole pepper	Pepper+Cowpea
Glomus mosseae	0kg Pha^{-1}	x	x
	60kg Pha^{-1}	x	x
Glomus etunicatum	0kg Pha^{-1}	x	x
	60kg Pha^{-1}	x	x
Un-inoculated	0kg Pha^{-1}	x	x
	60kg Pha^{-1}	x	x

Table 3.2. Treatment combinations 3x2x2 applied to chili pepper with mycorrhiza, cropping system and P-fertilization on sterilized soil.

Mycorrhiza	P-fertilization	Cropping systems	
		Sole pepper	Pepper+Cowpea
Glomus mosseae	0kg Pha^{-1}	x	x
	60kg Pha^{-1}	x	x
Glomus etunicatum	0kg Pha^{-1}	x	x
	60kg Pha^{-1}	x	x
Nonmycorrhizal	0kg Pha^{-1}	x	x
	60kg Pha^{-1}	x	x

3.6.3 Experiment 3: Effect of mycorrhizal inoculation, grain legume intercrops and rock phosphate addition on growth and yield of chili pepper.

This experiment that commenced on May 1999 was conducted within the premises of National Horticultural Research Institute's greenhouse under natural light intensity and daily temperature (25 – 28^0C). Six kilogram portions of sieved sterilized soil were weighed into plastic buckets (15L size) perforated and plugged with cotton wool at the bottom. The perforated buckets was filled initially with 4kg sterilized soil, 100g of mixed inoculum consisting of infected roots, spores and mycelium was spread over the 4kg sterilized soil and finally topped with additional two kilogram (2kg) sterilized soil. Each plastic bucket containing the sterilized soil and the mixed inoculum was well watered to provide adequate moisture regime for germination and emergence before introducing the test crop.

Vigna unguiculata var. Ife Brown, *Glycine max* and *Capsicum annum* var. Tatase seeds were surface sterilized for 5mins with 65ml of 70% (v/v) ethanol and 1.2% (w/v) sodium hypochlorite solution before rinsing thoroughly in distilled water. Roots of pepper seedlings (*Capsicum annum* var. Tatase), germinated in sterilized soil were rinsed thoroughly in distilled water before transplanting. Four seedlings were transplanted per pot where applicable. These were later thinned to two plants per pots. The treatments were arranged on benches in a 3 x 3 x 2 factorial experiment with randomized complete block design consisting of mycorrhiza; *Glomus fasciculatum*, *Glomus mosseae*, and non-mycorrhizal control, cropping systems; cowpea +

pepper, soybean + pepper and pepper only and P fertilization; 0kg P/ha and 60kg P/ha rock phosphate. Each treatment consisted of three replicates. Routine cultural operations were carried out during experimentation. These included growth maintenance and weekly data record of growth parameters such as height, stem diameter, number of leaves and number of branches.

Table 3.3 Treatment combinations 3x3x2 applied to chili pepper with mycorrhiza, cropping system and rock P-fertilization on sterilized soil.

Mycorrhiza	Rock P-fertilization	Cropping systems		
		Cowpea+pepper	Soybean+pepper	Pepper only
Glomus mosseae	0kg Pha^{-1}	x	x	x
	60kg Pha^{-1}	x	x	x
G. etunicatum	0kg Pha^{-1}	x	x	x
	60kg Pha^{-1}	x	x	x
Non mycorrhizal	0kg Pha^{-1}	x	x	x
	60kg Pha^{-1}	x	x	x

3.6.4 Experiment 4: Effect of mycorrhizal inoculation, organic manure and rock phosphate amendments on growth and yield of chili pepper.

This experiment was also conducted within the premises of National Horticultural Research Institute's greenhouse under natural light intensity and daily temperature (25 – 28^0C). Six kg portions of sieved sterilized soil were weighed into plastic buckets (15L size) perforated and plugged with cotton wool at the bottom. The initial filling of the perforated buckets with sterilized soil and 100g of mixed inoculum followed the same procedure as reported in previous experiments.

Roots of pepper seedlings (*Capsicum annum* var. "Tatase"), germinated in sterilized soil were rinsed thoroughly in distilled water before transplanting. Four seedlings were transplanted per pot initially which were later thinned to two plants per pot. The treatments were arranged on benches in a 3 x 3 x 2 factorial experiment with randomized complete block design consisting of mycorrhiza; *Glomus fasciculatum, Glomus mosseae*, and *Glomus etunicatum*, organic manure; nil, 2% and 5% metric tons per ha and P fertilization; 0kg P/ha and 60kg P/ha rock phosphate. Each treatment consisted of 3 replicates. Routine cultural operations were carried out during experimentation and data collected included weekly record of growth parameters such as height, stem diameter, number of leaves and number of branches.

.

Table 3.4: Treatment combinations 3x3x2 applied to chili pepper with mycorrhiza, organic manure and rock P-fertilization on sterilized soil.

Mycorrhiza	Rock P-fertilization	Organic manure		
		Nil	2%	5%
Glomus mosseae	0kg Pha^{-1}	x	x	x
	60kg Pha^{-1}	x	x	x
Glomus etunicatum	0kg Pha^{-1}	x	x	x
	60kgPha^{-1}	x	x	x
Non mycorrhizal	0kgPha^{-1}	x	x	x
	60kgPha^{-1}	x	x	x

3.7. Field experiments

3.7.1 Background history of the experimental location

The two field experiments were established at National Horticultural Research Institute, Ibadan on May 1998. National Horticultural Research Institute covers approximately 586 hectares and is situated directly on the West of Ibadan city. It falls within longitudes 3^0 50^1 and 3^0 52^1 east and latitudes 7^0 23^1 and 7^0 25^1 north. The wet season with high rainfall intensity is usually between March and September while the dry season is between October and February annually. The annual rainfall is about 1226.8mm.

The soils in the area fall into three major soil associations namely Iwo, Egbeda and Okemesi (Smyth and Montgomery, 1962). The soils also fall into three main drainage classes defined as follows; (i) well-drained soils in which the water table is always below a depth of about 120 cm at any period of the year (ii) poorly drained soils in which the water table may lie within a depth of 25 cm to 120cm and (iii) swampy soils in which the water table may rise within either the top 0 – 25 cm or above the soil surface (Jaiyeola, 1974).

The area selected is the well-drained soils in which the water table is always below a depth of about 120 cm at any period of the year. This area served as the vegetable plots for the Institute since its inception and has been under intensive continuous cultivation for close to three decades.

3.7.2. Experiment 5: Effect of mycorrhizal inoculation, organic manure and rock phosphate amendments on growth and yield of chili pepper under field conditions

The first field experiment was conducted on the vegetable plot of National Horticultural Research Institute Ibadan, Nigeria (3^0 50^1 and 3^0 52^1 east and latitudes 7^0 23^1 and 7^0 25^1 north). Roots of pepper seedlings (*Capsicum annum* var. "Tatase"), germinated in sterilized soil were rinsed thoroughly in distilled water before transplanting. Two seedlings were transplanted per stand initially which were later thinned to one plant per hole. The plot size was $2x2m^2$ and treatments were laid out in a 3 x 3 x 3 factorial experiment with randomized complete block design (Tables 3.5 and 3.6) consisting of mycorrhiza; *Glomus fasciculatum*, *Glomus mosseae*, and *Glomus etunicatum*, organic amendment; nil, grain legume intercrop and farmyard manure and P-fertilization; 0kg P/ha, 30kgP/ha and 60kg P/ha single super phosphate. Each treatment consisted of 3 replicates. Routine cultural operations were carried out during experimentation. Data collection including weekly record of growth parameters such as height, stem diameter, number of leaves and number of branches began two weeks after field establishment.

Table 3.5. Treatment combinations 3x3x3 applied to chili pepper with mycorrhiza, organic amendments and rock P-fertilization on field "A".

Mycorrhiza	Rock P-fertilizer	Soil organic amendments		
		Legume	Manure	Nil
Glomus etunicatum	0kg P/ha	x	x	x
	30kg P/ha	x	x	x
	60kg P/ha	x	x	x
Glomus fasciculatum	0kg P/ha	x	x	x
	30kg P/ha	x	x	x
	60kg P/ha	x	x	x
Glomus mosseae	0kg P/ha	x	x	x
	30kg P/ha	x	x	x
	60kg P/ha	x	x	x

Table 3.6. Experimental field "A" lay out in a randomized complete block design.

10	6	7
14	15	23
16	21	13
20	11	3
17	5	26
18	25	22
4	8	24
2	1	12
27	9	19

Rep 1

25	11	23
3	13	16
2	6	10
15	5	1
21	7	9
20	24	4
26	19	12
27	17	8
18	14	22

Rep 2

26	13	6
3	25	1
7	12	9
4	23	11
20	2	10
19	24	27
21	16	8
15	22	18
17	5	14

Rep 3

No	Treatments
1	*G.etunicatum* only
2	*G.etunicatum* +30kgP/ha
3	*G.etunicatum* +60kgP/ha
4	*G.etunicatum* +legume mixture
5	*G.etunicatum*+legumemixture+30kgP/ha
6	*G.etunicatum*+legumemixture+60kgP/ha
7	*G.etunicatum*+org. manure
8	*G.etunicatum* +org. manure+30kgP/ha
9	*G.etunicatum* +org. manure+60kgP/ha
10	*G.fasiculatum* only
11	*G.fasiculatum* +30kgP/ha
12	*G.fasiculatum*+60kgP/ha
13	*G.fasiculatum*+legume mixture
14	*G.fasiculatum*+legumemixture+30kgP/ha

No	Treatments
15	*G.fasiculatum*+legumemixture+60kgP/ha
16	*G.fasiculatum*+org. manure
17	*G.fasiculatum*+org. manure+30kgP/ha
18	*G.fasiculatum*+org. manure+60kgP/ha
19	*G.mosseae* only
20	*G.mosseae*+30kgP/ha
21	*G.mosseae*+60kgP/ha
22	*G.mosseae*+legume mixture
23	*G.mosseae*+legumemixture+30kgP/ha
24	*G.mosseae*+legumemixture+60kgP/ha
25	*G.mosseae*+org. manure
26	*G.mosseae*+org. manure+30kgP/ha
27	*G.mosseae*+org. manure+60kgP/ha

3.7.3 Experiment 6: Effect of mycorrhizal inoculation, cropping systems and rock phosphate amendments on growth and yield of chili pepper under field conditions

The second field experiment was also conducted on the vegetable plot of National Horticultural Research Institute Ibadan, Nigeria (3^{o} 46'E and 7^{o} 27'N). The plot size was $2x2m^2$ and treatments were laid out in a 3 x 3 x 2 factorial experiment with randomized complete block design (Tables 3.7 and 3.8) consisting of mycorrhiza; *Glomus etunicatum*, *Glomus fasciculatum*, and *Glomus mosseae*, cropping systems; cowpea+pepper, soybean+pepper, pepper only and P-fertilization; 0kg P/ha and 60kg P/ha rock P. Each treatment consisted of 3 replicates. Routine cultural operations were carried out during experimentation. Data collection including weekly record of growth parameters such as height, stem diameter, number of leaves and number of branches also began two weeks after field establishment.

Table 3.7. Treatment combinations 3x3x2 applied to chili pepper with mycorrhiza, cropping systems and rock P-fertilization on field "B".

Mycorrhiza	Rock P	Cropping systems		
		Cowpea+pepper	Soybean+pepper	Pepper only
G.etunicatum	0kg P/ha	x	x	x
	60kg P/ha	x	x	x
G.fasciculatum	0kg P/ha	x	x	x
	60kg P/ha	x	x	x
G.mosseae	0kg P/ha	x	x	x
	60kg P/ha	x	x	x

Table 3.8. Experimental field "B" lay out in a randomized complete block design.

6	9	17
13	18	16
4	8	5
7	10	11
12	15	3
1	2	14

Rep 1

8	11	2
5	16	9
17	4	1
3	7	6
12	18	14
13	15	10

Rep 2

4	5	15
6	16	12
7	14	2
20	2	10
18	3	17
10	13	1

Rep 3

No	Treatments	No	Treatments
1	*G. mosseae* only	10	*G. fasiculatum*+ cowpea + 60kgP/ha
2	*G.mosseae* + 60kgP/ha	11	*G.fasiculatum*+cowpea/soybean
3	*G. mosseae* + cowpea	12	*G.fasiculatum*+cowpea/soybean +60kgP/ha
4	*G. mosseae* + cowpea + 60kgP/ha	13	Control
5	*G. mosseae* +cowpea soybean mixture	14	+60kgP/ha
6	*G.mosseae*+cowpea/soybean +60kgP/ha	15	+ cowpea
7	*G. fasiculatum* only	16	+ cowpea + 60kgP/ha
8	*G. fasiculatum*+ 60kgP/ha	17	+cowpea soybean mixture
9	*G. fasiculatum* + cowpea	18	+cowpea soybean mixture + 60kgP

3.8. Estimation of AM infection

The AM infection was carried out for pepper only. This was done after the plants were cut at the onset of flowering. Two grams (fresh weight) of susceptible feeder roots from each plant sample were stored in 50% alcohol contained in Mac-Carthney bottle after being thoroughly washed with distilled water. The primary site for AM to develop is in the cortical region of the terminal feeder roots. This serves as the most active site for nutrient uptake. These root samples were later stained with trypan blue dye.

The ethanol was decanted and the roots washed in water. This was followed by clearing in 10% KOH at 90^0C for one hour and subsequent bleaching in 10% H_2O_2 for 30 minutes under room temperature. The roots were rinsed in at least three changes of water and acidified in 1% HCl for 30 minutes. Later the 1% HCl was decanted and the roots were stained in trypan blue dye (Sigma chemical Co. St Louis, USA). Trypan blue dye was prepared by mixing 500ml of glycerol, 450ml of H_2O_2, 50ml of HCl and 0.5g trypan blue. The stained roots were kept in an oven at 90^0 C for 30 minutes and left overnight before the stain was decanted. The treated samples were stored inside glycerol to prevent excessive distaining prior to determining root colonization percentage.

The percentage root colonization was estimated by grid line intersect method (Giovanetti and Mosse, 1980). Samples were spread on a grid line plate and presence of root colonization was scored at each point where stained

root with hyphae, vesicles or arbuscles intersects with a line. The percentage colonization was calculated as:

$$\frac{\text{No of root/gridline intersects with colonization}}{\text{Total no. of root/gridline intersects counted}} \times 100\%$$

3.9. Data collection

Routine observations and data collections commenced two weeks after seed emergence and terminated at the onset of flowering. From the sixth week after planting, height (cm), leaf number, number of branches and stem diameter were determined weekly. Stem diameter was taken at 2cm above the soil level using the digital Vernier calliper (Mituoyo Corporation, Japan) while height was determined above soil level using a meter rule.

At onset of flowering (applicable only to pot experiments), plants were harvested i.e. cut above soil level, carefully packed in large labeled brown envelopes and transferred to the oven for drying at a temperature of 70^0 C in 48hrs. The dry matters were determined and samples safely preserved for tissue analysis. For the field experiments data were taking until full maturity and final harvest.

Analysis of Variance was performed on all data. Duncan's multiple range test was used to separate the means of the significant measured parameters

CHAPTER 4

RESULTS

4.1. Pre-experimental physical and chemical properties of soil

The physical and chemical properties of unsterilized soil samples for the container medium greenhouse experiment analyzed prior to experiment initiation, are shown in Table 4.1. The soil is a loamy sand of moderately high fertility, slightly acidic with a pH (H_2O) of 6.3. The soil was moderately supplied with organic matter at 3.61%. The total nitrogen content was medium and rarely exceeded 0.19%. The dominant clay mineral is kaolinite but the cationic nutrients are considered moderately high, except K which is below the critical 0.15cmol/kg.

Table 4.1. The physical and chemical properties of unsterilized soil

Parameters	Values
Sand %	86.6
Silt %	8.0
Clay %	5.4
pH	6.3
Carbon %	2.1
Organic matter %	3.61
Total N %	0.19
Available P kg/ha	21.5
Exchangeable cations ($cmol_c/kg$)	
Ca	19.6
Mg	1.3
K	0.1
Na	0.6
Zn (mg/kg)	1.90
Cu	1.0
Mn	3.81
Fe	7.0

4.2. The chemical properties of unsterilized soil after harvest

There were significant ($P < 0.05$) variations among the treatments in soil pH, %C, available P and exchangeable Ca at the two levels of inorganic P additions in the different cropping systems (Table 4.2). However, the treatments were not significantly different from each other in the case of exchangeable Mg and Zn (Table 4.2). Treatment with *Glomus mosseae* at $60kgPha^{-1}$ showed significantly ($P < 0.05$) lower pH (6.5) than all other treatments. Uninoculated treatments contained significantly ($P < 0.05$) higher % soil organic carbon (1.65%) at $60kgPha^{-1}$ than all other treatments except treatment with *Glomus mosseae* (1.63%) at the same level of P-fertilization (Table 4.2). Soil available P was consistently low with *Glomus etunicatum* inoculation at the two levels of P-fertilizer application. However, the soil Mg and Zn did not vary significantly by treatments. Soil calcium was significantly ($P< 0.05$) higher in uninoculated treatment ($34.37meq100g^{-1}$soil) at 60kg P/ha addition than others in sole chili pepper (Table 4.2). There were significant interactions between mycorrhiza and P-fertilization in soil pH, available P, Ca, Mg and Zn (Table 4.2) and between cropping systems and P-fertilization in soil organic carbon content. There was also a three-way significant interaction among mycorrhiza, cropping system and P-fertilization in soil available P (Table 4.2).

Table 4.2. Post-experimental effect of mycorrhiza and P-fertilizer application on chemical properties of non sterilized soil under different cropping systems with *Capsicum annuum* var. Tatase

Treatments	pH	%C	Av P (ppm)	Ca (meq/100g)	Mg	Zn (ppm)
Nil P						
Glomus mosseae	6.8ab	1.51c	9.16a	29.64b	2.26a	0.8a
Glomus etunicatum	6.7b	1.51c	6.57b	29.74b	2.13a	0.96a
Un-inoculated	6.9a	1.54bc	9.13a	31.15b	2.3a	1.3a
60kgP/ha						
Glomus mosseae	6.5c	1.63ab	7.72ab	31.03b	2.28a	0.91a
Glomus etunicatum	6.8ab	1.54bc	6.11b	31.42b	2.11a	2.27a
Uninoculated	6.9a	1.65a	7.65ab	34.37a	2.47a	0.54a
Main effect(P values)						
AM	0.001**	0.024*	<.001***	<.001**	<.001**	.001**
Cropping systems	0.467	0.924NS	0.229NS	0.150NS	0.298NS	0.152NS
P-fertilization	0.016*	<0.001	<0.001	<0.001**	0.006	0.101
Interactions (P values)						
AM x Crop syst.	0.942NS	0.536NS	0.225NS	0.991NS	0.963NS	0.536NS
AM x Pfert	0.003**	0.214NS	0.044*	0.115*	0.122*	0.001**
Crop syst x Pfert	0.518NS	0.039**	1.00NS	0.756NS	0.233NS	0.665NS
AM xCrop syst x Pfert	1.00NS	0.216NS	0.996*	0.743NS	0.908NS	0.490NS

Means within each column followed by different letters are significantly different at P<0.05 according Duncan Multiple Range Test. * P<0.05, * P<0.01, NS, not significant

4.3. Effect of AM inoculation, cropping systems and SSP-fertilization on growth characteristics of *Capsicum annuum* var. Tatase under non- sterilized soil condition

Table 4.3 shows the effects of AM, cropping systems and Single super phosphate (SSP) fertilization on growth characteristics of *Capsicum annuum* var. Tatase on non sterilized soil. Mean heights of pepper in pots treated with *Glomus mosseae* (12.63cm) and *Glomus etunicatum* (12.57cm) although appeared similar were significantly ($P \leq 0.001$) different and shorter than height of plants in the un-inoculated pot (13.19cm). Difference between the two cropping systems was significant at ($P \leq 0.001$) with the blend (pepper-cowpea mixture) showing a higher height (15.25cm) over the sole pepper (10.34cm). SSP fertilizer enhanced the height of pepper; height at 60kgP/ha of 13.23cm was significantly ($P \leq 0.001$) higher than the height of plants (12.36cm) in pots that were not fertilized with SSP. Height of pepper in pots that received inoculation treatments were significantly ($P \leq 0.001$) influenced by cropping systems. Also the effect of P fertilization on the height of pepper was significantly influenced by inoculation treatment. This was evidenced by the significant ($P \leq 0.001$) interaction between arbuscular mycorrhiza inoculation treatment and SSP fertilization. The three factor interaction was significant, indicating that the effect of SSP fertilization on the height of pepper plant under the two cropping systems was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhiza treatment.

Results of the analysis of the greenhouse data for stem diameter (Table 4.3) show significant difference among all traits. Averaged over cropping systems and SSP fertilization treatments, plant stem diameter of *Capsicum annuum* var. Tatase were 3.76mm for *Glomus mosseae*, 3.35mm for *Glomus etunicatum* and 3.22mm for the un-inoculated treatments. Differences among the Arbuscular mycorrhizal treatments were significant at ($P \leq 0.05$). The difference between the two cropping systems was significant ($P \leq 0.001$) with the blend showing a larger stem diameter (3.64mm) over the sole pepper (3.25mm).

The addition of SSP brought a significant ($P \leq 0.05$) decrease on stem diameter; stem diameter at 0kgP/ha of 3.54mm was significantly larger than the stem diameter of plants in plots that were fertilized with 60kgP/ha (3.41mm) of single super phosphate. The effect of cropping systems was influenced by AM inoculation treatments as evidenced by the significant ($P \leq 0.001$) interaction between arbuscular mycorrhiza and cropping system treatment. A similar pattern was observed for other two-way interactions namely AM inoculation x single super phosphate and cropping system x single super phosphate respectively. Also, a three-way significant ($P \leq 0.001$) interaction was observed among mycorrhizal inoculation, cropping systems and single super phosphate application.

Arbuscular mycorrhizal inoculation significantly ($P \leq 0.001$) reduced dry matter yield of pepper; results of *Glomus mosseae* and *Glomus etunicatum* were 2.50g/plant and 2.49g/plant respectively and significantly ($P \leq 0.001$) less

than dry matter yield (3.1g/plant) of pepper plants in pots that were not inoculated (Table 4.3). The difference between the two cropping systems was significant at ($P \leq 0.001$); dry matter yield of pepper was significantly ($P \leq 0.001$) increased more in pepper-cowpea mixture (3.59g/plant) than in sole pepper (1.80g/plant). The addition of 60kgP/ha single super phosphate produced a significant reduction in dry matter yield (2.58g/plant) in comparison with pots where single super phosphate was not added (2.81g/plant). The effect of inoculation on dry matter yield was influenced significantly ($P \leq 0.001$) by cropping systems and likewise by single super phosphate treatment. However cropping systems and single super phosphate treatments exercised no significant influence on each other on dry matter yield. Evidence of three-way interaction was shown by the effect of single super phosphate fertilization treatment on dry matter yield of *Capsicum annuum* var. Tatase under two cropping systems significantly ($P \leq 0.001$) influenced by arbuscular mycorrhiza treatment.

