RESPONSE OF KENAF (*Hibiscus cannabinus* Linn.) TO FERTILIZERS AND ARBUSCULAR MYCORRHIZA IN A NUTRIENT DEGRADED ALFISOL IN IBADAN, SOUTHWESTERN NIGERIA

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ABSTRACT

High and sustainable kenaf production in a fragile tropical soil requires the use of soil amendments. Arbuscular Mycorrhizae (AM) are important for nutrition of plants in nutrient depleted soils of the tropics. Due to insufficient information on kenaf production using fertilizers and AM, the effects of fertilizers and AM on soil chemical properties, growth and fibre yield of kenaf were investigated.

Screenhouse and field experiments were conducted at the Institute of Agricultural Research and Training, Ibadan. The AM colonization of kenaf was assessed in the screenhouse experiment consisting of 2 x 12 x 2 factorial in a Randomized Complete Block Design (RCBD) with three replicates. The treatments were with mycorrhiza (M^+) and without (M^-), twelve levels of fertilizers: 0, NPK 20:10:10 (60 kgN/ha), organic (20, 40, 60, 80 and 100 kgN/ha), and organo-mineral (20, 40, 60, 80 and 100 kgN/ha) and two kenaf varieties (Cuba 108 and Tiannug 1). The higher yielding variety (Cuba 108) was used on the field to determine the optimum fertilizer rate for fibre production. The experimental design was split-plot in RCBD. Mycorrhizal inoculation was the main plot and twelve fertilizer levels as the sub-plot with three replicates. Residual effect of the treatments was also determined. Data on soil chemical properties, AM Root Colonization (RC), growth and yield parameters were collected and analysed using descriptive statistics and ANOVA.

Screenhouse and field experimental soils were low in organic matter with 15.0 g/kg and 13.0 g/kg, respectively. Under screenhouse, AM colonization ranged from 14.4 to 78.1 % in the two varieties of kenaf. Inoculated Cuba 108 at 40 kgN/ha Organo-Mineral Fertilizer (OMF) had significantly ($p<0.05$) higher stem girth (1.8 cm), plant height (275.2 cm), RC (79.8 %), bast (9.6 g/pot) and core (19.9 g/pot) yields than other treatments. On the field, optimum bast and core yields of 3.8 and 9.4 t/ha respectively were obtained at M^+ 40 kgN/ha OMF. Comparing 60 kgN/ha of fertilizers, M^+ OMF had significantly ($p<0.05$) highest bast and core yields followed by M^+ NPK and M^- OMF while M^- Organic Fertilizer (OF) had the least. After harvesting, M^- 100 kgN/ha OF had the highest organic matter, 25.9 g/kg; total N, 0.8 g/kg; available P, 6.8 mg/kg; exchangeable K, 0.4 cmol/kg and Ca, 9.6 cmol/kg. For the residual effect, M^+ 100 kgN/ha OF had significantly ($p<0.05$) highest RC (69.0%), bast (2.7 t/ha) and core (5.8 t/ha)

yields. Considering the 60 kgN/ha of fertilizers, organic had the highest bast and core yields followed by organo-mineral and inorganic. The highest organic matter was observed in M^- 100 kgN/ha OF.

Cuba 108 and Tiannug 1 roots were highly colonized by arbuscular mycorrhiza, while the optimum bast and core yields were observed in the inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer. Management of organo-mineral fertilizer along with indigenous mycorrhizae will reduce the application of chemical fertilizers and ensure optimum quantitative yield of kenaf under the assayed soil conditions.

Key words: Kenaf, Fertilizer application, Arbuscular mycorrhiza, Degraded Alfisol
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CERTIFICATION

I certify that this work was carried out by Babatunde Saheed Bada, of the Department of Agronomy, University of Ibadan under my supervision.

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DEDICATION

I dedicate this work to the Almighty Allah, the Dominion of the whole Universe, most Beneficent, most Compassionate who has guided and protected me towards the actualization of my dream.