Table 4.3. Post experimental effect of AM, cropping systems and P-fertilization on growth characteristics of *Capsicum annuum* var.Tatase on non-sterilized soil

Arbuscular mycorrhiza	Cropping systems	Single-super phosphate-fertilization	Height (cm)	Stem diameter (mm)	Dry matter yield (g/plant)
Glomus mosseae	Sole pepper	0kg P/ha	10.16f	3.84b	1.01b
		60kg P/ha	9.33h	3.44d	2.32ab
	Blend	0kg P/ha	16.16a	3.74bc	4.86a
		60kg P/ha	14.90b	4.05a	1.83ab
Glomus etunicatum	Sole pepper	0kg P/ha	10.00fg	3.44d	1.89ab
		60kg P/ha	10.83e	2.94e	1.06b
	Blend	0kg P/ha	13.30c	3.65c	3.56ab
		60kg P/ha	16.15a	3.39d	3.46ab
Un-inoculated	Sole pepper	0kg P/ha	9.76g	2.89e	1.10b
		60kg P/ha	12.00d	2.96e	3.45ab
	Blend	0kg P/ha	14.83b	3.33d	4.48ab
		60kgP/ha	16.20a	3.72bc	3.37ab
ANOVA					
AM inoculation (I)			***	*	***
Cropping systems (Cs)			***	***	***
SSP fertilization(Pf)			***	*	***
Interactions					
I x Cs			***	***	***
I x Pf			***	***	***
Pf x Cs			NS	***	NS
I x Cs x Pf			***	***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.4. Effect of AM inoculation, cropping systems and SSP-fertilization on nutrient uptake N, P and K of *Capsicum annuum* var. Tatase under non sterilized soil condition

Table 4.4 shows the effect of AM inoculation, cropping systems and P-fertilization on N, P and K uptake by *Capsicum annum* var. Tatase on non-sterilized soil. Mean N uptake of pepper in pots treated with *Glomus mosseae* (4.52mg/plant) and *Glomus etunicatum* (4.15mg/plant) were significantly ($P \leq 0.001$) different and lower than N uptake of plants in the un-inoculated pot (5.81mg/plant). N uptake was significantly ($P \leq 0.001$) higher in blend cropping of pepper (7.69mg/plant) than in sole cropping of pepper plant (1.94mg/plant). Single super phosphate fertilizer effect, even though significant ($P \leq 0.001$) failed to enhance N uptake at 60kgP/ha; N uptake at zero single super phosphate addition (4.99mg/plant) was significantly higher than N uptake at 60kgP/ha (4.65mg/plant). The effect of inoculation treatment on N uptake of *Capsicum annum* var. Tatase was significantly ($P \leq 0.001$) influenced by the two cropping systems. Evidence of significant ($P \leq 0.001$) interaction was equally shown between arbuscular mycorrhiza inoculation treatment and single super phosphate fertilization but non between cropping systems and single super phosphate application treatment. The three factor interaction was significant, showing that the effect of single super phosphate fertilization on N uptake of pepper plant under the two cropping systems was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhiza treatment.

Statistical analysis for P uptake (Table 4.4) shows significant difference among all traits except for single super phosphate fertilization treatment. Differences among the Arbuscular mycorrhizal treatments for P uptake were significant at ($P \leq 0.001$). Averaged over cropping systems and single super phosphate fertilization treatments, P uptake of *Capsicum annuum* var. Tatase were 1.17mg/plant for *Glomus mosseae*, 0.72mg/plant for *Glomus etunicatum* var. Tatase and 1.12mg/plant for the un-inoculated treatments. The difference between the two cropping systems was significant ($P \leq 0.001$) with the blend showing a bigger P uptake of 1.43mg/plant over the sole pepper of 0.58mg/plant. The treatments of single super phosphate brought no significant difference on P uptake of *Capsicum annuum* var. Tatase (Table 4.4).

The effect of inoculation on P uptake of the pepper plant was significantly ($P \leq 0.001$) influenced by the interaction between arbuscular mycorrhiza and cropping systems treatments. The same significant influence was observed between cropping systems and single super phosphate treatments. The three-way interaction was evident, indicating that the effect of single super phosphate fertilization on P uptake of *Capsicum annum* var. Tatase under the two cropping systems was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhiza treatment (Table 4.4).

Results of K uptake of pepper were both similar in pots treated with *Glomus mosseaa* (4.24mg/plant) and un-inoculated (4.23mg/plant) but significantly ($P \leq 0.001$) higher than K uptake of plants in the *Glomus etunicatum* treated pot (3.74mg/plant). K uptake was significantly ($P \leq 0.001$)

higher in blend cropping of pepper (6.20mg/plant) than in sole cropping of pepper plant (1.94mg/plant). SSP fertilizer effect, even though significant ($P \leq 0.001$) failed to enhance K uptake at 60kgP/ha on non-sterilized soil; K uptake without single super phosphate addition (4.36mg/plant) was significantly higher than K uptake at 60kgP/ha (3.78mg/plant). Effect of inoculation treatment on K uptake of *Capsicum annum* var. Tatase was not influenced by the two cropping systems. There was evidence of significant ($P \leq 0.05$) interaction shown between arbuscular mycorrhiza inoculation treatment and SSP fertilization. Also significant ($P \leq 0.001$) interaction was observed between cropping systems and SSP application treatment. The three factor interaction was significant, indicating that the effect of single super phosphate fertilization on K uptake of *Capsicum annum* var. Tatase under the two cropping systems was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhiza treatment (Table 4.4).

Table 4.4. Post experimental effect of AM, cropping systems and P-fertilization on N, P and K uptakes by *Capsicum annuum* var.Tatase on non-sterilized soil

Arbuscular mycorrhiza	Cropping systems	Single-super phosphate-fertilization	N uptake (mg/plant)	P uptake (mg/plant)	K uptake (mg/plant)
Glomus mosseae	Sole pepper	0kg P/ha	2.91e	0.54g	2.50d
		60kg P/ha	1.32h	0.16h	1.53de
	Blend	0kg P/ha	7.26c	2.57a	6.61ab
		60kg P/ha	6.60d	1.43b	6.32b
Glomus etunicatum	Sole pepper	0kg P/ha	1.40h	0.22h	1.24c
		60kg P/ha	1.73gh	0.80ef	2.29d
	Blend	0kg P/ha	7.04c	0.87e	7.47a
		60kg P/ha	6.40d	1.02d	3.97c
Un-inoculated	Sole pepper	0kg P/ha	2.22f	0.75f	1.99de
		60kg P/ha	2.11fg	1.01d	2.09e
	Blend	0kg P/ha	9.14b	1.20c	6.38b
		60kgP/ha	9.75a	1.54b	6.48b
ANOVA					
AM inoculation (I)			***	***	*
Cropping systems (Cs)			***	***	***
SSP fertilization(Pf)			***	NS	**
Interactions					
I x Cs			***	***	NS
I x Pf			***	***	*
Cs x Pf			NS	***	***
I x Cs x Pf			***	***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4. 5. Effect of AM inoculation, cropping systems and SSP-fertilization on Ca and Mg uptake by *Capsicum annuum* var. Tatase under non sterilized soil condition

Table 4.5 shows the effect of AM inoculation, cropping systems and P-fertilization on Ca and Mg uptake by *Capsicum annum* var.Tatase on non sterilized soil. Data analysis for Ca uptake of pepper shows significant differences among all traits and was significant at P≤0.001. Averaged over cropping systems and single super phosphate fertilization treatments, Ca uptake of *Capsicum annuum* var. Tatase was 3.39mg/plant for *Glomus mosseae*, 4.31mg/plant for *Glomus etunicatum* and 4.87mg/plant for the un-inoculated treatments. The difference between the two cropping systems was significant (P≤0.001) with the blend showing a bigger Ca uptake of 7.02mg/plant over and above the sole pepper of 1.37mg/plant. The treatments of single super phosphate also brought significant (P≤0.001) difference on Ca uptake of *Capsicum annuum* var. Tatase (Table 4.5). The data values for Ca uptake of zero and 60kgP/ha SSP additions were 3.54mg/plant and 4.85mg/plant respectively. The effect of inoculation on Ca uptake of the pepper plant was significantly (P≤0.001) influenced by the interaction between arbuscular mycorrhiza and cropping systems treatments. The same significant influence was observed between cropping systems and single super phosphate treatments as well as the three-way interaction of the treatments.

Arbuscular mycorrhizal inoculation significantly (P≤0.001) enhanced the uptake of Mg; results of *Glomus mosseae* and *Glomus etunicatum* were 0.88mg/plant and 0.93mg/plant respectively and were significantly (P≤0.001) higher than Mg uptake (0.79mg/plant) of *Capsicum annuum* var. Tatase in pots that were not inoculated (Table 4.5). The difference between the two cropping systems was significant at (P≤0.001); Mg uptake of pepper was significantly (P≤0.001) increased more in pepper-cowpea mixture (1.35mg/plant) than in sole pepper (0.39mg/plant). Single super phosphate treatments produced no significant reduction in Mg uptake of pepper plants. Effect of inoculation on Mg uptake was influenced significantly (P≤0.001) by cropping systems and likewise by single super phosphate treatments. There was also significant (P≤0.05) difference between cropping systems and single super phosphate treatments. The three factor interaction was significant, indicating that the effect of single super phosphate fertilization on the Mg uptake of pepper plants under the two cropping systems was significantly (P≤0.001) influenced by the AM treatments.

Table 4.5. Post experimental effect of AM, cropping systems and P-fertilization on Ca and Mg uptake by *Capsicum annuum* var.Tatase on non-sterilized soil

Arbuscular mycorrhiza	Cropping systems	Single-super phosphate-fertilization	Ca uptake (mg/plant)	Mg uptake (mg/plant)
Glomus mosseae	Sole pepper	0kg P/ha	1.65fg	0.41e
		60kg P/ha	1.38gh	0.37e
	Blend	0kg P/ha	6.64d	1.62a
		60kg P/ha	3.92e	1.14c
Glomus etunicatum	Sole pepper	0kg P/ha	0.71i	0.20f
		60kg P/ha	1.46g	0.45e
	Blend	0kg P/ha	7.77b	1.56a
		60kg P/ha	7.33c	1.53a
Un-inoculated	Sole pepper	0kg P/ha	0.98hi	0.40e
		60kg P/ha	2.05f	0.51e
	Blend	0kg P/ha	3.52e	0.91d
		60kgP/ha	12.96a	1.37b
ANOVA				
AM inoculation (I)			***	***
Cropping systems (Cs)			***	***
SSP fertilization(Pf)			***	NS
Interactions				
I x Cs			***	***
I x Pf			***	***
Pf x Cs			***	*
I x Cs x Pf			***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.6. Effect of AM inoculation, cropping systems and SSP-fertilization on growth characteristics of *Capsicum annuum* var. Tatase under sterilized soil condition

Table 4.6 shows the effect of AM inoculation, cropping systems and P-fertilization on growth characteristics of *Capsicum annum* var. Tatase on sterilized soil. Result of the data analysis for height of pepper shows significant ($P \leq 0.001$) difference among all traits. Averaged over cropping systems and single super phosphate fertilization treatments, mean heights of *Capsicum annuum* var. Tatase were 31.62cm for *Glomus mosseae*, 24.51cm for *Glomus etunicatum* and 20.54cm for the non mycorrhizal treatments. Pepper height under sole pepper which averaged 22.59cm was significantly ($P \leq 0.001$) lower than pepper-cowpea mixture which averaged 28.52cm. The average height of pepper in pots not augmented by single super phosphate addition was 26.65cm and significantly ($P \leq 0.001$) taller than pepper in pots receiving 60kgP/ha of single super phosphate. The effect of AM treatment on height of *Capsicum annum* var. Tatase was significantly (($P \leq 0.001$)) influenced by the two cropping systems. Evidence of significant ($P \leq 0.001$) interaction was equally shown between AM treatment and single super phosphate fertilization. The effect of single super phosphate fertilization on height of pepper was significantly ($P \leq 0.001$) influenced by the cropping systems. The three factor interaction was significant at $P \leq 0.001$, showing that the effect of single super phosphate fertilization on height of pepper plant

under the two cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhiza treatment (Table 4.6).

Average stem diameters of *Capsicum annuum* var. Tatase in pots having AM treatments were significantly (P≤0.001) different; *Glomus mosseae* and *Glomus etunicatum* were 3.72mm and 3.32mm respectively and significantly (P≤0.001) larger than non mycorrhizal pepper which was 2.77mm. No significant difference was established for cropping systems as well as single super phosphate application treatments (Table 4.6). AM inoculation treatment effect on stem diameter of *Capsicum annuum* var. Tatase on sterilized soil was significantly (P≤0.001) influenced by the two cropping systems. There was no significant three factor interaction effect on stem diameter of *Capsicum annuum* var. Tatase on sterilized soil (Table 4.6).

Results of the analysis of the greenhouse data for dry matter yield on sterilized soil (Table 4.6), show significant difference among all traits. Averaged over cropping systems and single super phosphate fertilization treatments, plant dry matter yield of *Capsicum annuum* var. Tatase were 1.89g/plant for *Glomus mosseae*, 1.47g/plant for *Glomus etunicatum* and 0.85g/plant for non mycorrhizal treatments. The difference between the two cropping systems was significant (P≤0.001) with the blend showing a bigger dry matter yield (2.41g/plant) than sole pepper (0.39g/plant). SSP treatment did not enhance the dry matter yield of pepper; dry matter yield at 60kgP/ha (1.28g/plant) was significantly (P≤0.001) lower than pepper plants in pot treated without single super phosphate (1.53g/ plant) (Table 4.6). All

interaction effects on dry matter yield of *Capsicum annuum* var. Tatase on sterilized soil were significantly different at P≤0.001. The effect of cropping systems on dry matter yield was influenced by AM inoculation treatments as evidenced by the significant (P≤0.001) interaction between arbuscular mycorrhiza and cropping system treatments. A similar effect was observed for the other two-way interactions namely AM inoculation by single super phosphate and cropping system by single super phosphate. Also, a three-way significant (P≤0.001) interaction was observed among mycorrhizal inoculation, cropping systems and single super phosphate application.

Table 4.6. Post experimental effect of AM, cropping systems and SSP-fertilization on growth characteristics of *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Cropping systems	P-fertilization	Height (cm)	Stem diameter (mm)	Dry matter yield (g/plant)
Glomus mosseae	Sole pepper	0kg P/ha	27.23c	4.04a	0.52e
		60kg P/ha	27.20c	3.89ab	0.50e
	Blend	0kg P/ha	41.35a	3.29cd	3.23b
		60kg P/ha	30.73b	3.69b	3.31b
Glomus etunicatum	Sole pepper	0kg P/ha	21.46h	3.72ab	0.22e
		60kg P/ha	24.42f	3.10cd	0.45e
	Blend	0kg P/ha	25.86e	3.11cd	3.68a
		60kg P/ha	26.32d	3.38c	1.55c
Non mycorrhizal	Sole pepper	0kg P/ha	19.75i	2.44e	0.38e
		60kg P/ha	15.51j	2.45e	0.29e
	Blend	0kg P/ha	24.30f	2.98d	1.15d
		60kgP/ha	22.61g	3.23cd	1.58c
ANOVA					
AM inoculation (I)			***	***	***
Cropping systems (Cs)			***	NS	***
P-fertilization (Pf)			***	NS	**
Interactions					
I x Cs			***	***	***
I x Pf			***	NS	***
Pf x Cs			***	***	***
I x Cs x Pf			***	NS	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.7. Effect of AM inoculation, cropping systems and SSP fertilization on nutrient uptake N, P and K under sterilized soil condition

Result of the effect of AM inoculation, cropping systems and SSP fertilization on N, P and K uptake by *Capsicum annum* var. Tatase on sterilized soil was as shown on Table 4.7. Mean N uptakes of pepper in pots treated with *Glomus mosseae* (3.76mg/plant) and *Glomus etunicatum* (3.14mg/plant) were significantly (P≤0.001) different and higher than N uptake of plants in non mycorrhizal pot (2.11mg/plant). N uptake was significantly (P≤0.001) higher in blend cropping of pepper (5.12mg/plant) than in sole cropping of pepper plant (0.89mg/plant). Single super phosphate fertilizer effect, although significant at P≤0.001, did not enhance N uptake at 60kgP/ha; N uptake at no P addition (3.20mg/plant) was significantly (P≤0.01) higher than N uptake at 60kgP/ha (2.82mg/plant). The effect of inoculation treatment on N uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the two cropping systems. Evidence of significant (P≤0.001) interaction between arbuscular mycorrhizal inoculation treatment and SSP fertilization was observed. The effect of the two cropping systems on N uptake of pepper was significantly (P≤0.01) influenced by SSP fertilization treatment. The three factor interaction was significant, showing that the effect of single super phosphate fertilization on N uptake of pepper plant under the two cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.7).

Differences among the Arbuscular mycorrhizal treatments for P uptake were significant at (P≤0.001) among all traits (Table 4.7). Averaged over cropping systems and SSP fertilization treatments, P uptake of *Capsicum annuum* var. Tatase was 1.23mg/plant for *Glomus mosseae*, 0.92mg/plant for *Glomus etunicatum* and 0.41mg/plant for non mycorrhizal treatment. The difference between the two cropping systems was significant (P≤0.001) with the blend showing a bigger P uptake of 1.50mg/plant over the sole pepper of 0.21mg/plant. Single super phosphate fertilizer effect, although significant at P≤0.001, failed to enhance P uptake; P uptake at zero P addition (1.05mg/plant) was significantly (P≤0.01) higher than P uptake at 60kgP/ha (0.66mg/plant). The effect of AM inoculation treatment on P uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by cropping system treatments. There was evidence of significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and single super phosphate fertilization. The effect of the two cropping systems on P uptake of pepper was also significantly (P≤0.01) influenced by SSP fertilization treatment. The three-way factor interaction was significant, indicating that the effect of single super phosphate fertilization on P uptake of pepper plant under the two cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.7).

Averaged over cropping systems and SSP fertilization treatments, K uptakes of *Capsicum annuum* var. Tatase were significantly (P≤0.01) different; 6.46mg/plant for *Glomus mosseae*, 7.41mg/plant for *Glomus*

etunicatum and were both significantly (P≤0.01) higher than 4.42mg/plant for the non mycorrhizal treatments. K uptake under sole pepper which averaged 2.34mg/plant was significantly (P≤0.001) lower than pepper-cowpea mixture which averaged 9.85mg/plant. There was no significant difference in K uptake of pepper plants treated with single super phosphate under sterilized soil condition. The effect of AM inoculation treatment on K uptake of *Capsicum annum* var. Tatase was significantly (P≤0.01) influenced by cropping system treatments. K uptake by *Capsicum annum* var. Tatase was not influenced by interaction between cropping systems and single super phosphate application treatment. The three factor interaction was significant at P≤0.01, indicating that the effect of single super phosphate fertilization on K uptake of *Capsicum annum* var. Tatase under the two cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.7).

Table 4.7. Post experimental effect of AM, cropping systems and P-fertilization on N, P and K uptakes by *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Cropping systems	P-fertilization	N uptake (mg/plant)	P uptake (mg/plant)	K uptake (mg/plant)
Glomus mosseae	Sole pepper	0kg P/ha	1.06f	0.22d	2.53de
		60kg P/ha	1.17f	0.32d	3.08de
	Blend	0kg P/ha	5.66c	2.62a	9.06bc
		60kg P/ha	7.16b	1.79b	11.18b
Glomus etunicatum	Sole pepper	0kg P/ha	0.56f	0.12d	1.44e
		60kg P/ha	1.01f	0.24d	2.80de
	Blend	0kg P/ha	8.02a	2.50a	16.12a
		60kg P/ha	3.00e	0.83c	9.29bc
Non mycorrhizal	Sole pepper	0kg P/ha	0.95f	0.19d	2.51de
		60kg P/ha	0.62f	0.18d	1.72e
	Blend	0kg P/ha	2.90e	0.62c	6.13bc
		60kgP/ha	3.99d	0.65c	7.33bc
ANOVA					
AM inoculation (I)			***	***	**
Cropping systems (Cs)			***	***	***
P-fertilization (Pf)			**	***	NS
Interactions					
I x Cs			***	***	**
I x Pf			***	***	NS
Pf x Cs			**	***	NS
I x Cs x Pf			***	***	**

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS. non-significant.

4.8. Effect of AM inoculation, cropping systems and SSP fertilization on nutrient uptake Ca and Mg under sterilized soil condition

Table 4.8 shows the effect of AM inoculation, cropping systems and P-fertilization on Ca and Mg uptake by *Capsicum annum* var.Tatase under sterilized soil. Averaged over cropping systems and single super phosphate fertilization treatments, Ca uptakes of *Capsicum annuum* var. Tatase were significantly ($P \leq 0.001$) different; 2.73mg/plant for *Glomus mosseae*, 2.08mg/plant for *Glomus etunicatum* and were both significantly ($P \leq 0.001$) higher than 0.98mg/plant for the non mycorrhizal treatments. Ca uptake under sole pepper which averaged 0.43mg/plant was significantly ($P \leq 0.001$) lower than pepper-cowpea mixture which averaged 3.43mg/plant. Single super phosphate fertilizer effect, even though significant ($P \leq 0.001$) did not enhance Ca uptake at 60kgP/ha; Ca uptake at no addition (2.30mg/plant) was significantly higher than Ca uptake at 60kgP/ha (1.47mg/plant). The effect of inoculation treatment on Ca uptake of *Capsicum annum* var. Tatase was significantly ($P \leq 0.001$) influenced by the two cropping systems. Evidence of significant ($P \leq 0.001$) interaction was equally shown between arbuscular mycorrhiza inoculation and single super phosphate fertilization treatments. Same significant influence was observed between cropping systems and single super phosphate application treatment effect on Ca uptake of *Capsicum annum* var. Tatase. The three factor interaction was significant, showing that the effect of single super phosphate fertilization on Ca uptake of pepper plant

under the two cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhiza treatment.

ANOVA results for the effect on Mg uptakes of *Capsicum annum* var. Tatase (Table 4.8) show significant (P≤0.001) difference among all traits. Mean Mg uptake of pepper in pots treated with *Glomus mosseae* (0.68mg/plant) and *Glomus etunicatum* (0.46mg/plant) were significantly (P≤0.001) different and higher than Mg uptake of plants in non mycorrhizal pot (0.24mg/plant). Mg uptake was significantly (P≤0.001) higher in blend cropping of pepper (0.74mg/plant) than in sole cropping of pepper plant (0.14mg/plant). Single super phosphate fertilizer effect, although significant at P≤0.001, did not enhance Mg uptake; Mg uptake at no SSP addition (0.5mg/plant) was significantly (P≤0.001) higher than Mg uptake at 60kgP/ha (0.43mg/plant). The effect of AM inoculation on Mg uptake of pepper plant was significantly (P≤0.001) influenced by the cropping systems treatments and likewise between AM inoculation and SSP treatments. The same significant (P≤0.001) influence was observed between cropping systems and single super phosphate treatments. There was also evidence of a three-way interaction for Mg uptake among the treatments (Table 4.8).

Table 4.8 Post experimental effect of AM, cropping systems and P-fertilization on Ca and Mg uptake by *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Cropping systems	P-fertilization	Ca uptake (mg/plant)	Mg uptake (mg/plant)
Glomus mosseae	Sole pepper	0kg P/ha	0.48g	0.18f
		60kg P/ha	0.76f	0.24e
	Blend	0kg P/ha	5.92a	1.16a
		60kg P/ha	3.76b	1.16a
Glomus etunicatum	Sole pepper	0kg P/ha	0.22h	0.08g
		60kg P/ha	0.48g	0.16f
	Blend	0kg P/ha	5.96a	1.15a
		60kg P/ha	1.67d	0.48b
Non mycorrhizal	Sole pepper	0kg P/ha	0.34gh	0.11g
		60kg P/ha	0.33gh	0.11g
	Blend	0kg P/ha	1.40e	0.34d
		60kgP/ha	1.87c	0.43c
ANOVA				
AM inoculation (I)			***	***
Cropping systems (Cs)			***	***
P-fertilization (Pf)			***	***
Interactions				
I x Cs			***	***
I x Pf			***	***
Pf x Cs			***	***
I x Cs x Pf			***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.9. Effect of AM inoculation, cropping systems and rock P fertilization on growth characteristics of *Capsicum annuum* var. Tatase under sterilized soil condition

Table 4.9 shows the effects of AM, cropping systems and rock P fertilization on growth characteristics of *Capsicum annuum* var. Tatase on sterilized soil. Mean number of leaves of pepper in pots treated with *Glomus fasciculatum* was 15.10 and significantly ($P \leq 0.05$) higher than those of *Glomus mosseae* (12.66) and on mycorrhizal treated pepper plant (12.21). Difference between the two cropping systems was not significant on the number of leaves. Rock P fertilizer enhanced the number of leaves of pepper; number of leaves at 60kgP/ha of rock phosphate was 14.70 and significantly ($P \leq 0.01$) higher than number of leaves of pepper plants (11.96) in pots that were not fertilized with rock P. Considering the interaction effect, only the cropping systems influenced rock P fertilization to show significant ($P \leq 0.05$) impact on number of leaves of *Capsicum annuum* var. Tatase under sterilized soil condition (Table 4.9).

Results of the analysis of the greenhouse data for dry matter yield (Table 4.9) show significant difference among all traits. Averaged over cropping systems and rock P fertilization treatments, plant dry matter yields of *Capsicum annuum* var. Tatase were 0.71g/plant for *Glomus fasciculatum*, 1.03g/plant for *Glomus mosseae*, and 0.64g/plant for non mycorrhizal plant treatments. Differences among the AM treatments were significant at $P \leq 0.001$.

The difference between the cropping systems was significant (P≤0.05) with the cowpea-pepper mixture showing a significantly (P≤0.05) heavier dry matter yield of 0.85g/plant than both soybean-pepper mixture and sole pepper having 0.77g/plant and 0.75g/plant respectively (Table 4.9). Mean dry matter yield of pepper (0.83g/plant) at 60kgP/ha rock P fertilization was significantly (P≤0.05) higher than dry matter yield of pepper (0.76g/plant) at 0kgP/ha of rock P application. The effect of cropping systems on dry matter yield of *Capsicum annuum* var. Tatase under sterilized soil condition (Table 4.9) was influenced by AM inoculation treatments and significant at P≤0.001. AM inoculation significant (P≤0.01) impact on dry matter yield of pepper was influenced by rock P treatments. Rock P application effect on dry matter yield of pepper was also influenced by the different cropping systems and significant at P≤0.001. A three-factor significant (P≤0.001) interaction was observed among mycorrhizal inoculation, cropping systems and rock P application (Table 4.9) under sterilized soil condition.

Table 4.9. Post experimental effect of AM, cropping systems and rock P application on growth characteristics of *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Cropping systems	Rock-P fertilization	No of leaves	Dry matter yield (g/plant)
Glomus fasciculatum	Cowpea+pepper	0kg P/ha	12.66bc	0.44hi
		60kg P/ha	19.66a	1.05b
	Soybean+pepper	0kg P/ha	12.00bc	0.55fgh
		60kg P/ha	15.00ab	0.61efgh
	Sole pepper	0kg P/ha	14.00abc	0.82cde
		60kg P/ha	17.33ab	0.82cde
Glomus mossae	Cowpea+pepper	0kg P/ha	12.00bc	1.01bc
		60kg P/ha	16.33ab	1.66a
	Soybean+pepper	0kg P/ha	11.33bc	1.64a
		60kg P/ha	11.00bc	0.65efgh
	Sole pepper	0kg P/ha	14.00abc	0.47ghi
		60kg P/ha	11.33bc	0.76def
Nonmycorrhizal	Cowpea+pepper	0kg P/ha	7.66c	0.29i
		60kg P/ha	14.33abc	0.68efg
	Soybean+pepper	0kg P/ha	13.33abc	0.66efgh
		60kg P/ha	13.00bc	0.55fgh
	Sole pepper	0kg P/ha	10.66bc	0.96bcd
		60kg P/ha	14.33abc	0.71f
ANOVA				
AM inoculation (I)			*	***
Cropping systems (Cs)			NS	*
Rock P-application (rP)			**	*
Interactions				
I x Cs			NS	***
I x rP			NS	**
Cs x rP			*	***
I x Cs x rP			NS	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.10. Effect of AM inoculation, cropping systems and rock P fertilization on nutrient uptake N, P and K, under sterilized soil condition

Result of the effect of AM inoculation, cropping systems and rock P fertilization on N, P and K uptake by *Capsicum annum* var. Tatase on sterilized soil was as shown on Table 4.10. Mean N uptakes of pepper in pots treated with *Glomus fasciculatum* (0.98mg/plant), *Glomus mosseae* (1.72mg/plant) and non mycorrhiza (0.99mg/plant) were significantly different at P≤0.001. AM inoculation with *Glomus mosseae* (1.72mg/plant) performed better than *Glomus fasciculatum* (0.98mg/plant) with a rather lower value than non mycorrhizal pepper plant (0.99mg/plant) on N uptake. No significant effect on N uptake by *Capsicum annum* var. Tatase was observed in cropping systems and rock P fertilization. The effect of inoculation treatment on N uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the cropping systems. Evidence of significant interaction was absent between arbuscular mycorrhizal inoculation treatment and rock phosphate fertilization. The effect of the cropping systems on N uptake of pepper was significantly (P≤0.001) influenced by rock phosphate fertilization treatment. The three factor interaction was significant, showing that the effect of rock phosphate fertilization on N uptake of pepper plant under the different cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.10).

Differences among the Arbuscular mycorrhizal treatments for P uptake were significant among all traits (Table 4.10). Averaged over cropping systems and rock P fertilization treatments, P uptake of *Capsicum annuum* var. Tatase was 0.26mg/plant for *Glomus fasciculatum*, 0.19mg/plant for *Glomus mosseae* and 0.14mg/plant for non mycorrhizal treatment. Significant ($P \leq 0.001$) differences were observed among the cropping systems with sole pepper having a bigger P uptake (0.24mg/plant) than soybean-pepper mixture (0.19mg/plant) and cowpea-pepper mixture (0.17mg/plant). Rock phosphate fertilizer effect, although significant at $P \leq 0.05$, failed to enhance P uptake; P uptake at zero P addition (0.21mg/plant) was significantly ($P \leq 0.05$) higher than P uptake at 60kgP/ha (0.19mg/plant). The effect of AM inoculation treatment on P uptake of *Capsicum annum* var. Tatase was significantly ($P \leq 0.001$) influenced by cropping system treatments. There was evidence of significant ($P \leq 0.01$) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on P uptake of pepper under sterilized soil condition. The effect of the cropping systems on P uptake of pepper was significantly ($P \leq 0.01$) influenced by rock P fertilization treatment. The three-way factor interaction was significant at ($P \leq 0.001$), indicating that the effect of rock phosphate fertilization on P uptake of pepper plant under the different cropping systems was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhizal treatment (Table 4.10).

Averaged over cropping systems and single super phosphate fertilization treatments, K uptakes of *Capsicum annuum* var. Tatase were

significantly (P≤0.001) different; 1.29mg/plant for *Glomus fasciculatum*, 1.88mg/plant for *Glomus mosseae* and were both significantly (P≤0.001) higher than 1.12mg/plant for the non mycorrhizal treatments. K uptake under sole pepper which averaged 1.52mg/plant was significantly (P≤0.01) higher than pepper-cowpea mixture which averaged 1.42mg/plant and pepper-soybean mixture which averaged 1.35mg/plant. Mean rock P fertilization effect at 60kgP/ha on K uptake of pepper under sterilized soil condition averaged 1.48mg/plant and was significantly (P≤0.01) higher than zero rock P addition which averaged 1.39mg/plant. Effect of inoculation treatment on K uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the different cropping systems. There was evidence of significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on K uptake of pepper. The three factor interaction was significant at P≤0.001, indicating that the effect of rock phosphate fertilization on K uptake of *Capsicum annum* var. Tatase under the different cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.10).

Table 4.10. Post experimental effect of AM, cropping systems and rock P application on N, P and K uptake of *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Cropping systems	Rock-P fertilization	N-uptake mg/plant	P-uptake mg/plant	K-uptake mg/plant
Glomus fasciculatum	Cowpea+pepper	0kg P/ha	0.68de	0.250bcde	0.68jk
		60kg P/ha	1.67bcd	0.246cde	1.51de
	Soybean+pepper	0kg P/ha	0.70de	0.176efg	1.11ghi
		60kg P/ha	0.73de	0.263abcde	0.93hij
	Sole pepper	0kg P/ha	1.05de	0.333ab	1.53de
		60kg P/ha	1.06de	0.330abc	2.03c
Glomus mossae	Cowpea+pepper	0kg P/ha	1.38cde	0.130fgh	1.93c
		60kg P/ha	3.76a	0.236de	3.10a
	Soybean+pepper	0kg P/ha	2.53b	0.316abcd	2.82b
		60kg P/ha	0.78de	0.210ef	1.18fgh
	Sole pepper	0kg P/ha	0.87de	0.210ef	0.85ijk
		60kg P/ha	1.03de	0.093gh	1.45ef
Non mycorrhizal	Cowpea+pepper	0kg P/ha	0.38e	0.073h	0.55k
		60kg P/ha	0.84de	0.106gh	0.77jk
	Soybean+pepper	0kg P/ha	0.81de	0.120gh	1.29efg
		60kg P/ha	0.91de	0.093gh	0.82jk
	Sole pepper	0kg P/ha	2.16bc	0.340a	1.76cd
		60kg P/ha	0.86de	0.140fgh	1.54de
ANOVA					
AM inoculation (I)			***	***	***
Cropping systems (CS)			NS	***	**
Rock P-application (rP)			NS	*	*
Interactions					
I x CS			***	***	***
I x rP			NS	**	***
CS x rP			***	***	***
I x CS x rP			***	***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.11. Effect of AM inoculation, cropping systems and rock P fertilization on nutrient uptake of Ca and Mg under sterilized soil condition

Table 4.11 shows the effect of AM inoculation, cropping systems and rock P fertilization on Ca and Mg uptake by *Capsicum annum* var.Tatase on sterilized soil. Averaged over cropping systems and rock phosphate fertilization treatments, Ca uptakes of *Capsicum annuum* var. Tatase were significantly ($P \leq 0.001$) different; 4.03mg/plant for *Glomus fasciculatum*, 5.50mg/plant for *Glomus mosseae* and were both significantly ($P \leq 0.001$) higher than 3.20mg/plant for the non mycorrhizal treatments. Ca uptake under sole pepper which averaged 4.33mg/plant and pepper-cowpea mixture which averaged 4.88mg/plant were both significantly ($P \leq 0.001$) higher than pepper-soybean mixture which averaged 3.51mg/plant. Rock phosphate fertilizer treatment had no significant effect on Ca uptake of pepper plant. The effect of inoculation treatment on Ca uptake of *Capsicum annum* var. Tatase was significantly ($P \leq 0.001$) influenced by the different cropping systems. Evidence of significant interaction was absent between arbuscular mycorrhiza inoculation and rock phosphate fertilization treatments. Same significant ($P \leq 0.001$) influence as seen between mycorrhizal inoculation treatment and cropping systems was observed between cropping systems and rock P application treatment. The three factor interaction was significant ($P \leq 0.001$), showing that the effect of rock phosphate fertilization on Ca uptakes of pepper plant under different cropping systems were significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhiza treatment (Table 4.11).

ANOVA results for the effect on Mg uptake of *Capsicum annum* var. Tatase (Table 4.11) show significant (P≤0.001) difference among mycorrhizal inoculation treatments. Mean Mg uptake of pepper in pots treated with *Glomus fasciculatum* (0.55mg/plant) and *Glomus mosseae* (0.46mg/plant) were significantly (P≤0.001) different and higher than Mg uptake of plants in non mycorrhizal pot (0.35mg/plant). No significant difference was observed between the different cropping systems as well as the rock P treatments. The effect of AM inoculation on Mg uptake of pepper plant was significantly (P≤0.001) influenced by the cropping systems treatments. AM inoculation effect on Mg uptake of *Capsicum annum* var. Tatase was significantly (P≤0.01) influenced by rock P treatment (Table 4.11). The same significant (P≤0.01) influence was observed between cropping systems and rock phosphate treatments. There was also evidence of a three-way interaction for Mg uptake among the treatments (Table 4.11).

Table 4.11. Post experimental effect of AM, cropping systems and rock P application on Ca and Mg uptake of *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Cropping systems	P-fertilization	Ca-uptake mg/plant	Mg uptake mg/plant
Glomus fasciculatum	Cowpea+pepper	0kg P/ha	3.71def	0.49cdef
		60kg P/ha	5.87bc	0.57bcde
	Soybean+pepper	0kg P/ha	3.39ef	0.52cdef
		60kg P/ha	1.45gh	0.52cdef
	Sole pepper	0kg P/ha	5.20bcd	0.58bcd
		60kg P/ha	4.57cde	0.62bcd
Glomus mossae	Cowpea+pepper	0kg P/ha	5.47bcd	0.66bc
		60kg P/ha	10.64a	1.52a
	Soybean+pepper	0kg P/ha	6.42b	0.87b
		60kg P/ha	3.99def	0.71bc
	Sole pepper	0kg P/ha	3.37ef	0.38cdef
		60kg P/ha	3.12efg	0.51cdef
Nonmycorrhizal	Cowpea+pepper	0kg P/ha	1.24h	0.20f
		60kg P/ha	2.38fgh	0.24ef
	Soybean+pepper	0kg P/ha	2.81efg	0.32def
		60kg P/ha	3.02efg	0.24ef
	Sole pepper	0kg P/ha	6.58b	0.66bc
		60kg P/ha	3.17efg	0.48cdef
ANOVA				
AM inoculation (I)			***	***
Cropping systems (Cs)			***	NS
Rock P-application (rP)			NS	NS
Interactions				
I x Cs			***	***
I x rP			NS	**
rP x Cs			***	**
I x Cs x rP			***	**

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.12. The effects of AM fungi, soil organic amendment and rock P fertilization on growth characteristics of *Capsicum annuum* var. Tatase on the field

Table 4.12 shows the effects of AM fungi, soil organic amendment and rock P fertilization on growth characteristics of *Capsicum annuum* var. Tatase on the field. Mean heights of pepper in plots treated with AM fungi were significantly (P≤0.001) different with *Glomus etunicatum*, *Glomus fasciculatum* and *Glomus mosseae* having 45.55cm, 37.12cm and 30.92cm respectively. Difference among the soil organic amendment effect on height of *Capsicum annuum* var. Tatase was not significant. Rock P fertilizer enhanced the height of pepper; height at 30kgP/ha of 39.80cm was significantly (P≤0.001) higher than the height of plants (36.71cm) in plots that were not fertilized with rock P and the height of plants (37.08cm) in plots that were fertilized with rock P at 60kgP/ha. Height of pepper in plots that received organic amendment treatments were significantly (P≤0.001) influenced by rock P application. However, no interaction effect was observed between mycorrhizal inoculation and organic amendment treatment, as well as between mycorrhizal inoculation and rock P treatments. The three factor interaction effect was not significant for the height of *Capsicum annuum* var. Tatase on the field (Table 4.12).

ANOVA results for the effect of AM fungi, soil organic amendment and rock P fertilization on number of leaves of *Capsicum annum* var. Tatase (Table 4.12) show significant (P≤0.001) difference among all traits.

Averaged over soil organic amendment and rock phosphate fertilization treatments, number of leaves of *Capsicum annuum* var. Tatase were significantly (P≤0.001) different; 45.97/plant for *Glomus etunicatum*, 56.22/plant for *Glomus fasciculatum* and 50.76/plant for *Glomus mosseae*. Difference among the soil organic amendment effect on number of leaves of *Capsicum annuum* var. Tatase on the field was significant at P≤0.001; number of leaves of pepper without organic amendment, with legume mixture and with compost were 57.48, 51.26 and 44.21 respectively. Rock P application effects at 0, 30 and 60kgP/ha were significant at P≤0.001 and were 43.38, 53.06 and 56.51 respectively. Effect of AM inoculation treatment on number of leaves of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the soil organic amendments. There was evidence of significant (P≤0.001) interaction between AM inoculation treatment and rock phosphate fertilization on number of leaves of pepper. The effect of the soil organic amendments on number of leaves of pepper was significantly (P≤0.001) influenced by rock P fertilization treatment. The three factor interaction was significant at P≤0.001, indicating that the effect of rock phosphate fertilization on number of leaves of *Capsicum annum* var. Tatase under the different soil organic amendment was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.12).

Table 4.12. Post experimental effect of AM fungi, different soil organic amendments and rock P on growth characteristics of *Capsicum annuum* var.Tatase on the field

Arbuscular mycorrhiza	Soil Organic amendment	Rock P application	Height (cm)	Number of leaves
Glomus etunicatum	nil	0kg P/ha	62.36a	35.90ij
		30kgP/ha	59.76ab	58.60c
		60kgP/ha	41.00cde	58.36c
	legume mix	0kg P/ha	31.00def	34.53j
		30kgP/ha	43.10cde	55.33cd
		60kgP/ha	40.16cde	79.10a
	compost	0kg P/ha	41.00cde	21.26k
		30kgP/ha	39.86cde	35.90ij
		60kgP/ha	51.73abc	34.80j
Glomus fasciculatum	nil	0kg P/ha	47.00bcd	77.86a
		30kgP/ha	38.30cdef	79.53a
		60kgP/ha	32.50def	48.33ef
	legume mix	0kg P/ha	33.73def	34.03j
		30kgP/ha	39.86cde	43.83fgh
		60kgP/ha	37.26cdef	64.83b
	compost	0kg P/ha	35.26def	57.56c
		30kgP/ha	34.60def	55.06cd
		60kgP/ha	35.60cdef	45.00fg
Glomus mosseae	nil	0kg P/ha	28.96ef	40.16ghi
		30kgP/ha	33.63def	54.76cd
		60kgP/ha	31.83def	63.90b
	legume mix	0kg P/ha	23.13f	37.86ij
		30kgP/ha	37.56cdef	55.23cd
		60kgP/ha	28.53ef	56.66c
	compost	0kg P/ha	28.03ef	51.33de
		30kgP/ha	31.56def	39.33hij
		60kgP/ha	35.13def	57.66c
ANOVA				
AM inoculation (I)			***	***
Organic amend. (Om)			**	***
Rock P application(rP)			NS	***
Interactions				
I x Om			NS	***
I x rP			NS	***
Om x rP			**	***
I x Om x rP			NS	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.13. The effects of AM fungi, soil organic amendment and rock P fertilization on yield characteristics of *Capsicum annuum* var. Tatase on the field

Table 4.13 shows the effects of AM, soil organic amendment and rock P fertilization on yield characteristics of *Capsicum annuum* var. Tatase on the field. Mean number of fruits of pepper in plots treated with *Glomus etunicatum*, *Glomus fasciculatum* and *Glomus mosseae* appeared similar but significantly different at P≤0.05. They were 4.9/plant, 5.48/plant and 5.45/plant respectively. Soil organic amendment enhanced the number of fruits of pepper; number of fruits at nil addition of soil organic amendment was 4.9 and was significantly (P≤0.001) lower than the number of fruits of pepper plants (5.45) in plots that were amended with legume mixture and number of fruits of pepper plants (5.48) in plots that were amended with compost (Table 4.13). Difference among the rock P application effect on mean number of fruits of *Capsicum annuum* var. Tatase was not significant on the field. Effect of inoculation treatment on fruit of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the soil organic amendments. There was evidence of significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on number of fruits of pepper. The effect of the soil organic amendments on number of fruits of pepper was significantly (P≤0.001) influenced by rock P fertilization treatment. The three factor interaction was significant at P≤0.001, indicating that the effect of rock phosphate fertilization on number of fruits of *Capsicum*

annum var. Tatase under the different soil organic amendment was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.13).

ANOVA results for the effect on yield of *Capsicum annum* var. Tatase (Table 4.13) show significant difference among all traits. Averaged over soil organic amendment and rock phosphate fertilization treatments, fruit yields of *Capsicum annuum* var. Tatase were significantly (P≤0.01) different; 14.71g/plant for *Glomus etunicatum*, 18.66g/plant for *Glomus fasiculatum* and 20.04g/plant for *Glomus mosseae*. Difference among the soil organic amendment effect on fruit yield of *Capsicum annuum* var. Tatase on the field was significant at P≤0.001; fruit yield of pepper without organic amendment, with legume mixture and with compost were 17.29g/plant, 19.18g/plant and 16.94g/plant respectively. Rock P application effects on fruit yield of *Capsicum annuum* var. Tatase at 0, 30 and 60kgP/ha were significantly (P≤0.001) different and were 13.57g/plant, 21.54g/plant and 18.30g/plant respectively. Effect of inoculation treatment on fruit yield of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the soil organic amendments. There was evidence of significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on fruit yield of pepper. The effect of the soil organic amendments on fruit yield of pepper was significantly (P≤0.001) influenced by rock P fertilization treatment. The three factor interaction was significant at P≤0.001, showing that the effect of rock phosphate fertilization on fruit

yield of *Capsicum annum* var. Tatase under the different soil organic amendment was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhizal treatment (Table 4.13).