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CHAPTER 1

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a member of the *Malvaceae* family native to east-central Africa where it has been grown for several thousand years for food and fiber (Dempsey, 1975; Wilson, 2003). It can grow to a height of 4 to 6 m in about 4 to 5 months and yield up to 13 - 24 t/ha total dry matter production (Angelini *et al.*, 1998; Alexopolou *et al.*, 2000; LeMahieau *et al*., 2003). The stem produces two types of fibre, a coarser fibre in the outer layer (bast) and a finer fibre in the inner (core). Its economic importance include fibre and food (Dempsey, 1975; Bert, 2002; Zhang, 2003), medicine (Cheng, 2001), medium for mushroom cultivation (Cheng, 2001; Liu, 2003), oil and chemical absorbents (Sameshima, 2000). In addition, the bast fibre can be converted to pulp for newsprint, hydro-carbon free bags, ropes and textiles (Robinson, 1988; Kuchinda and Ogunwole, 2000; Webber *et al*., 2002). In 1960, the United State Department of Agriculture (USDA) surveyed more than 500 plants and selected kenaf as the most promising source of "tree-free" newsprint and in 1970, Kenaf newsprint produced in International Paper Company's mill in Pine Bluff, Arkansas, was successfully used by six United State newspapers (Dempsey, 1975; Wilson, 2003). Kenaf growing as a compound crop in Nigeria has been going on for several centuries and its fibre has been used for making ropes, sack and other domestic purposes such as creating fences and thatching for dwelling (Abdullahi, 1973; Ogunlela and Adeoti, 1990). The young leaves have also been used for food as vegetable (Zhang, 2003). The primary purpose for which kenaf is grown as cash crop in Nigeria is the production of bast fibre in the manufacture of jute sacks. Now that packaging and / or handling agricultural produce in synthetic bags had been banned (Ogunlela and Adeoti, 1990), the manufacture of millions of jute bags is necessary.

Most of the West African soils are low to very low in organic matter and plant nutrients, especially N and P (Aina, 1979; Tian *et al.*, 1993). The low activity clay Alfisols, Oxisols / Ultisols, Vertisols and weakly differentiated coarse textured Entisols and Inceptisols found within the region are low to very low in plant nutrients and low in effective cation exchange capacity as Kaolinite is the dominant clay minerals (Yaro *et al*., 1997). The soils are susceptible to rapid nutrient depletion with intensive farming systems which is fast becoming

predominant in the area. Under this situation, high and sustainable crop production requires the use of fertilizer. Although high crop yield can be obtained with judicious application of inorganic fertilizer, it is not always easily available to the resource poor farmers because of high cost, logistics and other associated problems. Continuous application of inorganic fertilizer on agricultural land results in acidification of the soils (Yaro *et al*., 1997). The use of organic fertilizer is also limited by large quantity required to meet crop needs because of its low nutrients content, such large quantity are obviously not obtainable and even if they were, transportation and handling costs would constitute a major constraint. In view of this, complimentary use of low chemical inputs and organic manure (Organo-mineral fertilizer) may be a cost effective economic strategy (Omueti *et al*., 2000). The complementary use of organic manure and inorganic fertilizer ensures the availability of nutrient throughout the growth period of crops. While the application of mineral fertilizer will provide the immediate nutrient requirement for the early growth stages of a crop, the supplemented organic manure, which supplies its nutrient by slow release provides what is required during the later stages of growth. This system may offer a good opportunity to the small scale farmers to maintain yield at reasonable and sustainable cost levels. As a way of reducing total dependence on the use of fertilizer, an integrated fertility management system focusing on biological approach, which is eco-friendly and less expensive, is desirable. Mycorrhizal symbiosis is well recognized as a biological tool to enhance nutrient acquisition in most plants growing on deficient soils (Sieverding, 1991; Smith and Read, 1997; Cardoso and Kuyper, 2006).

Mycorrhizal is a symbiotic association between plant root and specialized soil fungi with evidence that it helps plants in nutrient acquisition of immobile nutrients such as P, N, Zn and Cu in deficient soils (Howeler *et al*., 1987; Kothari *et al*., 1991; Johansen *et al*., 1992; Smith and Read, 1997; Osonubi *et al*., 1998; Clark and Zeto, 2000; Hodge, 2003; Dare *et al*., 2008; Ibiremo and Fagbola, 2008). Apart from enhancing nutrient acquisition of crops, other benefits that have been attributed to mycorrhiza include improved soil structure, crop resistance to diseases and tolerance to water stress (Miller and Jastrow, 2000; Fagbola *et al*., 2001; Fagbola and Osonubi, 2001; Ryan and Graham, 2002; Abdel Fattah and Shabanam, 2002).

High amount of soil available phosphorous and total nitrogen may lower arbuscular mycorrhizal colonization (Treseder and Allen, 2002; Johnson *et al*., 2003). Brechelt (1990),

observed that increasing amount of fresh manure may decrease arbuscular mycorrhizal colonization ratings of *Capsicum annuum* and *Vigna unguiculata* (Cowpea). While composted manure and composted plant residues increased colonization ratings and dry matter yield of plants at all application levels (Brechelt, 1990). It has been established that roots of kenaf form symbiotic association with mycorrhizal fungi (Bunvong *et al*., 1999). Kenaf generally gives the greatest response to nitrogen, followed by phosphorus (Dempsey, 1975; Wilson, 2003). Effects of nitrogen applications on arbuscular mycorrhizal colonization are not constant (Sieverding, 1991). Therefore, for sustainable kenaf production in a nutrient degraded soil, there is need to study effect of arbuscular mycorrhizal inoculation and fertilizers application rates on the growth and yield of kenaf. This will go a long way in reducing total dependence on the use of fertilizer and also reduce the problem of nutrient acquisition especially in a nutrient degraded soil at little or no cost.

The objectives of this study were to:

(i) investigate the effect of organic and organo-mineral fertilizers levels on the root colonization of kenaf by Arbuscular Mycorrhiza (AM);

(ii) evaluate the effect of AM with organic and organo-mineral fertilizers levels on growth and yield of kenaf;

(iii) determine the optimum level of organic and organo-mineral fertilizers for high bast and core yield without mycorrhizal inoculation;

(iv) examine the residual effect of AM inoculation, organic and organo-mineral fertilizers on soil chemical properties, bast and core yield of kenaf.

CHAPTER 2

LITERATURE REVIEW

2.1 Kenaf (*Hibiscus cannabinus* Linn.): Origin, distribution and importance

Kenaf (*Hibiscus cannabinus* Linn.) (Plate 2.1) belongs to the plant family *Malvaceae*, the same family to which *Hibiscus sabdariffa*, *Hibiscus acetosella* and many others. They have been exploited for fibre and pulp production in different parts of the world. The family *Malvaceae* is an ancient fibre and pulp producing plant (Wilson, 2003). It is known by more than one hundred names all over the world; English: Kenaf (Persian origin), India (Bengal): Mesta, India (Madras): Palungi, India (Bombay): deccan hemp, India (Andhra Pradesh): Bimli jute, Taiwan: ambari, Egypt and northern Africa: til, teel or teal, Indonesia: Java jute (Dempsey, 1975; FAO, 1998; Wilson, 2003). The word kenaf, believed to have originated from Persia, has been commonly used in Asia to describe the two closely related species of the Malvaceae family, *H. cannabinus* (L) and *H. sabdariffa* var altissima (L) (Duke and duCellier, 1993). The former is generally called kenaf while its close relative *H. sabdariffa* var. altissima is called Siam jute. Both are believed to have their centres of origins in Africa; that of *H. cannabinus* being possibly Angola and *H. sabdariffa* var. *altissima* being probably Western Sudan (Dempsey, 1975; Wilson, 2003).

Kenaf is commercially cultivated in more than 20 countries, particularly in India, China, Thailand and Vietnam as an important crop (FAO, 1998). China, India and Thailand account for 90 percent of the global area sown to kenaf and more than 95 percent of global production (FAO, 2003). Other important production areas include Russia, Mozambique, Iran, Taiwan, El Salvador, Guatemala, Benin, Ivory Coast and Nigeria (Dempsey, 1975; Wilson, 2003). Kenaf was grown on commercial scale in Nigeria for the first time in 1965 (Makanjuola, 1973; Ogunlela and Adeoti, 1990). The only part of kenaf which has been produced in commercial quantity in Nigeria is the fibre.