Table 4.13. Post experimental effect of AM fungi, rock P and different soil organic amendments on yield characteristics of *Capsicum annuum* var.Tatase on the field

Arbuscular mycorrhiza	Soil Organic amendment	Rock P application	number of fruits	Yield (g/plant)
Glomus etunicatum	nil	0kg P/ha	7.83bcd	1.86m
		30kgP/ha	5.56fgh	17.40h
		60kgP/ha	5.00fgh	8.68k
	legume mix	0kg P/ha	3.00ijk	15.46i
		30kgP/ha	5.56fgh	25.26cd
		60kgP/ha	4.83fghi	18.03h
	compost	0kg P/ha	6.16defg	12.76i
		30kgP/ha	6.23def	11.96j
		60kgP/ha	5.16fgh	21.00g
Glomus fasciculatum	nil	0kg P/ha	2.00k	18.93h
		30kgP/ha	4.16ghij	17.76h
		60kgP/ha	4.83fghi	14.56i
	legume mix	0kg P/ha	4.50fghi	23.50ef
		30kgP/ha	9.06abc	26.10cd
		60kgP/ha	7.50cde	24.60de
	compost	0kg P/ha	4.00hij	12.43j
		30kgP/ha	5.86efg	22.46fg
		60kgP/ha	2.00k	7.66kl
Glomus mosseae	nil	0kg P/ha	4.16ghij	18.53h
		30kgP/ha	5.00fgh	23.16ef
		60kgP/ha	5.56fgh	34.76a
	legume mix	0kg P/ha	2.33jk	6.66l
		30kgP/ha	10.00a	26.76c
		60kgP/ha	2.33jk	6.26l
	compost	0kg P/ha	1.66k	12.06j
		30kgP/ha	9.50ab	23.00ef
		60kgP/ha	8.76abc	29.20b
ANOVA				
AM inoculation (I)			*	**
Organic amend. (Om)			***	***
Rock P application(rP)			NS	***
Interactions				
I x Om			***	***
I x rP			***	***
Om x rP			***	***
I x rP x Om			***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.14 The effects of AM, cropping systems and rock P fertilization on growth and yield characteristics of *Capsicum annuum* var. Tatase on the field

Table 4.14 shows the effects of AM, cropping systems and rock P fertilization on growth and yield characteristics of *Capsicum annuum* var. Tatase on the field. Mean heights of pepper in plots having arbuscular mycorrhizal treatments were significant at P≤0.001 with *Glomus mosseae* highest (40.49cm) and *Glomus etunicatum* (34.81cm) lower than uninoculated pepper plant (36.45cm). Difference among the cropping systems on height of *Capsicum annuum* var. Tatase was not significant. Rock P fertilizer significantly (P≤0.01) enhanced the height of pepper; height at 60kgP/ha of 37.97cm was significantly (P≤0.01) taller than pepper plants (36.54cm) in plots that were not fertilized with rock P. Heights of pepper in plots that received inoculation treatments were significantly (P≤0.001) influenced by cropping systems. Also the effect of P fertilization on the height of pepper was significantly influenced by inoculation treatment. This was evidenced by the significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and rock P fertilization. The three factor interaction was significant, indicating that the effect of rock P fertilization on the height of pepper plant under the three cropping systems was significantly (P≤0.001) influenced by the arbuscular mycorrhiza treatment.

Results of the analysis on the field data for number of fruits (Table 4.14) show significant difference among the traits. Differences among

the Arbuscular mycorrhizal treatments were significant at (P≤0.001). Averaged over cropping systems and rock P fertilization treatments, number of fruits of *Capsicum annuum* var. Tatase were 5.82 for *Glomus mosseae*, 6.17 for *Glomus etunicatum* and 4.49 for the un-inoculated treatments. The difference among the cropping systems was not significant. The addition of rock P brought a significant (P≤0.001) increase on number of fruits; number of fruits at 0kgP/ha of 5.19 was significantly (P≤0.001) smaller than the number of fruits of plants in plots that were fertilized with 60kgP/ha (5.79) of rock P.

The effect of AM inoculation number of fruits of pepper plants was influenced by cropping system treatments as evidenced by the significant (P≤0.001) interaction between arbuscular mycorrhiza and cropping system treatment. A similar pattern was observed for other two-way interactions namely AM inoculation x rock P and cropping system x rock P respectively. However, there exist no three factor interaction effect among the treatments (Table 4.14).

Arbuscular mycorrhizal inoculation significantly (P≤0.001) increased fruit yield of pepper; results of *Glomus mosseae* and *Glomus etunicatum* were 18.81g/plant and 16.91g/plant respectively and significantly (P≤0.001) higher than fruit yield (10.83g/plant) of pepper plants in plots that were not inoculated (Table 4.14). The difference among the cropping systems was significant at (P≤0.001); fruit yield of pepper was significantly (P≤0.001) increased more in sole pepper (16.85g/plant) than in pepper-cowpea mixture (15.58g/plant) than pepper-soybean mixture (14.12g/plant). The addition of rock Phosphate produced no significant result in fruit yield. The effect of

inoculation on fruit yield was influenced significantly (P≤0.001) by cropping systems and likewise by rock P addition. Cropping systems and rock P treatments also exercised significant (P≤0.001) influence on each other on fruit yield. The three-way interaction was significant showing that the effect of rock P fertilization treatment on fruit yield of *Capsicum annuum* var. Tatase under the cropping systems was significantly (P≤0.01) influenced by the arbuscular mycorrhiza treatment (Table 4.14).

Table 4.14. Post experimental effect of AM, rock P and cropping systems on growth and yield characteristics of *Capsicum annuum* var.Tatase on the field

Arbuscular mycorrhiza	Cropping systems	Rock P-application	Height (cm)	number of fruits	Yield (g/plant)
Glomus mosseae	Pepper only	0kg P/ha	46.46a	4.73ef	15.03ef
		60kg P/ha	44.36ab	5.00def	19.66bc
	Cowpea+pepper	0kg P/ha	35.73efg	5.66cde	20.10b
		60kg P/ha	38.80cde	5.70cde	19.43bcd
	Soybean+pepper	0kg P/ha	36.23efg	4.83ef	16.26ef
		60kg P/ha	41.40bc	9.00a	22.43a
Glomus etunicatum	Pepper only	0kg P/ha	27.26i	6.10bcd	16.60ef
		60kg P/ha	32.26h	6.23bc	17.20de
	Cowpea+pepper	0kg P/ha	29.23i	6.50bc	16.40ef
		60kg P/ha	40.36cd	6.33bc	17.16de
	Soybean+pepper	0kg P/ha	41.26bc	4.66ef	14.60f
		60kg P/ha	38.53cde	7.23b	19.53bcd
Uninoculated	Pepper only	0kg P/ha	37.00def	6.26bc	17.53cde
		60kg P/ha	33.03gh	5.00def	15.10ef
	Cowpea+pepper	0kg P/ha	38.96cde	4.93def	15.13ef
		60kg P/ha	38.53cde	3.23g	5.30g
	Soybean+pepper	0kg P/ha	36.76ef	3.10g	5.16g
		60kg P/ha	34.46fgh	4.43f	6.76g
ANOVA					
AM inoculation (I)			***	***	***
Cropping systems (CS)			NS	NS	***
RockP application (RP)			**	***	NS
Interactions					
I x CS			***	***	***
I x RP			***	***	***
CS xRP			***	***	***
I x CS x RP			***	NS	**

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.15. Effect of AM, organic manure applications and rock P on growth characteristics of *Capsicum annuum* var.Tatase on sterilized soil

Table 4.15 shows the effects of AM, organic manure and rock P fertilization on growth characteristics of *Capsicum annuum* var. Tatase on sterilized soil. Effect of AM inoculation treatment on height of *Capsicum annum* var. Tatase was not significant. Manure application treatment enhanced height of pepper; height at nil addition of manure was 29.21cm and significantly ($P \leq 0.001$) lower than the height of pepper plants (38.15cm) in pots that were amended with 2% organic manure and height of pepper plants (34.10cm) in pots that were amended with 5% organic manure (Table 4.15). Difference among the rock P application effect on mean height of *Capsicum annuum* var. Tatase was not significant under sterilized soil condition. Effect of AM inoculation treatment on height of *Capsicum annum* var. Tatase was significantly ($P \leq 0.001$) influenced by organic manure treatments. There was evidence of significant ($P \leq 0.001$) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on height of pepper. The effect of organic manure treatments on height of pepper was significantly ($P \leq 0.001$) influenced by rock P fertilization treatment. The three factor interaction was significant at $P \leq 0.001$, indicating that the effect of rock phosphate fertilization on height of *Capsicum annum* var. Tatase under the different organic manure treatment was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhizal treatment (Table 4.15).

ANOVA results for the dry matter yields of *Capsicum annum* var. Tatase were significant at P≤0.001. Mean dry matter yields of pepper in pots having arbuscular mycorrhizal treatments were significantly different at P≤0.001 with *Glomus fasciculatum* having 3.37g/plant, *Glomus mosseae* 2.80g/plant and *Glomus etunicatum* 3.15g/plant (Table 4.15). Averaged over AM inoculation and rock phosphate fertilization treatments, dry matter yields of *Capsicum annuum* var. Tatase were significantly (P≤0.001) different; 3.20g/plant for plants without organic manure addition which was significantly (P≤0.001) higher than pepper plants with 2% organic manure (3.18g/plant) and 5% organic manure (2.94g/plant) addition. Rock P application effect although significant at P≤0.01 did not improve the mean dry matter yield of *Capsicum annuum* var. Tatase; dry matter yield at nil rock P addition (3.19g/plant) was significantly (P≤0.01) higher than dry matter yield at 60kgP/ha of rock P which was 3.02g/plant under sterilized soil condition. Effect of inoculation treatment on dry matter yield of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by organic manure treatment. There was evidence of significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on dry matter yield of pepper. The effect of the organic manure treatment on dry matter yield of pepper was significantly (P≤0.001) influenced by rock P fertilization treatment. The three factor interaction was significant at P≤0.001, showing that the effect of rock phosphate fertilization on dry matter yield of *Capsicum annum* var. Tatase under the different soil organic manure

treatment was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhizal inoculation treatment (Table 4.15).

Table 4.15. Post experimental effect of AM, rock P and organic manure applications on growth characteristics of *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Organic manure	Rock P-application	Height (cm)	Dry matter (g/plant)
Glomus fasciculatum	Nil	0kg P/ha	33.40cde	2.33de
		60kgP/ha	28.60efgh	5.22b
	2%	0kgP/ha	43.00b	2.22e
		60kgP/ha	36.33c	2.75d
	5%	0kgP/ha	34.16cd	5.27b
		60kgP/ha	31.40cdefg	2.43de
Glomus mossae	Nil	0kg P/ha	33.16cde	1.57f
		60kgP/ha	28.36efgh	5.41b
	2%	0kgP/ha	36.50c	3.32c
		60kgP/ha	44.33b	1.75f
	5%	0kgP/ha	25.93gh	2.34de
		60kgP/ha	27.40fgh	2.45de
Glomus etunicatum	Nil	0kg P/ha	23.76h	1.39f
		60kgP/ha	28.00efgh	3.29c
	2%	0kgP/ha	36.46c	7.71a
		60kgP/ha	32.33cdef	1.34f
	5%	0kgP/ha	34.83c	2.61de
		60kgP/ha	50.93a	2.58de
ANOVA				
AM inoculation (I)			NS	***
Organic manure (M)			***	***
Rock P-application (RP)			NS	**
Interactions				
I x M			***	***
I x RP			***	***
RP x M			***	***
I x RP x M			***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.16. Effect of AM, organic manure applications and rock P on N, P and K uptake of *Capsicum annuum* var.Tatase on sterilized soil

Result of the effect of AM inoculation, organic manure and rock P fertilization treatments on N, P and K uptake by *Capsicum annum* var. Tatase on sterilized soil was as shown on Table 4.16. N uptake by *Capsicum annum* var. Tatase in pots inoculated with mycorrhiza was significantly ($P \leq 0.001$) different; mean N uptake of pepper in pots treated with *Glomus fasciculatum* was 7.49mg/plant and significantly ($P \leq 0.001$) higher than that of *Glomus mosseae* (6.46mg/plant) or *Glomus etunicatum* (6.49mg/plant). Organic manure treatment effect enhanced N uptake of pepper plant significantly at ($P \leq 0.001$) in the increasing order of 4.16mg/plant, 7.92mg/plant and 8.36mg/plant with nil, 2% and 5% organic manure application respectively. Rock P application had significant ($P \leq 0.001$) effect; pot with zero rock P addition has higher N uptake (7.67mg/plant) than pot with 60kgP/ha rock P addition (5.96mg/plant). The effect of inoculation treatment on N uptake of *Capsicum annum* var. Tatase was significantly ($P \leq 0.001$) influenced by the organic manure treatment. There was evidence of significant ($P \leq 0.001$) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on N uptake of pepper. The effect of the organic manure treatment on N uptake of pepper was significantly ($P \leq 0.001$) influenced by rock P fertilization treatment. The three factor interaction was significant at $P \leq 0.001$, showing that the effect of rock phosphate fertilization on N uptake of *Capsicum annum*

var. Tatase under the different soil organic manure treatment was significantly (P≤0.001) influenced by the arbuscular mycorrhizal inoculation treatment (Table 4.16).

Differences among the Arbuscular mycorrhizal treatments for P uptake were significant among all traits (Table 4.16). Averaged over organic manure and rock P fertilization treatments, P uptake of *Capsicum annuum* var. Tatase was 0.44mg/plant for *Glomus fasciculatum*, 0.62mg/plant for *Glomus mosseae* and 0.37mg/plant for *Glomus etunicatum* treatment and was significantly different at P≤0.001. Significant differences were observed among the manure applications with nil addition having a significantly (P≤0.001) higher P uptake of 0.51mg/plant than 2% addition which was 0.43mg/plant and for 5% addition which was 0.49mg/plant. Rock phosphate fertilizer effect, significant at P≤0.05, enhanced P uptake; P uptake at zero P addition (0.45mg/plant) was significantly (P≤0.05) less than P uptake at 60kgP/ha (0.50mg/plant). The effect of AM inoculation treatment on P uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by organic manure treatments. There was evidence of significant (P≤0.01) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on P uptake of pepper under sterilized soil condition. The effect of the organic manure treatment on P uptake of pepper was significantly (P≤0.001) influenced by rock P fertilization treatment. The three-way factor interaction was significant at (P≤0.001), indicating that the effect of rock phosphate fertilization on P uptake of pepper plant under the

different manure treatment was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.16).

Averaged over manure treatment and rock phosphate fertilization treatments, K uptake of *Capsicum annuum* var. Tatase was significantly (P≤0.01) different; 9.59mg/plant for *Glomus fasciculatum*, 10.13mg/plant for *Glomus mosseae* and 10.78mg/plant for *Glomus etunicatum*, all significant at P≤0.01. K uptake under the different manurial applications was significantly different at P≤0.001; nil manure addition was 5.58mg/plant, at 2% manure addition was 11.21mg/plant and at 5% addition was 9.42mg/plant. Mean rock P fertilization effect at 60kgP/ha on K uptake of pepper under sterilized soil condition averaged 9.80mg/plant and was significantly (P≤0.05) less than zero rock P addition which averaged 10.54mg/plant. Effect of inoculation treatment on K uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the manurial treatment. There was evidence of significant (P≤0.001) interaction between arbuscular mycorrhiza inoculation treatment and rock phosphate fertilization on K uptake of pepper. The effect of the manurial treatment on P uptake of pepper was significantly (P≤0.001) influenced by rock P fertilization treatment. The three factor interaction was significant at P≤0.001, indicating that the effect of rock phosphate fertilization on K uptake of *Capsicum annum* var. Tatase under the different manurial treatment was significantly (P≤0.001) influenced by the arbuscular mycorrhizal treatment (Table 4.16).

Table 4.16 Post experimental effect of AM, rock P and organic manure applications on N, P and K uptake of *Capsicum annuum* var.Tatase on sterilized soil

Arbuscular mycorrhiza	Organic manure	Rock P-application	N-uptake (mg/plant)	P uptake (mg/plant)	K-uptake (mg/plant)
Glomus fasciculatum	Nil	0kg P/ha	4.28fg	0.25gh	6.63fg
		60kgP/ha	5.22ef	0.54cde	12.98c
	2%	0kgP/ha	6.12de	0.30fgh	7.57efg
		60kgP/ha	7.44c	0.47def	8.41efg
	5%	0kgP/ha	15.47a	0.68bc	14.60c
		60kgP/ha	6.46cd	0.44def	7.39efg
Glomus mossae	Nil	0kg P/ha	1.97h	0.33fgh	4.42hi
		60kgP/ha	6.93cd	1.19a	20.90b
	2%	0kgP/ha	9.30b	0.75b	12.63c
		60kgP/ha	4.67fg	0.37efg	6.18gh
	5%	0kgP/ha	6.60cd	0.61bcd	8.25efg
		60kgP/ha	9.30b	0.54cde	8.45ef
Glomus etunicatum	Nil	0kg P/ha	2.45h	0.33fgh	3.71i
		60kgP/ha	4.14fg	0.53cde	10.61d
	2%	0kgP/ha	16.35a	0.54cde	28.17a
		60kgP/ha	3.66g	0.19h	4.35hi
	5%	0kgP/ha	6.49cd	0.34fgh	8.92de
		60kgP/ha	5.85de	0.33fgh	8.94de
ANOVA					
AM inoculation (I)			***	***	**
Organic manure (M)			***	***	***
Rock P-application (RP)			***	*	*
Interactions					
I x M			***	***	***
I x RP			***	**	***
RP x M			***	***	***
I x RP x M			***	***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

4.17. Effect of AM, organic manure applications and rock P on Ca and Mg uptake of *Capsicum annuum* var.Tatase on sterilized soil

Table 4.17 shows the effect of AM inoculation, organic manure and rock P fertilization on Ca and Mg uptake by *Capsicum annum* var.Tatase on sterilized soil. Averaged over organic manure and rock phosphate fertilization treatments, Ca uptakes of *Capsicum annuum* var. Tatase were significantly (P≤0.001) different; 10.9mg/plant for *Glomus fasciculatum*, 8.01mg/plant for *Glomus mosseae* and 9.04mg/plant for *Glomus fasciculatum* treatments. Ca uptake under the different manurial applications was highly significant at P≤0.001; mean manurial fertilization effect at 0% on Ca uptake of pepper under sterilized soil condition averaged 12.45mg/plant and was significantly (P≤0.001) higher than 2% manurial addition which averaged 9.66mg/plant or 5% manurial addition which averaged 7.35mg/plant. Rock phosphate fertilizer effect, was not significant on Ca uptake of pepper plant. The effect of inoculation treatment on Ca uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the different organic manure treatment. Evidence of significant (P≤0.001) interaction was seen between arbuscular mycorrhiza inoculation and rock phosphate fertilization treatments. Same significant (P≤0.001) influence as observed between mycorrhizal inoculation treatment and organic manure was observed between organic manure and rock P application treatment. The three factor interaction was significant (P≤0.001), showing that the effect of rock phosphate fertilization on Ca uptake of pepper plant under different

organic manure was significantly (P≤0.001) influenced by the arbuscular mycorrhiza treatment (Table 4.17).

ANOVA results for the effect of Mg uptake of *Capsicum annum* var. Tatase (Table 4.17) show significant (P≤0.01) difference among mycorrhizal inoculation treatment. Mean Mg uptake of pepper in pots treated with *Glomus fasciculatum* was 2.70mg/plant, *Glomus mosseae* was 2.16mg/plant and *Glomus etunicatum* was 2.22mg/plant. Mg uptakes under the different manurial applications were significant at P≤0.001; mean manurial fertilization effect at 0% on Mg uptake of pepper under sterilized soil condition averaged 2.29mg/plant and was significantly (P≤0.001) less than 2% manurial addition which averaged 2.81mg/plant but higher than 5% manurial addition which averaged 1.98mg/plant. Rock phosphate fertilizer effect on Mg uptake of pepper plant was not significant. The effect of inoculation treatment on Mg uptake of *Capsicum annum* var. Tatase was significantly (P≤0.001) influenced by the different organic manure treatment. Evidence of significant (P≤0.001) interaction was observed between arbuscular mycorrhiza inoculation and rock phosphate fertilization treatments. Same significant (P≤0.001) influence as seen between mycorrhizal inoculation treatment and organic manure was observed between organic manure and rock P application treatment. The three-way interaction was significant (P≤0.001), showing that the effect of rock phosphate fertilization on Mg uptake of pepper plant under different organic manure

treatment was significantly ($P \leq 0.001$) influenced by the arbuscular mycorrhiza treatment (Table 4.17).

Table 4.17. Post experimental effect of AM, rock P and organic manure applications on Ca and Mg uptake of *Capsicum annuum* var.Tatase on sterilized

Arbuscular mycorrhiza	Organic manure	Rock P-application	Ca-uptake (mg/plant)	Mg uptake (mg/plant)
Glomus fasciculatum	Nil	0kg P/ha	7.12de	1.42fg
		60kgP/ha	21.58a	3.22bc
	2%	0kgP/ha	11.18c	2.40cdef
		60kgP/ha	11.20c	3.71b
	5%	0kgP/ha	17.22b	3.73b
		60kgP/ha	6.10ef	1.76efg
Glomus mossae	Nil	0kg P/ha	7.21de	1.60efg
		60kgP/ha	18.96b	3.75b
	2%	0kgP/ha	8.52d	2.81bcd
		60kgP/ha	5.21fg	1.84efg
	5%	0kgP/ha	3.98g	1.16g
		60kgP/ha	4.22fg	1.81efg
Glomus etunicatum	Nil	0kg P/ha	7.78de	1.32g
		60kgP/ha	12.05c	2.47cde
	2%	0kgP/ha	18.48b	5.20a
		60kgP/ha	3.39g	0.90g
	5%	0kgP/ha	7.93de	1.91defg
		60kgP/ha	4.65fg	1.54efg
ANOVA				
AM inoculation (I)			***	**
Organic manure (M)			***	***
Rock P-application (RP)			NS	NS
Interactions				
I x M			***	***
I x RP			***	***
RP x M			***	***
I x RP x M			***	***

For each variate, values followed by the same letters in the same column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test. * P≤0.05. ** P≤0.01. *** P≤0.001. NS non-significant.

CHAPTER 5

DISCUSSION

The significant variations observed in some of the chemical properties of soil (sterilized or non-sterilized) established the fact that earlier study focused on mycorrhiza as a component of only the plant system was not adequate. The pH of soil (sterilized/non-sterilized) was 6.3 at the commencement of experiments. At the end of the experiments the pH range was between 6.6 - 6.9 for sterilized soil and 6.5 - 6.9 for non-sterilized soil. The clay minerals are dominated by kaolinite and oxides of iron and aluminum which are generally characterized by strong acidity, low levels of exchangeable potassium, calcium and magnesium. Deficiencies of nitrogen, phosphorus, potassium, calcium and magnesium are common occurrence (Sanchez, 1981; Kang and Juo, 1983). In this study, the experimentation began with a weak acid soil and ended with a further decrease in soil acidity thereby increasing the levels and availability of exchangeable N, P, K, Ca and Mg in the soil. There was a highly significant interaction between AM and P-fertilization in this regard which was also applicable to soil Mg and Zn in the sterilized soil. There was significant interaction for soil available P, Ca and Mg and Zn in non-sterilized soil at the end of the experiment. Similar to previous findings, it was evident that the presence of mycorrhiza undoubtedly effected physiological changes in host plants and the chemical presence of external hyphae of the AM fungi affected the chemical, physical, and microbiological composition of the rhizosphere (Linderman, 1988, Schisler and Linderman,

1989). AM fungi has thus become unique among the myriad of microbes and have been identified as both agents of plant nutrition as well as soil nutrition (Reid, 1984; Elliot and Coleman, 1988; Bethlenfalvay and Newton, 1991) usually with a production base of an improved soil-plant system. The importance of mycorrhizal fungi in sustainable agriculture is also based on their primary role as agents of nutrient transport providing links between plants and soil.

The study further examines the effect of AM inoculation, cropping systems and SSP-fertilization on nutrient uptake of *Capsicum annuum* var. Tatase under both sterilized and non sterilized soil conditions. *Glomus mosseae* consistently performed best on P uptake of *Capsicum annuum* var. Tatase in both sterilized and non sterilized soil when compared to other AM species. However, there were variations in other uptakes as well as inconsistency in performance of other AM species subject to soil conditions. Ealier studies have shown that cultural practices influence the presence of AM fungi both qualitatively and quantitatively (Jasper *et al*., 1991; Land *et al*., 1993), results from present study further reiterate the performance of AM fungi subject to soil chemical conditions. The variations may also be due to antagonistic behaviour of other microbes in the soil as clearly shown with results obtained with non mycorrhizal pots under sterilized soil condition.

AM inoculation treatment on pepper plants were observed to have consistently higher nutrient uptake of N, P, K, Ca and Mg than non mycorrhizal pepper plants in sterilized soil as opposed to inconsistency

observed in the data obtained from unsterilized soil. This is similar to the results of other studies in Nigeria and around the globe (Siddique and Mahmood, 1996; Ryan and Graham, 2002; Uyanoz, 2007). This also suggests that other factors apart from introduced AM fungi come into play under non sterilized soil condition. However with pepper plants, addition of 60kg P/ha of SSP resulted in a lot of variation on nutrient uptake; a decrease for N and Ca uptake in both sterilized and unsterilized soils, P and Mg in sterilized soil only and K uptake in unsterilized soil.

The apparent improved growth of *Capsicum annuum* var. Tatase on height, stem diameter and dry matter yield in both sterilized and unsterilized soil suggests the ability of the introduced AM fungi to enhance water and nutrient uptake thereby increasing growth rate. The effect was more obvious on sterilized soil particularly for indigenous AM fungi *Glomus mosseae* to manifest these growth enhancement characteristics on pepper. Mean heights and dry matter yield of pepper in pots treated with AM in soil not sterilized, although appeared similar, were significantly different and lower than plants in the un-inoculated pots. Results from AM fungi studies have revealed that variation in plant responses depend on host plant species (Rao *et al*., 1990). The negative response for AM on height and dry matter yield of *Capsicum annuum* var. Tatase on unsterilized soil as opposed to what obtained under sterilized soil in the present investigation may imply high effectiveness, competitiveness or abundance of indigenous AMF in the soil. Also in growth parameters, *Glomus fasciculatum* enhanced higher leaf number and

dry matter yield than other mycorrhizal treatments under different cropping system with rock P additions.

AM inoculation is a promising fertilizer because it is inexpensive, easy to handle and improves plant growth. The types of treatments used considerably enhanced the macro and micronutrients in the pepper plant when compared with the control. There was an improved growth of *Capsicum annuum* var. Tatase having AM treatments on leaf number and dry matter yield over non mycorrhizal pepper plants in sterilized soil. This also confirms the ability of the introduced AM fungi to enhance water and nutrient uptake.

This observation supports ealier findings that apart from P uptake, AM association has been found to improve nutrient uptake and nutritional status of host plants for other elements; N (Nielsen and Jensen, 1983; Ames *et al*., 1983), K (Nielsen and Jensen, 1983; Sieverding and Toro, 1988; Osonubi *et al*., 1995), Mg (Sieverding, 1991), Zn and Cu (Benson and Covey, 1976; Cooper and Tinker, 1981), S (Rhodes and Gerdemann, 1978; Buwalda *et al*., 1983), Bo and Mo (Sieverding, 1991), Fe, Mn and Cl (Buwalda *et al*., 1983). Also, there have been reported cases, where AM did not increase the uptake of some of these elements (Krikun and Levy, 1980; Nielsen and Jensen, 1983). A variety of agricultural practices are known to impact on AMF. Apart from effect of AM on nutrient uptake being influenced by either cropping systems or single superphosphate fertilizer treatments, there is clear evidence of tripartite interaction among these factors. This is an area where not much has been reported.

In both sterilized and unsterilized soil, the difference between the two cropping systems was significant with the pepper in the blend showing a greater height and dry matter yield over the sole pepper. Similar to other findings, legumes intercropped with other crops have been associated with higher yields, more efficient land use per unit area and soil fertility improvement (Eaglesham *et al.,* 1981). Such benefit could be to the succeeding phases of the cropping sequence or effect direct transfer of N to companion plants by sharing some of the fixed N with them (Haynes, 1980). This also corroborates with earlier findings that greater benefit of mycorrhiza to the P nutrition of some legumes in comparison to other plant species can affect plant competition and survival in mixed cropping (Crush, 1974; Uyanoz *et al*., 2007).

The apparent improved nutrient uptake of *Capsicum annuum* var. Tatase on N, P, K, Ca and Mg in blend for both unsterilized and sterilized soil suggests the beneficial effect of mixed cropping over sole cropping in agreement with earlier findings (Van der Heijden *et al*., 1988; Kabir *et al.*, 1998; Thingstrup *et al.,* 1998). Among the cropping system treatments, the combination of cowpea with pepper gave the highest dry matter yield for pepper plant.

The study also examines the effect of AM inoculation, cropping systems and rock P fertilization on growth characteristics and nutrient uptake N, P, K, Ca and Mg of *Capsicum annuum* var. Tatase under sterilized soil condition. There was an upward trend of nutrient uptake from non

mycorrhizal to mycorrhizal pepper plants with *Glomus fasciculatum* taking the lead for P uptake and *Glomus mosseae* having the highest uptake of N, K, Ca and Mg.. Addition of rock P at 60kgP/ha had a depression on P uptake but a significant increase on K uptake. The effects of microbial activities on the biogeochemical cycling of plant nutrients are essential for sustainable ecosystems (Jeffries and Barea, 1994). The results of this study of the interaction between a biotechnological practice (microbial inoculation) and a low-input technology (rock P application) have demonstrated the effectiveness of such combined practices in improving sustainable nutrient supply to plants. The introduction of rock P at 60kgP/ha produced significant improvement in both number of leaves and dry matter yield of pepper over non addition of rock P in sterilized soil. The addition of SSP brought a significant increase on height and dry matter yield of pepper on both sterilized and unsterilized soil while significant increase on stem diameter of *Capsicum annuum* var. Tatase was only visible in unsterilized soil.

The study focuses on the effect of AM, organic manure applications rock P and on growth characteristics and nutrient uptake N, P, K, Ca and Mg of *Capsicum annuum* var.Tatase on sterilized soil. However, the use of organic amendment did not increase the number of leaves above where no application was made. The integrated nutrition showed a positive impact on fruit size and beneficial effect on yield similar to pevious result (Srivastava *et al*., 2009). Generally, apart from N uptake, there was an upward trend for other nutrient uptake for both *Glomus mosseae* and *Glomus fasciculatum*

against non mycorrhizal pepper plants on the sterilized soil. Both number of fruits and yields were also exceptionally greater with *Glomus mosseae* than other AM treatments. The use of soil organic amendment showed significant improvement on fruit number while legume mix produced the highest fruit yield. Rock P addition was at its best for pepper plant height at 30kgP/ha whereas the highest leaf number for pepper plant was obtained at 60kgP/ha rock P addition on the field. Quite a lot of variation did emerge.

Since the strategy of how to benefit from AM symbiosis in agriculture is changing, the field conditions have increasingly become the focus of mycorrhiza research. While inoculation becomes less important, the successful management of indigenous or introduced AMF populations in the field is gaining priority. The effects of AM fungi, soil organic amendment and rock P fertilization on growth and yield characteristics of *Capsicum annuum* var. Tatase on the field was yet another focus in this study. On the field, while consistent upward trend was observed on AM treatment for fruit weight on mycorrhizal pepper plants as against un-inoculated pepper plants, inconsistent trends were observed for height and fruit number. Un–inoculated pepper plants performed better than mycorrhizal pepper plants in plant height while *Glomus etunicatum* produced the highest fruit number. Rock P application at 60kgP/ha also improved both height and fruit number over non application but not significant for fruit weight. Studies with low cost partially acidulated rock phosphate sources have given inconsistent results and no obvious advantage over conventional sources (Bationo *et al.*, 1986). Owing to

low phosphate fixing capacity of Alfisols derived from acidic rocks (Juo and Fox, 1977), phosphorus placement is only advantageous at very low rates of phosphorus application i.e. initial dressing of 30kgP/ha followed by maintenance dressing of 15 - 20kgP/ha. The observation from the present study shows that a higher dressing rate than rate earlier suggested above can still be helpful.

Subsequently this study as a follow up further probes the effects of AM fungi, cropping systems and rock P fertilization on growth and yield characteristics of *Capsicum annuum* var. Tatase on the field. Further field experiment with three *Glomus* species; *Glomus etunicatum*, *Glomus fasciculatum* and *Glomus mosseae* shows *Glomus etunicatum* to be topmost in improving pepper height as well as fruit number while *Glomus fasciculatum* excelled most in improving leaf number and *Glomus mosseae* in fruit weight. Soil organic amendment treatment had no significant effect on height of pepper but showed significant variation on leaf number, fruit number and fruit weight per pepper plant. Rock P addition applied at 30kgP/ha produced the best result for fruit yield.

In another experiment on sterilized soil, AM inoculation treatment had no significant effect on plant height but showed significant difference on dry matter yield N, P, K, Ca and Mg uptake. The application of organic manure at 2% improves height, dry matter yield, N, K, Ca and Mg uptake but a decrease in P uptake. The addition of rock P caused improvement effect on some growth characteristics and nutrient uptake while depression in others. This observation

supports ealier findings that apart from P uptake, AM association has been found to improve nutrient uptake and nutritional status of host plants for other elements; N (Nielsen and Jensen, 1983; Ames *et al*., 1983), K (Nielsen and Jensen, 1983; Sieverding and Toro, 1988; Osonubi *et al*., 1995), Mg (Sieverding, 1991), Zn and Cu (Benson and Covey, 1976; Cooper and Tinker, 1981), S (Rhodes and Gerdemann, 1978; Buwalda *et al.*, 1983), Bo and Mo (Sieverding, 1991), Fe, Mn and Cl (Buwalda *et al.*, 1983). Also, there have been reported cases, where AM did not increase the uptake of some of these elements (Krikun and Levy, 1980; Nielsen and Jensen, 1983). A variety of agricultural practices are known to impact on AMF. Apart from effect of AM on nutrient uptake being influenced by either cropping systems or single superphosphate fertilizer treatments, there is clear evidence of tripartite interaction among these factors. This is an area where not much has been reported.

Crop management involves a range of practices which have impact on the AM association either directly or indirectly and may create conditions favourable or unfavourable to AM fungi. In general, agricultural practices have a negative impact on the AM association and agricultural soils are AMF impoverished, particularly in terms of number of species (Helgason *et al*., 1998).

CHAPTER 6

CONCLUSION

The production of adequate and sustainable food to meet the need of increasing population has become a challenge for us especially the tropical Africa. The possibility of increasing agricultural productivity in this arena under the present land and population pressure is through aggressive, intensive and continuous cropping of cultivated land. A successful continuous and intensive cropping may be achieved with improved multiple cropping systems in standard agricultural systems as well as in marginal lands for which pressure is continuously mounting all over the world.

The present study has established the application of Arbuscular mycorrhiza capable of developing an integrated soil management system, involving legumes that have capability of full exploits of N_2 fixation while combining, manure and rock P utilization for efficient nutrient uptake to promote growth and yield of pepper. Generally, AM enhanced almost all the nutrient uptakes with *Glomus mosseae* having greater uptake than others in both sterilized and non sterilized soil under different cropping systems and single super phosphate treatment. However with the introduction of rock phosphate in place of single super phosphate, *Glomus fasciculatum* took the lead with the exception of Calcium uptake. Averaged over organic manure and rock P fertilization treatments, P uptake of *Capsicum annuum* var. Tatase was again higher in *Glomus mosseae* than *Glomus etunicatum* and *Glomus*

fasciculatum treatments while *Glomus fasciculatum* took the lead for Ca and Mg uptake.

Whereas Glomus *mosseae* consistently performed best on P uptake of *Capsicum annuum* var. Tatase in both sterilized and non sterilized soil compared to others, there were variations in other uptakes as well as inconsistency in performance of other AM species subject to soil conditions. These variations may be due to antagonistic behaviour of other microbes in the soil as clearly shown with results obtained with non mycorrhizal pots under sterilized soil condition. Apart from effect of AM on nutrient uptake being influenced by either cropping systems or single superphosphate fertilizer treatments, there is clear evidence of tripartite interaction among these factors. This is an area where not much has been reported. Based on the experimental findings it can be concluded therefore that;

1. There is variation in the performance of mycorrhizal species subject to soil environment and organic manure.
2. Most nutrient uptake and not P only are improved by the presence of mycorrhiza.
3. There is yield improvement through mycorrhizal inoculation.
4. There is variation in performance of mycorrhizal species with level and forms of P and manure supplements to the soil. Generally mycorrhizal plants showed significantly higher nutrients uptake especially N, P, K, Ca and Mg than non-mycorrhizal plants on sterilized soil. The reverse was observed on non-

sterilized soil for some nutrients, which might be due to antagonistic action from other active microbes.

In order to maximize the benefits from above findings, there is need for subsequent research to focus on soil and plant environment in a sequential order so as to be able to identify both beneficial and antagonistic factors that come into action in the interactive process of employing AM, different cropping systems and the use of fertilizers (organic/inorganic) in sustainable cropping systems.

REFERENCES

Abbott, L.K., and A.D. Robson. (1985). Assessing the potential for wide scale VA mycorrhizal inoculation. In: Molina, R. (ed.) Proceedings of North America Conference. on Mycorrhizae, 6th, Bend, OR. 25–29 June 1984. Forest Res. Lab., Oregon State Univ., Corvallis. 76–79.

Abbott, L.K., Robson, A.D. (1989). Factors affecting the occurrence of vesicular-arbuscular mycorrhizal. Agric Ecosystems Environ. *Advances in Soil Science* 15:1-39

Adediran, J.A. and Sobulo, R.A. (1995). The potentials and use of rock phosphate in the sub-sahara Africa. Paper presented at the 3rd African Soil Science Society Conference.

Adepetu, J.A. (1970). The relative importance of organic phosphorus to crop nutrition in soils of Western Nigeria. M. Phil Thesis University of Ife.

Agboola, A.A. (1987). Farming systems in Nigeria. In*:* Lathan M. and Ann P. (eds). Land development and management of acid soils in Africa. Proceedings. Second regional workshop on land development and management of acid soils in Africa. Lusaka and Kasama, Zambia,

Agboola, A.A. and Fayemi, A.A. (1972). Fixation and excretion of nitrogen by tropical legumes. *Agronomy Journal*, 64 (4): 409-412.

Ahn, P.M. (1970). West African Soils vol 1.West African Agriculture Oxford.

Ali Asgharzadeh, N. and Saleh Rastin, N. (1997). The effects of inoculations with VAM fungi and *Bradyrhizobium japonicum* on growth and nutrient. *Soil and Water Journal*. 10:1-*2*

Allen, E.B. and Allen, M.F. (1986). Water relations of xeric grasses in the field: interactions of mycorrhizas and competitions *New Phytologist* 104: 559-571.

Allen, M.F. (1983). Formation of vesicular-arbuscular mycorrhizae in Atriplex gardneri (Chenopodiacea) Seasonal response in a cold desert. *Mycologia*, 75, 773-776.

Allen, M.F., Moore, T.S. and Chritensen, M. (1980). Phytohormone changes in *Bouteloua gracilis* infected by vesicular arbuscular mycorrhizae: 1 Cytokinin increases in the host plant. *Canadian Journal of Botany* 58:371-374.

Allen. M.F., Smith, W.K., Moore, T.S. Jr. and Christensen, M. (1981). Comparative water relations and photosynthesis of mycorrhizal and non-mycorrhizal *Bouteloua gracilis* H.B.K. *New Phytologist* 88: 683–693.

Alom, M.S., Paul, N.K. and Quayyum, M.A. (2009). Performances of different hybrid maize *(Zea mays* l.) varieties under intercropping systems with groundnut *(Arachis hypogaea* l.) *Bangladesh Journal of Agricultural Research*. 34(4): 585-595.

Ames, R.N., Porter, L., St John, T.V. and Reid, C.P.P. (1984). Nitrogen sources and 'A' values for vesicular-arbuscular and non mycorrhizal sorghum grown at three rates of N ammonium sulphate. *New Phytologist* 97: 269-276

Ames, R.N., Reid, C.P.P., Porter, L.K., and Cambardella, C. (1983). Hyphal uptake and transport of nitrogen from two 15N-labeled sources by Glomus mosseae, a vesicular-arbuscular mycorrhizal fungus. *New Phytologist* 95: 381-396.

Anderson, G. (1980). Assessing organic phosphorus in soil. In: Khasawneh, F.E., Sample, E.C. and Kamprath, E.J. (eds) The role of phosphorus in agriculture. American Society of Agronomy.Madison USA. 411-431.

Andrew. D.J. and Kassam, A.H. (1976). The importance of multiple cropping in increasing world food suplies. In: Papendick *et al*. (ed). Multiple cropping ASA Special publication no 27 Madison: ASA, CSSA and SSSA. 1-10.

Annes, R.N., Porter, L., St John, T.V. and Reid, C.P.P. (1984). Nitrogen sources and 'A' values for vesicular-arbuscular and non mycorrhizal sorghum grown at three rates of N ammonium sulphate. *New Phytology* 97:269-276.

Asgharzadeh, N. And Saleh Rastin, N. (1997). The effects of inoculations with VAM fungi and *Bradyrhizobium japonicum* on growth and nutrient. *Soil and Water Journal* 10:1-2

Augé RM, Schekel KA, Wample R.L. (1987a). Leaf water and carbohydrate status of VA mycorrhizal rose exposed to drought stress. *Plant Soil*. 99:291–302

Augé RM, Schekel KA, Wanple RL (1987b). Rose leaf elasticity changes in response to mycorrhizal colonization and drought acclimation. *Physiologia Plantarum*. 70:175-182.

Augé, R.M., Schekel, K.A., and Wample, R.L. (1986). Greater leaf conductance of well-watered VA mycorrhizal rose plants is not related to phosphorus nutrition. *New Phytologist*. 103:107-116.

Ayanaba, A. and Sanders, F.E. (1981). Microbial factors. In: Greenland, D J (ed.). Characterization of soils in relation to their classification and management for crop production. Examples from some areas of the Humid Tropics. Clarendon Press, Oxford. 164-186.

Azcón, R. (1987). Germination and hyphal growth of Glomus mosseae in vitro: Effects of rhizosphere bacteria and cell-free culture media. *Soil Biology and Biochemistry* 19: 417-419.

Azcón, R. and Ocampo, J.A. (1981). Factors affecting the vesicular arbuscular infection and mycorrhizal dependency of thirteen wheat cultivars. *New Phytologist.* 87:677-685

Azcón, R., Rubio. R. and Barea, J.M. (1991). Selective interactions between different species of mycorrhizal fungi and *Rhizobium meliloti* strains and their effects on growth, N_2 fixation (15N) and nutrition of *Medicago sativa*. *New Phytologist*, 117: 399-404.

Azcón-Aguilar, C., and Barea J.M. (1985). Effect of soil microorganisms on formation of vesicular-arbuscular mycorrhizas. Trans . br. Mycol. Soc. 84:536-537.

Azcón-Aguilar, C., Diaz-Rodriguez, R.M. and Barea J.M. (1985). Effect of soil microorganisms on spore germination and growth of the vesicular-arbuscular mycorrhizal fungus *Glomus mosseae*. Trans. Br. Mycol. Soc. 86:337-340

Azcón-G de Aguilar C, Azcón R, Barea J.M. (1979). Endomycorrhizal fungi and Rhizobium as biological fertilisers for Medicago sativa in normal cultivation. *Nature* 279: 325-236

Bagyaraj, D.J. and A. Verma, (1995). Interactions between *Arbuscular mycorrhizal* fungi and plants: Their importance in sustainable agriculture in arid and semi arid tropics. Adv. Microbiol. Ecol., 14: 119-122.

Bagyaraj, D.J. and Menge, J.A. (1978). Interactions between a VA mycorrhiza and Azotobacter and their effects on rihzosphere microflora and plant growth. *New Phytologist*. 80:567-573.

Bahl, G.S. and Singh, V.T. (1986). Phosphorus diffusion in soils in relation to some edaphic factors and its influence on P uptake by maize and wheat. *Journal of Agricultural Science.* Cambridge. 107:335-341.

Barea, J.M. (1991). Vesicular-arbuscular mycorrhizae as modifiers of soil fertility. *Advances in Soil Science* 15:1-39

Barea, J.M. and Azcón -Aguilar, C. (1985). Mycorrhiza and their significance in nodulating nitrogen-fixing plants. *Advances in Agronomy*. 36:1 – 54.

Barea, J.M. and Jeffries, P. (1995). Arbuscular mycorrhizas in sustainable soil-plant systems. In: Varma, A. and Hock, B. (Eds). Mycorrhiza-Structure, Function, Molecular Biology and Biotechnology. Springer-Verlag, Berlin. 521-560.

Barea, J.M., Navarro, E. and Montoya, E. (1976). Production of plant growth regulators by rhizosphere phosphate-solubilizing bacteria. *Journal of Applied Bacteriology* 40:129-134.

Barea,J.M., Azcón, R. and Azcón-Aguilar, C., (1992). The use of 15N to assess the role of VA mycorrhiza in plant N nutrition and its application to evaluate the role of mycorrhiza in restoring Mediterranean ecosystems. In: Read, D.J., Lewis, D.H., Fitter, A.H. and Alexander, I.J. (eds) *Mycorrhizas in Ecosystems*. CAB International, UK. 190-197.