Kenaf grows quickly, rising to a height of 1.5 to 3.5 m and the stem are 1 - 3 cm diameter within 3 – 4 months (Dempsey, 1975; Wilson, 2003). Kenaf is generally known for its bast (outer) and core (inner) fibers. The stalk of the kenaf plant consists of two distinct fibre types. The outer fibre is called “bast” (Plate 2.2) and comprises roughly 40 % of the stalk’s dry weight. The whiter, inner fibre is called “core” (Plate 2.3), and comprises 60 % of the stalk’s dry weight (Dempsey, 1975; Wilson, 2003).

Plate 2.1: Kenaf plant growing under field conditions

Plate 2.2: Bast of a kenaf plant (important ingredient in the production of sack)

Plate 2.3 Core of kenaf plant (alternative source of papermaking fibre)

The fibers are used separately or together in the manufacture of different products ranging from paper to woven fabrics to industrial absorbents. It is remarkably versatile as a multi-use crop. There is scarcely any part of kenaf plant that is wasted. Uses of kenaf include

1. Fibre :

   Kenaf has been used mainly to make bags (for packaging agricultural produce), cordage, rope, burlap cloth and fish net because of its rot and mildew resistance (Cook, 1960). Today, one of the major uses of kenaf is for making a range of paper and cardboard products as substitutes for wood. Because of environmental problems (artificial fibre produce long-term pollution) and increase paper consumption, this application of kenaf fibre has drawn tremendous attention in the world (Bert, 2002).

2. Food:

   People plant kenaf in home garden and eat the scions and leaves either raw or cooked. Dried kenaf leaves contain 30 % crude protein and are eaten as vegetable in some countries (Zhang, 2003).

3. Medicine:

   A sort of polysaccharide was extracted from kenaf seeds by Japanese researcher. Mixed and fed to mice. The scientist observed that it reduced the cholesterol of the mice (Cheng, 2001).

4. Medium for mushroom cultivation:

   Use of kenaf core with wood powder as plant medium to produce mushroom is better than using only wood powder. Yield could be doubled compare to using only wood powder. Kenaf medium was commercially used in mushroom cultivation in Japan and China (Cheng, 2001). Kenaf potting soil is a substitute for peat moss, a non – renewable resource (Liu, 2003).

5. Oil and chemical absorbents:

   Kenaf core is strong and as an absorbent it can be used to clean up oilspills as well as chemicals. For its low density, once oil is absorbed, the product floats on the surface, which makes collection easier. Kenaf core is also non – toxic, non –

abrasive and is more effective than classical remediants like clay and silica (Sameshima, 2000).

6. Natural fibre / plastic compounds:

   Kenaf natural fibre /plastic compounds are light and easy to process. They could replace glass – reinforced plastics in many cases. Kenaf compound panels have the mechanical and strength characteristics of glass – filled plastics. At the same time, they are less expensive and completely recyclable in many instances (Kano, 1997); they can be used in the automotive industry, construction, housing and food packaging industry (Zhang, 2003).

7. Animal bedding and poultry litter:

   Kenaf bedding has superior absorbency, is labour saving, it costs less than most traditional litter and bedding products comprised of wood shaving, saw dust or shredded paper (Liu, 2003).

8. Phytoremediation:

   Kenaf can be used to clean up heavy metal (such as cadmium) contaminated soils (Bada and Raji, 2010).

Ogunlela and Adeoti (1990) listed advantages of using kenaf bags for packaging agricultural produce to include:

(a) Kenaf bags are normally used for bulk transportation of basic agricultural and semi processed produce.

(b) Kenaf bags allow the grains stored inside to “breath” and thereby prevent rotting and deterioration of the grains.

(c) Kenaf bags are ideal for stacking. They prevent slipping (sliding).

(d) Kenaf bags are durable in nature; they can be re-used several times with guaranteed satisfaction.

(e) On health ground, since kenaf bags are products of natural fibre, without any chemical treatment, it is safer to pack edible produce without danger to health. As a matter of fact, in most countries of the world, particularly in the third world countries, edible agricultural produce like groundnuts, cocoa, rice, beans etc. must be bagged only in kenaf bags. This is to protect the health of the consumers of these products.

(f) Apart from the health aspect, it will be beneficial also to the kenaf farmers since they will readily have a market for their produce, thereby increasing their market base.