Bationo, A., Mughogho, S.K. and Mokwunye, U. (1986). Agronomic evaluation of phosphate fertilizers in tropical Africa. In: Mokwunye, A U and Vlex P G (eds) Management of nitrogen and phosphorus in sub Saharan Africa. Martinus Nijhoff Publ. Dordrecht: 283-318.

Baya, A.M., Boethiling, R.S. and Ramos-Cormenzana A. (1981). Vitamin production in relation to phosphate solubilization by soil bacteria. *Soil Biology and Biochemistry*. 13:527-531.

Bayne, H. G. and Bethlenfalvay, G. J. (1987). The *Glycine–Glomus-Rhizobium* symbiosis. II. In interaction between the mycorrhizal nitrogen fixing endophytes. *Plants. Cell Environ*.10, 607- 612.

Becard, G. and Piche´ Y. (1989). Fungal growth stimulation by CO2 and root exudates in vesicular-arbuscular mycorrhizal symbiosis. *Applied and Environmental Microbiology*. 55:2320–2325.

Benson, N.R.. and Covey Jr., R.P. (1976). Response of apple seedlings to fertilization and mycorrhizal inoculation. *Horticultural Science*.11: 252-253.

Bethlenfalvay, G.J. (1982). Conditions affecting parasitic or mutalistic growthin mycorrhizal plants. *Phytophatology*. 72: 950-961

Bethlenfalvay, G.J. Brown, M.S. and Stafford, A. E. (1985). *Glycine–Glomus-Rhizobium* symbiosis. II. Antagonistic effects between mycorrhizal colonization and nodulation . 79: 1054-1058.

Bethlenfalvay, G.J., Brown, M.S., Ames, R.N. and Thomas, R.S, (1988). Effects of drought on host and endophyte development in mycorrhizal soybeans in relation to water use and phosphate uptake. 72:565–571

Bethlenfalvay, G.J., Thomas, R.S., Dakessian, S., Brown, M.S., Ames, R.N. and Whitehead, E.E. (1988). Mycorrhizae in stressed environments: effects on plant growth, endophyte development, soil stability and soil water. In: Hutchinson C.F., Timmermann, B.N. (eds) Arid lands: today and tomorrow. Westview, Boulder, Colo. 1015–1029.

Bethlenfavay, G.J. and Newton, W.E. (1991). Agro-ecological aspects of the mycorrhizal, nitrogen-fixing legume symbiosis. The rhizophere and plant growth. In: D.L. Keister and P.B. Cregan (ed). Kluwer academic Publishers. Dordrecht, the Netherlands. 349-359.

Bledsoe, C.S. and Zasoski, R.J. (1983). Effects of ammonium and nitrate on growth uptake by mycorrhizal Douglas-fir seedlings. *Plant and Soil*.71:445-454

Bolgiano, N.C., Safir, G.R. nd Warneke, D.D. (1983). Mycorrhizal colonization and growth of onion in the field in relation to phosphorus and water availability. *Journal of American Society and Horticultural Science*. 108: 819-825.

Bonfante, P. and Perotto, S. (1995). Strategies of arbuscular mycorrhizal fungi when infecting host plants. *New Phytologist* 130: 3-21

Bouyoucos, G.H. (1962). Hydrometer improved for making particle size analysis of soils. *Agronomy Journal*. 54:464-465.

Bromfield, S.M. (1959). Some factors affecting the solubility of phosphates during microbial decomposition of plant material. *Journal of Agricutural Research*. 2:304-316.

Bryla, D.R. and Koide, R.T. (1990). Factors affecting the vesicular arbuscular infection in the growth and reproduction of wild vs cultivated plants II. Eight wild accession and two cultivars of *Lycopersicon esculentum* Mill. *Ocologia*. 84:82-92.

Buwalda, J.G., Goh, K.M. (1982). Host-fungus competition for carbon as a cause of growth depressions in vesicular-arbuscular mycorrhizal ryegrass. *Soil Biology and Biochemistry* 14:103-106

Buwalda, J.G., Stribley, D.P. and Tinker, P.B. (1983). Increased uptake of anions by plants with vesicular arbuscular mycorrhiza. *Plant and Soil*. 71:463-467

Cecilio Filho, A.B. Rezende, B.L.A. and Costa, C.C. (2010). Economic analysis of the intercropping of lettuce and tomato in different seasons under protected cultivation. *Horticultura Brasileira*. 28: 326-336.

Chambers, C.A., Smith, S.E., Smith F.A., Ramsey, M.D. and Nicholas, D.J.D. (1980). Symbiosis of *Trifolium subterraneum* with mycorrhizal fungi and *Rhizobium trifolii* as affected by ammonium sulphate and nitrification inhibitors. *Soil Biology and Biochemistry*. 12:93-100.

Chandreshekara, C.P., Patil, V.C. and Sreenivasa, M.N. (1995). VA-mycorrhiza mediated P effect on growth and yield of sunflower (*Helianthus annus* L.) at different P levels. *Plant and Soil*. 176: 325-328.

Chanway, C.P., Turkington, R. and Holl, F.B. (1991). Ecological implications of specificity between plants and rhizosphere microorganisms. *Advances in Ecological Research*. 21:122-169

Cooper, K.M. (1984). Physiology of VA mycorrhizal associations. *In* C.L. Powell and D.J. Bagyaraj ed. FA mycorrhizal. CRC Press Boca Raton. FL. P155-186

Cooper, K.M. and Tinker, P.B. (1981). Translocation and transfer of nutrients in vesicular arbuscular mycorrhizas. II Uptake and translocation of phosphorus, zinc and sulphur. *New Phytologist*. 81:43-52.

Cox, G., Sanders, F.E.and Wild, J.A. (1975). Ultra-structural evidence relating to host-endophyte transfer in a vesicular arbuscular mycorrhiza. In: Sanders, F.E., Mosse, B. and Tinker, P.B. (eds). *Endomycorrhizas* pp 297-312. Academic Press. London and New York.

Crush, J.R. (1974). Plant growth responses to vescular arbuscular mucorrhiza VII. Growth and nodulation of some herbage legumes. *NewPhytologist*. 73:743-749.

Daft, M.J, and Okusanya, B.O. (1973). Effects of *Endogone* on plant growth. IV. Influence of the infection on the anatomy and reproductive development in four hosts. *New Phytologist*. 97:277–284

Daft, M.J. and El-Giahmi, A.A. (1978). Effect of arbuscular mycorrhiza on plant growth. VIII. Effects of defoliation and light on selected hosts. *New Phytologist* 80: 365-372.

Daniels, B.A., and Trappe, J.M. (1980). Factors affecting spore germination of the vesicular-arcbuscular mycorrhizal fungus, *Glomus epigaeus*. *Mycologia*. 72:457-471.

Davidson, D.E. and Christensen, M. (1977). Root microfungal associations in a short grass prairie *In*: Marshall, J.K. (ed). The Belowground Ecosystem: A synthesis of plant associated processess. Ft. Collins Colorado. Colorado State University. Pp 279-287.

Dodd, J.C. (2000). The role of arbuscular mycorrhizal fungi in agro and natural ecosystems. *Outlook on Agriculture*. 29 (1):55-62.

Dodd, J.C., Burton, C.C., Burns, R.G. and Jeffries, P. (1987). Phosphatase activity associated with the roots and the rhizosphere of plants infected withvesicular-arbuscular mycorrhizal fungi. *New Phytology*. 107, 163-172.

Elliot, E.T. and Coleman, D.C. (1988). Let the soil work for us. Ecology Bull. 39:23-32

Ellis, J.R., Larsen, H.J. and Boosalis, M.G. (1985). Drought resistance of wheat plants inoculated with vesicular arbuscular mycorrhizae. *Plant and Soil* 86: 369-378.

Enwezor, W.O. and Moore, W.A. (1966). Phosphate status in some Nigeria soils. *Soil Science*. 102:322-327.

Espinoza-Victoria, D., Quintero-Ramos, M., Ferrera-Cerrato, R. and Bethlenfalvay, G.J. (1993). Fitting plants to soil through mycorrhizal fungi: plant nutrition in host-endophyte combinations evaluated by the diagnosis and recommendation integrated system. *Biology and Fertility of Soils* 15: 96-102.

Evans, D.G. and Miller, M.H. (1990). VA mycorrhiza and the soil disturbance induced reduction of nutrient absorption in maize. *New Phytologist*. 110:67-75.

Finlay, R. and Soderstrom, B. (19920. Mycorrhiza and carbon flow to the soil. In: Allen, Allen, M.F. (ed) Mycorrhizal Functioning- An integrative plant fungal process. Pp 134-160. Chapman and Hall, New York, USA.

Fitter, A.H. (1988). Water relations of red clover *Trifolium pratence* L. as affected by VA mycorrhizal colonization of phosphorus supply before and during drought. *Journal of Exprimental Botany*. 39: 595-603.

Fitter, A.H. and Garbaye, J. (1994). Interaction between mycorrhizal fungi and soil organisms. In: Robson, A.D., Abbott, L.K. and Malajczuk, N. (eds). Management of mycorrhizas in Agriculture, Horticulture and Forestry. Developments in Plant and Soil Sciences. Vol 56 pp123-132. Kluwer Academic Publishers, Netherlands.

Fitter, A.H. and Merryweather, J.W. (1992). Why are some plants more mycorrhizal than others? An Ecological Enquiry. *In* Read, D.J., Lewis, D.H, Fitters, A.H,. and Alexander, I.J. (eds) Mycorrhizas in Ecosystems pp 26-36 CAB International, UK.

Fitter, A.H., Heinemeyer, A. and Staddon, P.L. (2000). The impact of elevated CO_2 and global climate change on arbuscular *mycorrhizas*: a mycocentric approach. *New Phytologist*. 147,179-187.

Francis, R. and Read, D.J. (1984). Direct transfer of carbon between plants connected by vesicular-arbuscular mycorrhizal mycelium.. *Nature*. 307: 53–56.

Friese, C.F. and Allen, M.F. (1991). The spread of VA mycorrhizal fungal hyphae in the soil: inoculums types and external hyphal architecture. *Mycologia*, 83: 409-418.

George, E., Häussler, K.U., Vetterlein, D., Gorgus, E., and Marschner, H. (1992). Water and nutrient translocation by hyphae of *Glomus mosseae*. *Canadian Journal of Botany* 70: 2130-2137.

George, E., Marschner, H. and Jakobsen, I. (1995). Role of arbuscular mycorrhizal fungi in uptake of phosphorus and nitrogen from soil. Critical Reviews in Biotechnology 15(3-4), 257-270.

Gerdermann, J.W. and Nicolson, T.N. (1963). Spores of mycorrhiza endogone extracted from soil by wet sieving and decanting. *Trans. Br. Mycol. Soc*. 46:235-244.

Gerretson F.C. (1948). The influence of micro organisms on the phosphate intake by the plant. *Plant and Soil*. 1:51-81.

Gianinazzi, S., Plumey-Jacquot, E., Gianinazzi-Pearson, V., Leyval, C. (2005). Contribution of arbuscular mycorrhizal to soil quality and terrestrial ecology. In: J Bloem, DW Hopkins, A Benedetti (eds). *Microbiological Methods for Assessing Soil Quality*. Cambridge, USA: CABI publishing. pp. 248-56.

Gianinazzi-Pearson, V. and Gianinazzi, S. (1983). The physiology of vesicular arbuscular mycorrhizal roots. *Plant and Soil*. 73:197-209

Gianinazzi-Pearson, V., Fardeau, J.C., Asimi, S. and Gianinazzi, S. (1981). Source of additional phosphorus absorbed from soil by vesicular arbuscular mycorrhizal soybeans. *Physiol.Veg.* 19:33-43

Giovannetti, M., and Mosse, B., (1980). An evaluation of techniques for measuring vesicular-arbuscular mycorrhizal infection in roots. *New Phytologist* 84, 489-500.

Graham, J.H., Leonard, R.T. and Menge, J.A. (1981). Membrane-mediated decrease in root exudation responsible for phosphorus inhibition of vesicular-arbuscular mycorrhiza formation. . 68:548-552.

Graham, J.H., Linderman, R.G. and Menge, J.A. (1982). Development of external hyphae by different isolates of mycorrhizal Glomus spp. in relation to root colonization and growth of Troyer citrange. *New Phytologist*. 91:183-189

Graham, R.D. (1983). Effects of nutrients on susceptibility of plants to disease with particular reference to the trace elements. *Advances in Botany Research*. 10:221-276.

Hall, I.R. and Armstrong, P. (1979). The effect of vesicular-arbuscular mycorrhizas on growth of clover, lotus and ryegrass in some eroded soils. *New Zealand Journal of Agricultural Research*., 22: 479-484.

Hamel, C., Furlan, V. and Smith, D.L. (1991). N_2 fixation and transfer in a field grown mycorrhizal corn and soybean intercrop. *Plant and Soil*. 133:177-185.

Hardie. K. and Leyton, L. (1981). The influence of vesicular arbuscular mycorrhiza on growth and water relations of red clover. 1. In phosphate deficient soil. *New Phytologist* 89:599-608.

Harley, J.L, and Smith, S.E. (1983). Mychorrhizal symbiosis. Academic Press, New York.

Harpstead, M.I. (1973). The classification of some Nigeria soils. *Soil Science*. 116:437-443.

Hayman, D.S. (1975). Phosphorous cycling of soil microorganism and plant roots. In: Walker, N. (ed). Soil Microbiology. Halstead Press. New York and Wiley and sons. 67-91.

Hayman, D.S. (1980). Mycorrhiza and crop production. *Nature*. 287:487-488.

Hayman, D.S. (1983). The physiology of VAM endomycorrhizal symbiosis. *Canadian Journal of Botany* 63:944-963.

Hayman, D.S. (1984). Improved establishment of white clover in hill grass land by inoculation with mycorrhizal fungi. In: Thomson, D.J. (ed). Forage legumes, British grassland Society occassional symposium. Harley: BGS. 16: 44-47.

Hayman, D.S. (1986). Mycorrhizae of Nitrogen fixing legumes. *Mircen Journal*. 2:121-145.

Haynes, R.J. (1980). Competitive aspects of the grass-legumes association. *Advances in Agronomy* 33:227-261.

Helgason, T, Daniell, T.J. Husband, R.,. Fitter, A.H. and Young., J.P.W. (1998). Ploughing up the woodwide web? *Nature*. 394:431

Hetrick, B.A.D. Kitt, D.G. and Wilson, G.T. (1988). Mycorrhizal dependency and growth habit of warm-season and cool-season tall grass prairie plants. *Canadian Journal of Botany* 66:1376-1380.

Hirrel, M.C., Mehravaran, H. and Gerdemann, J.W. (1978). Vesicular-arbuscular mycorrhizae in the Chenopodiaceae and Cruciferae: do they occur? *Canadian Journal of Botany*. 56: 2813-2817.

Ho, I. and Trappe, J.M. (1973). Translocation of ^{14C} from Festuca plants to their endomycorrhizal fungi. *Nature*. 244:30-31.

Huang, R., Smith W.R. and Yost, R.S. (1985). Influence of vesicular arbuscular mycorrhiza on growth, water rlations and leaf orientation in *Leucaena leucocephala* (Lam) De Wit. *New Phytologist*. 99:229-243

Hunt, R., Stribley, D.P. and Read, D.J. (1975). Root/shoot equilibria in cranberry (*Vacciniummacrocarpon* Ait). *Annaals of Botany*. 39:807-810.

Ianson, D.C. and Linderman, R.G. (1990). Variation in V A mycorrhizal strain interactions with Rhizobium on pigeon pea. *In* The Rhizosphere and Plant Growth. Eds. D L Keister and P B Cregan. P 371.Kluwer AcademicPublishers, Dordrecht, The Netherlands.

Jackson, R.M and Mason, P.A. (1984). Mycorrhiza. *Studies in Biology*. No. 159 60pp.

Jaiyeola, K.E. (1974). Soil and land use studies for fruits and vegetables experimental and demonstration centre, Ibadan. Project for Agricultural Research Council of Nigeria. Research memorandum no 58

Jakobsen, I., Abbott, L.K. and Robson, A.D. (1992). External hyphae of vesicular arbuscular mycorrhizal fungi associated with *Trifolium subterraneum* L. I. Spread of hyphae and phosphorus inflow into roots. *New Phytologist*. 120:371-381.

Jasper, D. A., Abbott, L. K. and Robson A. D. (1989). Soil disturbance reduces the infectivity of external hyphae of vesicular arbuscular mycorrhizal fungi. *New Phytologist*. 112**:**93–99.

Jasper, D.A., Abott, L.K. and Robson, A.D. (1991). The effect of soil disturbance on vesicular arbuscular mycorrhiza fungi in soils from different vegetation types. *New Phytologist*. 118 (3): 471-476.

Jeffries, P. (1987). Use of mycorrhiza in agriculture. Crit. Rev. Biotechnol. 5:319-357.

Jeffries, P., and Barea, J.M. (1994). Biogeochemical cycling and arbuscular mycorrhizas in the sustainability of plant-soil systems, In: Gianinazzi, S. and Schu¨epp, H. (ed.). Impact of arbuscular mycorrhizas on sustainable agriculture and natural ecosystems. Birkha¨user Verlag, Basel, Switzerland. 101–115.

Jenny, H. (1961). Plant root-soil interactions. In: Zarrow, M.X. (ed). Growth in Living Systems. Basic Book Inc. New York. 665-694.

Johansson, J.F., Paul, L.R. and Finlay, R.D. (2004). Microbial interactions in the mycorrhizosphere and their significance for sustainable agriculture. *Fems Microbiology Ecology*. 48(1):1-13.

Juo, A.S.R. (1981). Chemical characteristics. In: Greenland D J (ed.) Characterization of soils in relation to their classification and management for crop production: Examples from some areas of the humid tropics. Clarendon Press. Oxford 51-79.

Juo, A.S.R. and Adams, F. (1986). Chemistry of LAC soils In: Proc Symposium on how activity clay (LAC) soils. Tech monographs no. 14. SMSS, Soil Conservation Service.

Juo, A.S.R. and Adams, F. (1986). Chemistry of LAC soils In: Proc Symposium on how activity clay (LAC) soils. Tech monographs no. 14. SMSS, Soil Conservation Service.

Juo, A.S.R. and Fox, R.L. (1977). Phosphate sorption characteristics of some benchmark soils of West Africa. *Soil Science*. 124: 370-376.

Juo, A.S.R. and Kang, B.T. (1979). Effect of liming on the availability of three rock Phosphate sources in two West African Ultisols. *Communications in Soil Science and Plant Analysis*. 10: 93-103.

Kabir, Z., O'Halloran, I.P., Fyles, J.W. and Hamel, C. (1998). Dynamics of the *Mycorrhizal symbiosis* of corn (*Zea mays* L.): Effects of host physiology, tillage practice and fertilization on spatial distribution of extra-radical mycorrhizal hyphae in the field. *Agricultural Ecosystem and. Environment*. 68: 151-163.

Kang, B.T. and Fox, R.L. (1981). Management of the soils for continuous production: controlling nutrient status. In: Greenland D.J. (ed). Characterization of soils in relation to their classification and

management for crop production: Examples from some areas of the humid tropics. Clarendon Press. Oxford 202-213.

Kang, B.T. and Juo, A.S.R. (1983). Management of low activity clay soils in tropical Africa for food crop production. In: Bedroth F H , Neel H and Eswaran H (eds) Proc. Fourth Int Soil classification workshop.Rwanda. ABOS-AGCD, Brussls: 450-470.

Kang, B.T. and Osiname, O.A. (1979). Phosphorus response of maize grown on Alfisols in southern Nigeria. *Agronomy Journal* 71:383-394.

Kang, B.T., Gichuru., M., Hulugalle, N. and Swift, M.J. (1990). Soil constraints for sustainable upland crop production in humid and sub-humid West Africa. Proceedings of the 24th International Symposium of Tropical Agriculture Research Kyoto, August 14-16, (1990). *Tropical Agriculture Research Series* No 24 pp 101-112.

Keay, R.W.J. (1959). An outline of Nigeria vegetation 2nd Ed. Federal Government Printer Lagos, Nigeria.

Khalil, S., Loynachan, T.E. and Mcnabb, H.S. Jr. (1992). Colonization of soybean by mycorrhizal fungi and spore populations in Iowa soils. *Agronomy Journal* 84(5) 832-836.

Koide, R.T., Li, M., Lewis, J. and Irby, C. (1988). Role of mycorrhizal infection in the growth of wild vs cultivated oats. *Ocologia* 77:537-543.

Kothari, S.K., Marschner, H. and George, E. (1990). Effect of VA mycorrhizal fungi and rhizosphere microorganisms on root and shoot morphology, growth and water relations in maize. *New Phytologist*. 116:303–311

Krikun, J. and Levy, Y. (1980). Effect of vesicular arbuscular mycorrhizaon citrus growth and mineral composition. *Phytoparasitica*. 8:195-200

Krishna, K.R., Shetty, K.G., Dart, P.J. and Andrews, D.J. (1985). Genotype dependent variation in mycorrhizal colonization and response to inoculation of pearl millet. *Plant and Soil*. 86:113-125.

Kurle, J.E., and Pfleger, F.L. (1996). Management influences on arbuscularmycorrhizal fungal species composition in a corn-soybean rotation. *Agronomy Journal*. 88**:**155–161.

Lal, R. (1987). Managing the Soils of Sub-Saharan Africa. *Science*. 236:1069-1076.

Land, S., Alten, H. Von. and Schonbeck, F. (1993). The influence of host plant, nitrogen fertilization and fungicide appliction on the abundance and season dynamics of VAM fungi in arable soils of Northern German. *Mycorrhiza*. 29 (4) 157-166.

Larsen, J. and Bodker, L. (2001). Interactions between pea rooting-inhabiting fungi examined using signature fatty acids. *New Phytologist*.149:487-493.

Lester, D. (2009). Buying and applying mycorrhizal fungi. Max. Yield. USA. pp:126-131. http://www.maximumyield.com/article. Accessed March 02, 2010.

Lewis, D. H. and Harley, J.L. (1965). Carbonhydrate physiology of mycorrhizal roots of beech. III. Movement of sugars between host and fungus. *New Phytologist*. 64:256-269

Lindahl, B. and Olsson, S. (2004). Fungal translocation—Creating and responding to environmental heterogeneity. *Mycologist*. 18: 79–88.

Linderman, R.G. (1988). Mycorrhizal interactions with the rhizosphere microflora: The mycorrhizophere effect. *Phytopathology* 78:366-371.

Linderman, R.G. (1992). Vesicular-arbuscular mycorrhiza and soil microbial interaction In: Bethlenfalvay G J, Linderman RD (eds) Mycorrhizal in sustainable agriculture. *American Society of Agronomy*. Madison. 45-70.

Linderman, R.G. and Davis, E.A. (2004). Evaluation of commercial inorganic and organic fertilizer effects on arbuscular mycorrhizae formed by Glomus intraradices. *Horttechnology*. 14(2):196-202.

Mahdi, A.A. and Atabani, I.M.A. (1992). Response of Brady Rhizobium-inoculated soybean and lablab bean to inoculation with vesicular arbuscular mycorrhizae. *Exploratory Agriculture*. 28:399-407.

Manjunath, A. And Habte, M. (1990). Establishment of soil solution P levels for studies involving vesicular-arbuscular mycorrhizal symbiosis. *Commun Soil Science and.Plant Analysis*. 21:557-566.

Materechera, S.A and Sakeala, W.D.M. (1989). The effect of prunning height on growth, seed yield and yield components of pigeon pea. *International Pigeon Pea Newsletter*. No 9 pp 19-21.

Menge, J.A. (1982). Utilization of vesicular arbusclar mycorrhizal fungi in agriculture.*Canadian Journal of Botany*. 61:1015-1024.

Menge, J.A. and Timmer, L.W. (1982). Procedures for inoculation of plants with vesicular arbuscular mycorrhizae in the laboratory greenhouse and field. In: Schenck, N.C.(ed).Methods and Principles of Mycorrhizal Research. The American Phytopathological Society, Minnesota, USA. 59-68.

Mercy, M.A., Shivashankar, G. Bagyaraj, D.J. (1990). Mycorrhizal colonization in cowpea is host dependent and heritable. *Plant and Soil*.121:292-294.

Meyer, F.H. (1973). Distribution of ectomycorrhizal in nature and man made forest. In: Ectomycorrhizal. Their ecology and Physiology, ed. Marks GC and Kozlowski TT New York: Academic Press. 79-105.

Meyer, J.R and Linderman, R.G. (1986). Response of subterranean clover to dual inoculation with vesicular-arbuscular mycorrhizal fungi and a plant growth-promoting bacterium, *Pseudomonas putida. Soil Biology and Biochemistry*. 18:185-90.

Miller, R.M. (1979). Some occurrences of vesicular-arbuscular mycorrhiza in natural and disturbed ecosystems of the Red Desert. *Canadian Journal of Botany*. 57:619-623.

Miller, R.M. (1987). The ecology of vesicular arbuscular mycorrhizae in grass and shrublands. In: Safir, G.R. (ed). *Ecophysiology of VA Mycorrhizal Plants*. CRC Press Inc. Boca Raton, Fla. 135-170.

Miller, R.M. and Jastrow, J.D. (1990). Hierarchy of root and mycorrhizal fungal interactions with soil aggregation. *Soil Biology and Biochemistry*. 22:579–584

Miller, R.M. and Jastrow, J.D. (1992). The application of VA mycorrhizae to ecosystem restoration and reclamation. In: Allen MF (ed) Mycorrhizal functioning: an integrative plant–fungal process. Chapman and Hall, New York. 438–467.

Molina, R., Massicotte, H., Trappe, J.M. (1992) Specifity phenomena in mycorrhizal symbiosis: Community ecological consequences and practical implications. In: Allen, M.F. (ed.) Mycorrhizal functioning. New York: Chapman & Hall. 357-423.

Morton, J.B. (1988). Taxonomy of VA mycorrhizal fungi: classification, nomenclature and identification, M*ycotaxcon*. 32:267-324.

Morton, J.B. and Benny, G.L. (1990). Revised classification of arbuscular mycorrhizal fungi (Zygomycetes): A new order, Glomeleo, two new suborders, Glomineae and Gigasporineae and two new families, Acalosporaceae and Gigasporaceae with an amendation of Glomaceae. *Mycotaxon*. 37: 471-491.

Morton, J.B. and Bentivenga, S.P. (1994). Levels of diversity in endomycorrhizal fungi (Glomales, Zygomycetes) and their role in defining taxonomic and non taxonomic groups. In: Robson, A.D.,Abbott,L.K. and Malajczuk, N. (eds). Management of

Mycorrhizas in agriculture, Horticulture and Forestry. Kluwer Academic Publishers, Netherlands. 47-60.

Mosse, B. (1959). The regular germination of resting spores and some observations on the growth requirements of an Endogone sp. Causing vesicular-arbuscular mycorrhiza. Trans. Br mycol. Soc. 42:273-286.

Mosse, B. (1973). Advances in the study of vesicular-arbuscular mycorriza. *Annual Review of phytopathology* 11:171-196.

Mosse, B. (1977). Plant growth responses to vesicular arbuscular mycorrhiza. X. Responses of *Stylosanthes* and maize to inoculation in unsterile soils. *New Phytologist*. 78:277-288.

Mosse, B. (1981). Vescular-arbuscular mycrrhizal research for tropical agriculture. Hawaii Inst. Of Tropical Agriculture and Human Resources Bulletin, 194: 82p.

Mosse, B. and Hepper, C.M. (1975). Vesicular-arbuscular mycorrhizal infections in root organ culture. *and Pathology*. 5: 215-225.

Nagarajah, S., Posner, A.M. and Quirk, J.P. (1979). Competitive adoption of phosphate with polygalacturonate and other organic anions on kaolinite and oxide surface. *Nature*. (London). 228:83-84.

Nehikhare, J.A. (1987). Raw materials sourcing for fertilizer production in Nigeria. Towards efficiency of fertilizer use and development in Nigeria. Proceedings of the National Fertilizer Seminar, Port Harcourt Oct. 28-30.

Nelsen, C.E. and Safir, G.R. (1982). The water relations of well watered mycorrhizal and non mycorrhizal onion plants. *Journal of American Society and Horticultural science.* 107:271-274.

Newbould, P. and Rangeley, A. (1984). Effect of lime, phosphorus and mycorrhizal fungi on growth, nodulation and nitrogen fixation by white clover (*Trifolium repens*) grown in U.K. hil soils. *Plant and Soil*. 76:105-114.

Newman, E.I. (1988). Mycorrhizal links between plants: Their functioning and ecological significance. *Advances in Ecological Research*. 18:243-270.

Newman, E.I. and Eason, W.R. (1989). Cycling of nutrients from dying roots to living plants, including the role of mycorrhizas. *Plant and Soil*. 115:211-215.

Newsham, K.K., Fitter, A.H. and Watkison, A.R. (1995). Arbuscular mycorrhiza protect an annual grass from pathogenic fungi in the field. *Journal of Ecology*. 83:991-1000.

Nielsen, J.D. (1983). Influence of vesicular-arbuscular mycorrhiza fungi on growth and uptake of varius nutrients as well as uptake ratio of fertilizer P for lucerne (Medicago sativa). *Plant and Soil*. 70: 165-172.

Nielsen, J.D. and Jensen, A. (1983). Influence of VAM fungi on growth and uptake of various nutrients as well as uptake ratio of fertilizer for lucerne (*Medicago sativa*). *Plant and Soil*. 70:165-172.

Nye, P.H. and Tinker,P.B. (1977). Solute movement in the soil-root system. *Studies in Ecology*. 4. Blackwell Scientific Publications. Oxford, London.342p.

Oades, J.M. (1984). Soil organic matter and structure stability. Mechanisms and implications for management. *Plant and Soil*. 76:319-337.

Ofori, F. and Stern, W.R. (1987). Cereal-legume intercropping systems. In: Brady, N.C. (ed). *Advances in Agronomy*. Academic Press. New York. Pp.41-48.

Olaitan, S.O., Lombin, G. (1985). Introduction to Tropical Soil Science, Macmillan Publ. Hong Kong pp 126.

Ollivier, B., Bertheali, Y., Diem, H.G. and Gianinazzi-Pearson, V. (1983). Influence de la variate de Vigna unguiculata dans l'expression da trois associations endomycorrhizieumses a vesicules et arbuscules. *Canadian Journal of Botany* 61:354-358

Olsen, J.K., Schaeffer, J.T., Hunter, M.N., Edwards, D.G., Galea, V.J. and Muller, L.M. (1996). Response of Capsicum *(Capsicum annum L)* sweet corn (*Zea mays* L.) anad tomato (*Lycopersicon esculentum* Mill) to inoculations with vesicular arbuscular mycorrhiza. *Australian Journal of Agricultural Research* 47:5, 651-671.

Ortas, I., Rowell, D.L. and Harris, P.J. (2004). Effect of mycorrhizae and pH change at the root-soil interface on phosphorus uptake by Sorghum using a rhizocylinder technique. *Communications in Soil Science and Plant Analysis*. 35(7-8):1061-1080.

Osonubi, O. (1994). Comparative effects of vesicular-arbuscular mycorrihzal inoculation and phosphorus fetilization on growth and phosphorus uptake of maize (*Zea mays* L.) and sorghum (Sorghum bicolor L.) plants under drought-stressed conditions. *Biology and Fertility of Soils* 18:55-59.

Osonubi, O., Bakare, O.N. and Mulongoy, K. (1992). Interactions between drought stress and vesicular-arbuscular mycorrhiza on the growth of *Faidherbia albida* (Syn. *Acacia albida*) and *Acacia nilotica* in sterile and non-sterile soils. *Biology and Fertility of Soils*. 14:159–165.

Osonubi, O., Mulongoy, K., Awotoye, O.O., Atayese, M.O. and Okali, D.U.U. (1991). Effects of ectomycorrhizal and vesicular-arbuscular mycorrhizal fungi on drought tolerance of four leguminous woody seedlings. *Plant and Soil*. 136:131-141.

Osonubi, O., Okon, I.E., Fagbola, O. And Ekanayake, I.J. (1995). Mycorrhiza inoculation and mulching applications in alley organic manure. Proc 6th symp. ISTRC-AB. 13-18.

Owusu-Bennoah, E. and Wild, A. (1979). Autoradiography of the depletion zone of phosphorus around onion roots in the presence of vesicular arbuscular mycorrhiza. *New Phytologist*. 82:133-140.

Pacovsky, R.S., Fuller, G., Stafford, A.E. and Paul, E.A. (1986). Nutrient and growth interactions in soybeans colonized with Glomus fasciculatum and Rhizobium japonicum. *Plant and Soil* 92:37-45.

Peoples, M.B. and Herridge, D.F. (1990). Nitrogen fixation by legumes in tropical and subtropical agriculture. *Advances in Agronomy* 44:155-223.

Polhill, R.M. and Paul, E.A. (1981). Eds, Advances in Legume Systematics. Royal Botanic Gardens. Knew. 1049 p.

Ponder, F.Jr. (1986). Effect of three weeds on the growth and mycorrhizal infection of black walnut seedlings. *Canadian Journal of Botany*. 64: 1888-1892.

Porter, D.M. and Beute, M.K. (1972). Endogone species in root of Virginia type peanuts *Phytopathology*. 62: 783 (Abstr.)

Porter, W.M., Abbott, L.K. and Robson, A.D. (1978). Effect of rate of application of superphosphate on populations of vesicular-arbuscular endophytes. *Australian Journal of Experimental Agriculture and Animal Husbandry* 18:573-578.

Powell, C.L.l. and Bagyaraj, D.J. (1984). Effect of mycorrhizal inoculation on the nursery production of blueberry cuttings - a note. N. Z. J. Agric. Res. 27: 467-471.

Pozo, M.J., Cordier, C.and Dumas-Gaudot, E. (2002). Localized versus systemic effect of arbuscular mycorrhiza fungi on defense responses to Phytophthora infection in tomato plants. *Journal of Experimental Botany*. 53(368):525-534.

Puppi,G. and Brass, A. (1990). Nutrients water relations of mycorrhizal white clover. *Agricultural Ecosystem and Environment*. 29:317-322.

Rao, P.S.K., Tilak, K.V.B.R, Arunachalam, V., (1990). Genetic variation for VA mycorrhiza dependent phosphate mobilization in groundnut (*Arachis hypogaea* L.). Plant and soil 122:137-142.

Read, D.J. (1991). Mycorrhizas in ecosystems. *Experientia*. 47, 376–391.

Redhead, J. F. (1975). Endotrophic mycorrhizas in Nigeria: some aspects of the ecology of the endotrophic mycorrhizal association of *Khaya grandifolia* C.D.D. In: Sanders FE, Mosse B, Tinker PB (eds) Endomycorrhizas. Academic, London. 447–459.

Reid, C.P.P. (1984). Micorrhiza: A root-soil interface in plant nutrition. In: R.L.Todd and J.D. Giddens (eds) Microbial-plant interactions. ASA Special Pub. 47 ASA, CSSA and SSSA Madison. 29-50

Rhodes, L.H. and Gerdemann, J.W. (1975). Phosphate uptake zones of mycorrhizal and non mycorrhizal onions. *New Phytologist*. 75:555-561

Rhodes, L.H. and Gerdemann, J.W. (1978). Hyphal translocation and uptake of sulphur by vesicular arbuscular mycorrhizae of onion. *Soil biology and Biochemistry*. 10:355-360.

Ross, J.P. and Harper, J.A. (1970). Effect of endogone mycorrhiza on soyabean yields *Phytopathology* 60:1552-1556

Ross, J.P. and Ruthencutter R. (1977). Population dynamic of two vesicular-arbuscular endomycorrhizal fungi and the role of hyper parasitic fungi. *Phytopathology*. 67:490-496

Russell, E.W. (1973). Soil conditions and plant growth. Longman; London.

Ryan, M.H. and Graham, J.H. (2002). Is there a role for arbuscular mycoerrhizal fungi in production agriculture? *Plant and Soil*. 244: 263-271.

Ryan, M.H., Norton, R.M., Kirkgaard, J.A., Mc Cormick, K.M. Knights, S.E. and Angus J.F. (2002). Increasing mycorrhiza colonization does not improve growth and nutrition of wheat on vertisols in south-eastern Australia. *Journal of Agricultural Research*. 53(10):1173-1181.

Sanchez, P.A. (1981). Soil management in the Oxisol savannah and Ultisol jungles of tropical South America. In: Greenland D J (ed) Characterization of soils in relation to their classification and management for crop production: Examples from some areas of the humid tropics. Clarendon Press. Oxford 214-257.

Sanders, F.E. (1975). The effect of foliar applied phosphate on the mycorrhizal infections of onion roots. In: Sanders, F.E., Mosse, B. Tinker, P.B. (eds). *Endomycorrhizas*. Academic Press. London. 261-276.

Sanders, F.E. and Sheikh, N.A. (1983). The development of vesicular arbuscular mycorrhizal infection in plant root systems. *Plant and Soil*. 71: 223-246.

Schenck N.C. and Smith G.S. (1982). Responses of six species of vesicular-arbuscular mycorrhizal fungi and their effects on soyabean at four soil temperatures. *New Phytologist*. 92:193-211.

Schenck, N.C., Graham, S.O. and Green, N.E. (1975). Temperature and light effect on contamination and spore germination of vesicular arbuscular mycorrhizal fungi. *Mycologia* 67:1189-1192.

Schisler, D.A. and Linderman, R.G. (1989). The influence of volatiles purged from soil around Douglas-fir ectomycorrhizae on soil microbial populations. *Soil Biology and Biochemistry*. 21:389-396.

Screenivasa, M.N. Basavaraj, G.T. and Kulkarni, J.H. (1995). Vesicular-arbuscular mycorrhiza assist in nodulation and N2-fixation in soya bean. *Journal of Maharashtra Agricultural Universities* 21(2): 292-293.

Sharma, M.P, Adholeya, A. (2004). Effect of arbuscular mycorrhizal fungi and phosphorus fertilization on the post vitro growth and yield of micropropagated strawberry grown in a sandy loam soil. *Canadian Journal of Botany-Revue Canadienne de Botanique*. 82(3):322-328.

Siddiqui, Z.A. and Mahmood, I. (1996). Biological control of *Heterodera cajani* and *Fusarium udum* on pigeonpea by *Glomus mosseae*, *Trichoderma harzianum* and *Verticillium chlamydosporum*. *Israel Journal of Plant Science*. 44: 49-56.

Sieverding, E. (1991). Vesicular arbuscular mycorrhiza management in tropical Agrosystems. Tech. Cooperation – Federal Republic of Germany. Eschborn. 371p.

Sieverding, E. and Toro, T.S. (1988). Influence of soil water regimes on VA mycorrhiza. V. Performance of different VAM fungal species with cassava. *Journal of Agronomy and Crop Science* 161:322–332.

Singh, J.P., Karamonaos, R.E. and Stewart, J.W.B. (1986). Phophorus induced zinc deficiency in wheat on residual phosphorus plots. *Agronomy Journal*. 78:668-675.

Skujins, J. and Allen, M.F. (1986). Use of mycorrhizae for land rehabilitation. *Mircen Journal of Applied Microbiology and Biotechnology* 2:161-176.

Smith, J.E., Johnson, K.A., and Cazares, E. (1998). Vesicular mycorrhizal colonization of seedlings of Pinaceae and Betulaceae after spore inoculation with Glomus intraradices." Mycorrhiza 7, no. 6:279-285.

Smith, S. E., and Read, D. J. (1997). Mycorrhizal symbiosis, 2nd ed. Academic Press London, England.

Smith, S.E. (1980). Mychorrhizae of autotropic higher plants. *Biological Review* 55:475-510.

Smith, S.E. and Gianinazzi-Pearson, V. (1988). Physiological interactions between symbionts in vesicular-arbuscular mycorrhizal plants. *Annual Review of Plant Physiology and Plant Molecular Biology*. 39:221–244.

Smith, S.E., Nicholas, D. J. D. and Smith, F. A. (1979). Effect of early mycorrhizal infection on nodulating and nitrogen fixation in Trifolium subterraneum L. *Australian, Journal of Plant Physiology.* 6: 305-316.

Smith, S.E., Smith, F.A. and Jakobsen, I. (2004). Functional diversity in arbuscular mycorrhizal (AM) symbioses: the contribution of the

mycorrhizal P uptake pathway is not correlated with mycorrhizal responses in growth or total P uptake. *New Phytologist*. 162(2):511-524.

Smyth, A.J. and Montgomery, R.F. (1962). Soils and Land Use in Central Western Nigeria; Government of Western Nigeria, Ibadan. 265p.

Sobulo, R.A. (1980). Phosphorus and trace element status of savanna soils of Nigeria. In selected papers from the Man and Biosphere state of knowledge workshop Kainji Lake Research Institute. Kainji, Nigeria pp 34-41.

Sobulo, R.A. (1990). Agro-minerals for fertilizers in Nigeria. Paper presented at the Nigerian Institute for Oceanography and Marine Research (NIOMR) Lagos.

Sobulo, R.A. and Osiname, O.A. (1985). Fertilizer use in the tropics – Nigeria Experience. *Proceedings International Society of Soil Science (Commissions IV and VI)* 21-26 July, (1985) Ibadan, Nigeria pp 193-213

Srivastava, B.K., Singh, M.P., Sobaran, S., Shashim, L., Pankaj, S. and Shahi, U.P. (2009). Effect of integrated nutrient management on the performance of crops under brinjal (*Solanum melongena*) – pea (*Pisum sativum*) – okra (*Hibuscus esculentus*) cropping system. *Indian Journal of Agricultural Sciences*. 79 (2): 91–93.

Stribley, D.P., Tinker, P.B. and Snellgrove, R.C. (1980). Effects of vesicular – arbuscular mycorrhiza fungi on the relations of plant growth, internal

phosphorus concentration and soil phosphate analyses. *Journal of Soil Science* 31:655-672.

Struble, J.E. and Skipper, H.D. (1988). Vesicular-arbuscular mycorrhizal fungal spore production as influenced by plant species. *Plant and Soil*. 109, 277–280.

Sylvia, D.M. (1992). Quantification of external hyphae of vesicular-arbuscular mycorrhizal fungi. Methods Microbiol. 24:53-66.

Sylvia, D.M. and Williams, S.E. (1992). Vesicular arbuscular mycorrhizae and environmental stress. In: G.J. Bethlenfalvay & R.G. Linderman (eds.) *Mycorrhizae and Sustainable Agriculture*. ASA Special Publication 54. Madison, QWI. 101-124.

Tarafdar, B.D. and Marschner, H. (1994). Phosphatase activity in the rhizoshere and hyphosphere of VA mycorrhizal wheat supplied with inorganic and organic phosphorus. *Soil Biology and Biochemistry*. 26:378-395.

Tarafdar, J.C and Rao, A.V. (1997). Response of acid legumes to VAM fungal inoculation. *Symbiosis Rehovot*. 22:3, 265-274.

Thingstrup, I., Rubaek, G., Sibbesen, E. and Jakobsen, I. (1998). Flax (*Linum usitatissimum* L.) depends on arbuscular mycorrhizal fungi for growth and P uptake at intermediate but not high soil P levels in the field. *Plant and Soil*. 203: 37-46.

Thompson, B.D., Robson, A.D. and Abbott, L.K. (1990). Mycorrhizas formed by *Gigaspora calospora* and *Glomus fasciculatum* on subterranean

clover in relation to soluble carbohydrate concentration in roots. *New Phytologist*. 114:217-225.

Tinker, P.B. (1980). The role of rhizosphere microorganisms in phosphorus uptake by plants. In: Kwasaneh, F. and Sample, E. (eds). The role of phosphorus in agriculture. *American Society of Agronomy*. Pp. 617-654.

Tisdall, J.M. and Oades, J.M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science* 33: 141–163.

Toljander, J.F., Artursson, V., Paul, L.R., Jansson, J.K. and Finlay, R.D. (2005). Attachment of different soil bacteria to arbuscular mycorrhizal fungi is determined by hyphal vitality and fungal species. FEMS Microbiology Letters, 254: 34–40.

Tommerup, I.C. and Kidby, D.K. (1980). Production of asceptic spores of vesicular arbuscular endophytes and their viabilty after chemical and physical stress. *Applied Environmental Microbiology*. 39:1111-1119.

Trappe, J.M. (1987). Phylogenetic and ecologic aspects of mycotrophy in the angiosperms from an evolutionary standpoint. In: Safir, G.R.(ed). *Ecophysiology of VA mycorrhizal Plants*. Pp 5-25. CRC Press, Boca, Raton.

Uyanoz, R., Akbulut, M., Cetin, U. and Gultepe, N. (2007). Effects of microbial inoculation, organic and chemical fertilizer on yield and physicochemical and cookability properties of bean (Phaseolus vulgaris L.) seeds. *Philippine Agricultural Scientist*. 90(2):168-172.

Van der Heijden, M.G.A., Boller, T. Wiemken, A. and Sanders, I.R. (1988). Different arbuscular mycorrhizal fungal species are otential determinants of plant community structure. *Ecology*. 79:2082-2091.

Van Kessel, C., Singleton, P.W. and Hoben, H.J. (1985). Enhanced N-transfer from a soybean to maize by vesicular arbuscular mycorrhizal fungi. *Plant Physiology*. 79:562-563.