2.2 Agronomy of kenaf production

2.2.1 Ecological conditions favourable for kenaf production

Kenaf plant easily adapts itself to a wide range of climatic and soil conditions in the tropical and subtropical region (Dempsey, 1975; Wilson, 2003). Areas which are susceptible to strong winds or heavy rains constitute hazards resulting in lodging and consequent difficulty in harvesting (Dempsey, 1975).

2.2.2 Different varieties of kenaf for the production of fibre and seed

Generally, *Hibiscus cannabinus* may be roughly classified into photosensitive and photo-insensitive cultivars. Typically, photosensitive kenaf cultivars are preferred for use in the production of kenaf fibre in the United States. Two of these cultivars 'Everglades 41' and 'Everglades 71' were developed by USDA researchers (Wilson *et al*., 1965; Wilson, 2003) to extend the growing season of Kenaf plant before the plants initiate flowering. These photosensitive cultivars initiate flowering when day lengths decrease to approximately 12.5 h, mid-September in Southern States (Scott, 1982). In photo sensitive cultivars, the initiation of flowering results in plant growth reductions (Wilson, 2003). Due to late floral initiation and inability to produce mature seed prior to a killing frost, seed production in the United States for these cultivars is limited to Southern Florida, the lower Rio Grande Valley of Texas, and Southernmost Arizona and California (Scott, 1982). Unlike photosensitive cultivars, photo-insensitive cultivars (i.e. Guatemala series) can initiate flowering and produce mature seed before a killing frost (Dempsey, 1975).

Photo-insensitive cultivars such as 'Guatemala 4', Guatemala 45', "Guatemala 48', 'Guatemala 51', 'Cuba 2032' can initiate flowering after 100 days and prior to a decrease day length of 12.5 h (Dempsey, 1975). Photo – insensitive plants can therefore be planted during May or early June and still have ample time to produce mature seeds. The earlier production of mature seed for photo-insensitive cultivars greatly expands the potential seed production areas. After floral initiation, photo – insensitive cultivars continue to grow without as much reduction in growth rate as with photosensitive cultivars (Webber *et al*., 2002).

It is important to choose the right variety for the different ecological zones of Nigeria. This is important because its fibre yield is a function of how much growth can take place before flowering in photo sensitive varieties. IAR&T (1997), identified two high yielding varieties of kenaf namely Cuba 108 and Tiannung 1 which are suitable for cultivation throughout several agro – ecological zones in Nigeria.

2.2.3 Rainfall requirement for effective kenaf production

Ogunlela and Adeoti (1990), recommended that kenaf should be sown in areas with about 600 mm rainfall over a period of 4 – 5 months, if good yield and high quality fibre is to be obtained. Also for photoperiod-sensitive cultivars, the planting of kenaf should be done at a time of the year when day length is about 12½ hours duration or longer and remain so over a period of 3 to 4 months. This is essential so that the plants do not develop flower until the plants attain suitable height that will ensure adequate yields of fibre per area of land.

2.2.4 Soil type suitable for kenaf cultivation

IAR&T (1997), stated that the best type of soil for kenaf production is a well-drained sandy-loam soil. Poorly drained soil causes stunting and eventual death of plants before flower initiation. Similarly, light sandy soil is not recommended for kenaf production as plant growing in such soils bloom rather early, without attaining sufficient height; consequently low yields are obtained from such soils. Nematode – infested soils should be avoided.

2.2.5 Land preparation for growth of kenaf

Kenaf should be planted on flat land but steeply sloping land which is susceptible to erosion should be avoided (Dempsey, 1975; Wilson, 2003). The land must be properly ploughed. To avoid double-ploughing, it is important to clear heavy trash and weeds from the farm. After ploughing, the tractor should disc the land, and a second time two weeks later. This period is to allow weeds to emerge, and destroy them (weeds).