Walkley, A and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of techromic acid titration method. *Soil Science*. 37:29-38.

Wang, S.G, Lin, X.G, Yin, R and Hou, Y.L. (2004). Effect of inoculation with arbuscular mycorrhizal fungi on the degradation of DEHP in soil. *Journal of Environmental Sciences-China* 16(3):458-461

Wang, S.R. and Hayman, D.S. (1982). Effects of Nitrogen on mycorrhizal infection. Rothamsted Report for (1981). Part 1 p. 211.

Webley, D.M., Duff, R.B. and Mitchel, W.A. (1960). A plate method for studying the breakdown of synthetic and natural silicates by soil bacteria Nature (London) 188:766-767.

Welbaum, G. E, Sturz, A.V, Dong, Z.M and Nowak, J. (2004). Managing soil microorganisms to improve productivity of agro-ecosystems. C*ritical Reviews in Plant Sciences.* 23(2):175-193.

APPENDICES

Organic manure	N g/kg	P g/kg	K g/kg	C:N
Maize residues	8.6c	2.0c	11.0ab	35.5b
Urban waste	6.4c	3.5b	8.0c	30.4c
Poultry manure	12.4a	8.1a	13.4a	16.2d
Leaf litter	9.2b	7.8a	10.2b	38.5b
Weed biomass	7.4c	3.2b	8.6c	45.0a
Soybean residue	10.0b	8.4a	7.5c	30.0c
Organo-mineral	2.25%	0.89%	2.01%	-

vam	cropsys	pfert	rep	trt	drymat	lfno1	Nuptake	Puptake	Kuptake
101	101	101	1	1	0.48	13	0.79	0.25	0.74
101	101	101	2	1	0.41	13	0.52	0.24	0.62
101	101	101	3	1	0.45	12	0.74	0.26	0.68
101	101	102	1	2	1	20	1.49	0.26	1.45
101	101	102	2	2	1	12	1.85	0.25	1.44
101	101	102	3	2	1.15	27	1.67	0.23	1.64
101	102	101	1	3	0.56	15	0.64	0.17	1.14
101	102	101	2	3	0.55	11	0.7	0.2	1.11
101	102	101	3	3	0.54	10	0.77	0.16	1.1
101	102	102	1	4	0.54	15	0.65	0.23	0.93
101	102	102	2	4	0.55	18	0.7	0.24	0.94
101	102	102	3	4	0.74	12	0.84	0.32	0.94
101	103	101	1	5	0.78	12	1	0.32	1.47
101	103	101	2	5	0.79	15	1.01	0.32	1.32
101	103	101	3	5	0.91	15	1.16	0.36	1.8
101	103	102	1	6	0.83	19	1.06	0.33	2.03
101	103	102	2	6	0.81	15	1.05	0.32	2
101	103	102	3	6	0.82	18	1.07	0.34	2.06
102	101	101	1	7	0.85	6	1.02	0.11	1.81
102	101	101	2	7	1.18	12	1.84	0.15	2.18
102	101	101	3	7	1	18	1.28	0.13	1.8
102	101	102	1	8	1.66	11	2.36	0.28	3.07
102	101	102	2	8	1.72	16	4.4	0.22	3.15
102	101	102	3	8	1.6	22	4.54	0.21	3.09
102	102	101	1	9	1.62	10	4.37	0.39	3.01
102	102	101	2	9	1.65	12	2.11	0.4	2.49
102	102	101	3	9	1.65	12	1.11	0.16	2.98
102	102	102	1	10	0.81	9	1.04	0.26	1.24
102	102	102	2	10	0.45	12	0.51	0.14	1.16
102	102	102	3	10	0.69	12	0.79	0.23	1.15
102	103	101	1	11	0.36	10	0.96	0.16	0.6
102	103	101	2	11	0.58	15	0.9	0.27	0.99
102	103	101	3	11	0.48	17	0.77	0.2	0.96
102	103	102	1	12	0.74	11	1.01	0.09	1.5
102	103	102	2	12	0.78	13	1.11	0.1	1.58
102	103	102	3	12	0.76	10	0.97	0.09	1.28
103	101	101	1	13	0.28	9	0.48	0.07	0.45
103	101	101	2	13	0.45	9	0.51	0.11	0.75
103	101	101	3	13	0.15	5	0.17	0.04	0.46
103	101	102	1	14	0.9	13	1.12	0.15	0.99
103	101	102	2	14	0.67	16	0.83	0.11	0.74
103	101	102	3	14	0.49	14	0.59	0.06	0.59
103	102	101	1	15	0.79	13	1.01	0.14	1.56
103	102	101	2	15	0.61	15	0.69	0.12	1.16
103	102	101	3	15	0.6	12	0.73	0.1	1.17
103	102	102	1	16	0.57	10	0.81	0.09	0.92
103	102	102	2	16	0.34	13	0.44	0.06	0.56
103	102	102	3	16	0.75	16	1.5	0.13	0.98
103	103	101	1	17	0.96	6	2.11	0.32	1.77

103	103	101	2	17	0.99	11	2.25	0.37	1.77
103	103	101	3	17	0.95	15	2.14	0.33	1.75
103	103	102	1	18	0.84	16	0.96	0.17	1.63
103	103	102	2	18	0.81	12	0.98	0.16	1.36
103	103	102	3	18	0.5	15	0.64	0.09	1.63

rep	vam	manure	rockp	flowers	fruitn	yld	htcm	brchno
100	100	100	100	37	7	1.8	37	8.8
101	100	100	100	2.7	7	1.9	38	6
102	100	100	100	13.5	9.5	1.9	39	6.8
100	100	100	101	38.3	5.2	17.7	38	8.8
101	100	100	101	8.7	5.8	17.5	37.3	9.8
102	100	100	101	10.3	5.7	17	38.7	8.8
100	100	100	102	6.3	5	8.05	35.3	9
101	100	100	102	7.5	5	8.5	35.3	8
102	100	100	102	4	5	9.5	35	8.7
100	100	103	100	4	3	15.9	18	5.5
101	100	103	100	3	3	15	19.5	2.3
102	100	103	100	3	3	15.5	19	7.3
100	100	103	101	4.5	5.7	25	36.2	9.8
101	100	103	101	6	5	25	36.2	1.5
102	100	103	101	11	6	25.8	36.3	5
100	100	103	102	8	5	18.8	32.8	7
101	100	103	102	2	5	17.5	32	6
102	100	103	102	5	4.5	17.8	32.7	8.3
100	100	104	100	9.5	6.5	12.3	23	8
101	100	104	100	3	6	13	23	4
102	100	104	100	6	6	13	23	6.5
100	100	104	101	12.3	6.2	12.2	27.5	10
101	100	104	101	4	6	11.7	25.3	8
102	100	104	101	10	6.5	12	23.3	8.3
100	100	104	102	12	5.3	23	41	9.5
101	100	104	102	2	5	20	41	3
102	100	104	102	2.5	5.2	20	40.7	8.3
100	101	100	100	14.5	1	18.8	31	8
101	101	100	100	2.7	2	20	31.7	2.5
102	101	100	100	12.8	3	18	31	13.3
100	101	100	101	7.8	3	19	35.5	13.5
101	101	100	101	11	3	17	34	6.7
102	101	100	101	16.3	6.5	17.3	34.3	9.3
100	101	100	102	12	5	15.7	35.8	12.5
101	101	100	102	1.5	5	13	35	2.3
102	101	100	102	10.3	4.5	15	35	18.3
100	101	103	100	10.3	6	23.6	40.7	7.3
101	101	103	100	1	6	23	40.7	4.5
102	101	103	100	4.5	1.5	23.9	40.5	7.3
100	101	103	101	14.3	9.7	27.3	45.7	5
101	101	103	101	5.3	8	25	45	5
102	101	103	101	9.3	9.5	26	45.7	12.8

100	101	103	102	8.3	7.5	25.8	31	8
101	101	103	102	5	8	26	32	2.5
102	101	103	102	6.7	7	22	32.3	8.8
100	101	104	100	7	4	12.3	34	5
101	101	104	100	5	4	12.5	34	6.7
102	101	104	100	13.8	4	12.5	35.3	7.8
100	101	104	101	11.5	6	22.5	35.2	14
101	101	104	101	5	5.6	22.1	35	2.3
102	101	104	101	16.5	6	22.8	35.8	4
100	101	104	102	14.8	2	7.6	28.3	9.3
101	101	104	102	2.8	2	7.6	28.3	9
102	101	104	102	7.5	2	7.8	28	6
100	102	100	100	9.5	4.5	18.6	35	10.3
101	102	100	100	4.5	4	18.6	35	3.7
102	102	100	100	9.5	4	18.4	35	9.3
100	102	100	101	8	4	21.8	29.6	7.3
101	102	100	101	11.5	3	21.6	29.1	5.7
102	102	100	101	10.5	8	26.1	30	9
100	102	100	102	3.5	5	34.5	28.5	12.5
101	102	100	102	6	6	35	28.5	3.8
102	102	100	102	15.3	5.7	34.8	28	7.3
100	102	103	100	14	1	6.3	37	9.5
101	102	103	100	5.5	3	6.8	37	7.7
102	102	103	100	3.7	3	6.9	37	9
100	102	103	101	4.3	9	27.5	35	9.5
101	102	103	101	0	9	25	33	1.3
102	102	103	101	7.7	12	27.8	34	11.5
100	102	103	102	7	2	6	37.5	12.8
101	102	103	102	7	2	6	37	2
102	102	103	102	6.5	3	6.8	37.1	13.5
100	102	104	100	6.3	2	12.2	30.7	5.7
101	102	104	100	6	1	12	29.7	1
102	102	104	100	9.3	2	12	29	8.8
100	102	104	101	12.5	9.5	23	36	11.8
101	102	104	101	2	9.5	23	34	2.5
102	102	104	101	8.5	9.5	23	36	10
100	102	104	102	9.8	8.8	29.3	33	7
101	102	104	102	3	8.7	29	32	2.5
102	102	104	102	10.5	8.8	29.3	33	11.7

rep	vam	cropsys	rockp	leafno	branchno	htcm	flowers4	frutno	yld
101	105	105	106	175	16.3	33.6	21.3	4.7	15.6
102	105	105	106	78.7	11	31.4	12	4.7	15
103	105	105	106	244.3	12.5	33.5	45.3	4.8	14.5
101	105	105	107	126.5	20	31.8	10.8	5	19.7
102	105	105	107	106.5	28.7	30.3	10.3	5	19.7

103	105	105	107	121.5	19.5	32.1	19.8	5	19.6
101	105	106	106	75.7	36	34.8	4.3	6	20.2
102	105	106	106	49	29.3	34.5	4.3	5	19.8
103	105	106	106	25.5	10	27	8	6	20.3
101	105	106	107	154.5	21.3	35	16	6.8	20.5
102	105	106	107	85.7	17.8	30.1	2	5.3	19.8
103	105	106	107	69.3	19	29.6	6	5	18
101	105	107	106	139	27.5	34.4	6	3.5	13.8
102	105	107	106	63	17.3	34.5	5.5	4	14
103	105	107	106	80.5	13.5	35.8	8	7	21
101	105	107	107	136.3	24	43.9	13.3	9	22.8
102	105	107	107	20	5.6	28.5	1.3	9	22.5
103	105	107	107	51.8	18.3	28.8	7.8	9	22
101	106	105	106	154.5	18.5	38.7	18.3	6.5	17.4
102	106	105	106	80.3	13.3	28.9	5.8	5.8	16.6
103	106	105	106	46	7	22.1	4	6	15.8
101	106	105	107	148.8	24.5	30.3	16.3	6.7	16.8
102	106	105	107	78.5	38.3	28.8	8	6	16
103	106	105	107	32.7	9.5	24.5	5.5	6	18.8
101	106	106	106	129	20.8	28	7.3	6.5	18.8
102	106	106	106	36.5	8.8	27.5	6	6	15
103	106	106	106	89.5	17	30.3	8.8	7	15.4
101	106	106	107	108.8	16.8	29	10.3	6.5	18.2
102	106	106	107	30.5	31.3	25	2.5	6	16.6
103	106	106	107	87.8	11.3	32.5	11.3	6.5	16.7
101	106	107	106	169.3	24.8	30	19.8	5	15.4
102	106	107	106	108.8	17	29.3	7	4	13.4
103	106	107	106	107.3	13.3	24.3	17.7	5	15
101	106	107	107	119	8.5	27	14.8	8.2	21.1
102	106	107	107	56	13.5	26.8	6.5	7	19.4
103	106	107	107	38.8	6.8	29.3	3.3	6.5	18.1
101	107	105	106	75.3	25	39.1	11.5	6.5	17.7
102	107	105	106	124.3	12.5	26.1	10.3	6	17.6
103	107	105	106	131.3	10.5	37	12.3	6.3	17.3
101	107	105	107	223.5	33.3	38.8	15.3	5	14.8
102	107	105	107	30.8	7.3	24.5	2.7	5	15.1
103	107	105	107	70.7	15.8	35.7	4	5	15.4
101	107	106	106	166	17	33.4	12.8	5	15
102	107	106	106	47.3	35.5	34.3	4.5	4.5	14.9
103	107	106	106	56.3	25.5	36.6	5.3	5.3	15.5
101	107	106	107	164.3	12.5	24.6	5.3	3.7	5.7
102	107	106	107	67.3	13	29	4.3	3	5.1
103	107	106	107	79	7.8	26	11	3	5.1
101	107	107	106	105.8	45.8	42.3	7.8	3	5.2
102	107	107	106	104.3	24.8	30.4	4.7	3.3	5.1
103	107	107	106	33	10.8	31	1.5	3	5.2
101	107	107	107	97	23.8	32.3	23	4.7	6.9
102	107	107	107	49.3	19.8	33.1	4.7	4.3	6.8
103	107	107	107	56.5	13	25.3	9	4.3	6.6

REP	VAM	CROPSYS	ROCKP	DRYMAT	STEMDIA	N_UPT	P_UPT	K_UPT
101	101	101	101	1.22	3.84	2.71	0.49	2.34
102	101	101	101	1.43	3.89	3	0.57	2.62
103	101	101	101	1.4	3.8	3.02	0.56	2.56
101	101	101	102	1.13	3.44	1.36	0.18	1.56
102	101	101	102	1.18	3.58	1.36	0.15	1.64
103	101	101	102	1.01	3.3	1.26	0.15	1.39
101	101	102	101	3.86	3.7	7.33	2.62	6.21
102	101	102	101	3.76	3.63	7.14	2.48	6.13
103	101	102	101	3.86	3.91	7.33	2.62	7.49
101	101	102	102	3.35	4	6.67	1.37	6.03
102	101	102	102	3.33	4.09	6.69	1.37	6.43
103	101	102	102	3.42	4.06	6.46	1.57	6.5
101	102	101	101	0.85	3.44	1.49	0.23	1.26
102	102	101	101	0.82	3.43	1.23	0.22	1.21
103	102	101	101	0.85	3.45	1.49	0.23	1.26
101	102	101	102	1.12	2.92	1.7	0.76	2.15
102	102	101	102	1.18	2.94	1.9	0.78	2.27
103	102	101	102	1.28	2.97	1.6	0.88	2.46
101	102	102	101	3.32	3.6	7.17	0.86	7.47
102	102	102	101	3.23	3.71	6.85	0.87	7.69
103	102	102	101	3.23	3.65	7.11	0.9	7.27
101	102	102	102	2.54	3.63	6.53	1.04	3.96
102	102	102	102	2.42	3.26	6.34	1.02	3.68
103	102	102	102	2.44	3.29	6.34	1	4.29
101	103	101	101	1.1	2.82	2.21	0.76	1.99
102	103	101	101	1.2	2.96	2.44	0.82	2.17
103	103	101	101	1	2.91	2.03	0.67	1.81
101	103	101	102	1.22	2.99	2.43	1.06	2.21
102	103	101	102	1.1	2.94	2.05	0.97	1.99
103	103	101	102	1.15	2.96	1.87	1.02	2.08
101	103	102	101	4.35	3.4	8.87	1.17	4.92
102	103	102	101	4.61	3.21	9.59	1.29	7.88
103	103	102	101	4.48	3.4	8.96	1.16	6.36
101	103	102	102	3.57	3.85	9.39	1.5	6.68
102	103	102	102	3.59	3.58	9.44	1.47	5.82
103	103	102	102	3.97	3.73	10.44	1.67	6.95

vam	cropsys	pfert	Cauptake	mguptake	drymat	Height	stemdia	Nuptake
101	101	101	0.5	0.18	0.52	27.3	4.04	1.05
101	101	101	0.48	0.18	0.53	27.1	4.04	1.08
101	101	101	0.48	0.18	0.52	27.3	4.04	1.07
101	101	102	0.76	0.24	0.5	27.3	3.89	1.17
101	101	102	0.75	0.24	0.5	27	3.9	1.17
101	101	102	0.78	0.24	0.5	27.3	3.89	1.18
101	102	101	5.9	1.14	3.78	41.27	3.3	6.62
101	102	101	5.96	1.17	3.24	41.3	3.29	5.73
101	102	101	5.9	1.18	2.69	41.5	3.3	4.65
101	102	102	3.85	1.13	3.32	30.8	3.69	7.24

101	102	102	3.56	1.17	3.02	30.8	3.85	6.52
101	102	102	3.89	1.19	3.61	30.6	3.54	7.73
102	101	101	0.23	0.09	0.23	21.6	3.74	0.59
102	101	101	0.23	0.08	0.24	21.6	3.7	0.6
102	101	101	0.22	0.07	0.21	21.2	3.74	0.5
102	101	102	0.49	0.17	0.47	24.67	3.11	1.09
102	101	102	0.47	0.14	0.4	24	3.19	0.84
102	101	102	0.48	0.17	0.48	24.6	3.01	1.12
102	102	101	5.73	1.13	3.75	25.8	3.06	8.1
102	102	101	6.18	1.14	3.68	26.2	3	8.13
102	102	101	5.98	1.19	3.63	25.6	3.28	7.84
102	102	102	1.66	0.45	1.51	26.37	3.39	2.97
102	102	102	1.67	0.49	1.59	26.4	3.38	3.07
102	102	102	1.69	0.5	1.57	26.2	3.38	2.97
103	101	101	0.35	0.1	0.34	19.67	2.47	0.83
103	101	101	0.32	0.11	0.37	19.6	2.4	0.93
103	101	101	0.35	0.12	0.43	20	2.47	1.1
103	101	102	0.34	0.1	0.29	15.5	2.49	0.57
103	101	102	0.34	0.13	0.38	15.63	2.41	0.73
103	101	102	0.33	0.1	0.2	15.4	2.47	0.58
103	102	101	1.36	0.34	1.18	24.3	3.29	3.12
103	102	101	1.48	0.39	1.27	24.4	3.32	3.11
103	102	101	1.37	0.31	1.02	24.2	2.33	2.47
103	102	102	1.92	0.4	1.83	22.5	3.26	4.59
103	102	102	1.85	0.45	1.13	22.83	3.29	3.03
103	102	102	1.85	0.45	1.8	22.5	3.15	4.36

TRT	DRYMAT	HEIGHT	NUPTAKE	PUPTAKE	KUPTAKE	CAUPTAKE	MGUPTAKE
1	2.4	30	4.44	0.31	6.82	7.32	1.46
1	2.39	22	4.66	0.24	6.93	7.34	1.41
1	2.2	22	3.74	0.22	6.16	6.71	1.39
2	5.1	30	5.1	0.66	11.99	21.06	3.06
2	5.27	25	5.27	0.69	14.49	21.61	2.32
2	5.31	24	5.31	0.29	12.48	22.09	4.3
3	2.22	24	6.13	0.29	7.44	10.66	2.42
3	2.23	18	6.11	0.29	7.92	11.51	2.34
3	2.23	28	6.13	0.34	7.36	11.37	2.45
4	2.83	30.5	7.64	0.36	8.63	11.52	3.65
4	2.74	21	7.34	0.38	8.36	11.1	3.97
4	2.7	17	7.34	0.68	8.24	10.99	3.51
5	5.3	21.5	15.52	0.69	14.05	17.6	4.24
5	5.23	16.5	15.58	0.68	14.91	17.52	2.77
5	5.3	22	15.32	0.69	14.84	16.54	4.19
6	2.27	22	6.13	0.41	6.92	5.99	1.63
6	2.42	22	5.83	0.46	7.26	6.82	1.79
6	2.62	20	7.44	0.47	8	5.5	1.86
7	1.63	27.5	1.71	0.34	4.56	7.66	1.64
7	1.9	28	1.9	0.42	5.42	8.65	1.96
7	1.2	21	2.32	0.25	3.3	5.33	1.2

8	5.36	25.5	6.97	1.29	20.64	17.15	3.91
8	5.46	21.5	6.88	1.2	21.18	21.29	3.49
8	5.43	21	6.95	1.09	20.9	18.46	3.86
9	3.08	17	8.32	0.8	11	7.61	2.49
9	3.44	22	9.29	0.79	13.24	8.26	2.92
9	3.46	24	10.31	0.67	13.67	9.69	3.04
10	1.91	31	4.6	0.5	7.07	3.87	2.02
10	1.8	21	5.02	0.32	6.12	6.39	1.87
10	1.55	27	4.4	0.31	5.35	5.38	1.64
11	2.25	22	6.71	0.59	7.2	3.83	1.24
11	2.73	22	6.99	0.71	10.78	4.64	1.34
11	2.05	16.5	6.11	0.53	6.77	3.49	0.92
12	2.2	19	8.4	0.53	7.81	3.78	1.74
12	2.2	25.5	8.12	0.44	7.15	3.78	1.58
12	2.97	17	11.4	0.65	10.4	5.11	2.11
13	1.45	24	2.64	0.29	4.13	8.15	1.38
13	1.35	30	2.51	0.36	3.31	7.56	1.27
13	1.37	19	2.22	0.36	3.7	7.63	1.33
14	3.1	24	4.03	0.53	9.5	11.47	2.14
14	3.53	23	4.52	0.46	11.65	12.71	2.68
14	3.24	23.5	3.89	0.62	10.69	11.99	2.59
15	7.6	18	16.19	0.53	25.46	21.28	6.99
15	7.67	21	16.18	0.54	29.15	16.87	4.68
15	7.87	25	16.68	0.55	29.91	17.31	3.94
16	1.2	26	3.32	0.16	4.26	2.82	0.7
16	1.74	21	4.7	0.23	5.22	4.18	0.96
16	1.1	19	2.97	0.19	3.58	3.19	1.05
17	2.6	22	7.02	0.34	10.01	7.59	1.69
17	2.6	22	6.66	0.34	7.54	8.66	2
17	2.63	22	5.79	0.34	9.21	7.55	2.05
18	2.1	19	4.77	0.27	7.25	3.78	1.43
18	2.85	18	6.47	0.37	9.55	5.13	1.34
18	2.8	24	6.33	0.36	10.02	5.04	1.85