2.2.6 Planting date suitable for fibre and seed production

For kenaf production, planting date is an important yield factor in that total fibre yield and yield of seeds are both strongly influenced by this factor and partly by day – length

(White *et al*., 1970). Late planting followed by dry period contributes to low yield because the roots of young kenaf plants may develop sufficiently to use the limited supply of soil moisture (White *et al*., 1970). The time of planting is dependent on the photoperiodic requirements of varieties to be planted. The time of planting also varies depending on the purpose for which the crop is required (LeMahieau *et al.,* 2010). Late planting is more suited for seed production than for the fibre production. Fibre yield and quality decrease if the crop is planted late in the rainy season (KI, 1989). Results of fields studies conducted in the more humid parts of the Nigerian savanna and forest zone showed that overall yield of fibre increase up to mid – April and thereafter decreased (Taylor et *al*., 1982). In Southwestern Nigeria, April is recommended for fibre and July for seed production (IAR&T, 1997).

2.2.7 Spacing and seed rate used for growth of kenaf

Results of studies conducted at Institute of Agricultural Research and Training (IAR&T) Ibadan, Nigeria to determine the optimum plant spacing and plant population have led to a recommendation of a spacing of 50 x 20 cm for kenaf growing in Western Nigeria for fibre and 50 x 10 cm for seed production (IAR&T, 1997). The seed rate is in the range of 25 – 30 kg per hectare; with two plants per stand.

2.2.8 Planting methods for kenaf cultivation

To reduce drudgery in kenaf production, planting should be done by the use of hand-operated planters (Dempsey, 1975; Wilson, 2003). Drilling machines should be used where available. This method is better than hand sowing. Otherwise, hand seeding can be used. The planting depth is within the range of 0.5 – 3.2 cm and with good soil condition, optimal temperature and moisture; seedlings will emerge in 3 to 6 days (Dempsey, 1975; Wilson, 2003).

2.2.9 Fertilizer requirement for kenaf production

Kenaf generally gives the greatest response to nitrogen, followed by phosphorus (Dempsey, 1975; Wilson, 2003). Fertilizer application rates for kenaf differ from one place to another, depending on the nutrient status of such soils. The fertilizer recommendation for kenaf growing for fibre is 60 kgN/ha of N.P.K. (20:10:10) and 40 kgN/ha for seed production

(Ogunbodede and Adediran, 1996). Kenaf, with its deep tap root and wide spreading lateral root system, is considered to be an excellent user of residual nutrient from previous cropping (Dempsey, 1975; Wilson, 2003).

2.2.10 Weed control methods for kenaf production

Expectedly, weeds can seriously affect kenaf growth and development, especially during the early stages. But once the crop is well established and the canopy is full and complete, kenaf is able to compete well with weeds and thus suppress them (Dempsey, 1975; Wilson, 2003). Kenaf is a vigorously growing plant and under optimum growing conditions, can form a canopy over the middle row in at least five weeks (Neill and Kurtz, 1994). Weeding should not continue as soon as kenaf plants are 60 – 90 cm tall (LeMahieau *et al*., 2010). Treflan, a pre - emergent grass killer is registered for use in Florida (KI, 1989)

2.2.11 Control of pests and diseases during kenaf growth

Nematodes and other soil-borne pathogens constitute the major problem to kenaf cultivation. No nematode-resistant kenaf variety has been found (Dempsey, 1975; Wilson, 2003). Crop rotation is therefore the only recommended control measure to combat nematode infestation on lands that are used for kenaf cultivation (IAR&T, 1997).

Insects constitute second group of pests in kenaf production. Leaf defoliators, stem borers, flower and capsule borers all cause significant reductions in fibre and seed yields (Dempsey, 1975; Wilson, 2003). Early application of systemic chemicals such as Nuvacron will control leaf-eating beetles whose activities retard the growth of kenaf plants (IAR&T, 1997).

2.2.12 Kenaf harvesting and retting

Harvesting of kenaf plants for fibre is usually done when the plants begin to flower and the flowering time is variety-dependent, varying between 90 and 120 days after planting (Dempsey, 1975). However, the best time to begin to harvest kenaf for fibre is at approximately 25 % flowering (IAR&T, 1997). At that stage of growth, fibre quality is high and fibre can be extracted from the plants with less difficulty (Anonymous, 2003). Harvesting

can either be done manually (i.e. by hand) or preferably by using machinery that is similar to silage harvesters, by cutting the plants at ground level and the kenaf can then be chopped, baled or transported as full – length stalks (Webber *et al*., 2002).

Kenaf plants have to be retted to separate core from bast fibre. Of all the methods of retting: Tank retting, canal / stream retting, moist chamber retting, stack retting, retting of diseased stems and chemical retting, stream retting produce best fibre quality (LeMahieu *et al*., 2010).

2.3 Characteristics of the major tropical soils

Soil is the thin layer covering the entire earth's surface, except for open water surfaces and rock outcrops. The properties of soil are determined by environmental factors. Five dominant factors are often considered in the development of the various soils: (a) the climate, (b) parent materials (rocks and physical and chemical derivatives of same), (c) relief, (d) organisms (fauna and flora), and (e) the time factor.

USDA (1975), grouped world soils under ten orders (the highest category). Brief descriptions of these ten orders are given as follows:

1. Alfisols: soils with a clayey B horizon and exchangeable (Ca + Mg + K + Na) saturation greater than 50 %.
2. Ultisols: soils with a clayey B horizon and base saturation less than 50 %. They are acidic, leached soils from humid areas of the tropics and subtropics.
3. Oxisols: Oxisols are strongly weathered soils but have very little variation in texture with depth. Some strongly weathered, red, deep, porous Oxisols contain large amount of clay-sized Fe and Al oxides.
4. Vertisols: Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.
5. Mollisols: Prairie soils formed from colluvial materials with dark surface horizon and base saturation greater than 50 percent, dominating in exchangeable calcium.
6. Entisols: Soils with little or no horizon development in the profile. They are mostly derived from alluvial materials.

7. Inceptisols: Young soils with limited profile development. They are mostly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols.
8. Aridisols: Soils of arid region, such as desert soils. Some are saline.
9. Spodosols: Soils with a bleached surface layer (A2 horizons) and an illuvial accumulation of sesquioxides and organic matter in the B horizon. These soils are mostly formed under humid conditions and coniferous forest in the temperate region.
10. Histosols: Soils rich in organic matter such as peat and muck.

All the soil orders listed with the exception of Spodosols occur in tropical regions. USDA (1975), further stated that Oxisols are the most abundant soils in the humid and perhumid tropics covering about 35 percent of the land area. Ultisols are the second most abundant, covering an estimated 28 percent of the region. About half of the Ultisols and 60 percent of the Oxisols are located in humid and perhumid tropical Africa and Asia. In tropical Africa, they are abundant in the eastern Congo basin bordering the lake region; in the forested zones of Sierra Leone; in Ivory Coast; in parts of Liberia; and in the forested coastal strip from Ivory Coast to Cameroon. The Alfisols, which have high to moderate fertility, cover a smaller area of the humid tropics. In West Africa they are found in Ivory Coast, Ghana, Togo, Benin, Nigeria and Cameroon. They are, however, the most abundant soils in Africa's subhumid and semi-arid zones, covering about one third of these regions. The Alfisols are widely distributed in the subhumid and semi-arid tropical regions of Africa, including large areas in western, eastern, central, and southeastern Africa.

2.4 Soil fertility degradation and agricultural production

Soil degradation is the declining of soil quality and loss of productivity which is caused by irrational land use by humans. It has a significant impact on human survival, global environmental change, crop production, forestry and animal husbandry production. The soil is undoubtedly the most important basic natural resource of any nation. It is an irreplaceable natural resource and therefore the need to conserve it cannot be overemphasized. Unfortunately, Nigerian soils have been neglected, misused and mismanaged in a way that has brought all our soils to variable levels of degradation. The situation in Nigeria, as in most

tropical countries is particularly bad because of the inherent fragile and infertile nature of our soils.

Degradation is evidenced by significant deterioration in the physical, chemical and biological properties of the soil and biosphere in such a way that fertility and productivity are adversely affected to the extent that yields of crops are reduced. The overall result is that technologies being employed to maintain or increase yields give results, which are less than expected. The FAO estimates a worldwide soil loss of 5 of 7 million hectare per annum of agricultural soil (FAO, 1993) including 2.7 million hectare through erosion and 1.6 million hectare due to salinization far more than could be offset by new land. In the world map on status of human induced soil degradation, one quarter of agricultural land is estimated to be seriously damaged by soil degradation (FAO, 1993). Estimates for the African continent are even more alarming. Out of a total of 1020 million hectares of potential agricultural land, 124 million hectares (12 %) have been seriously damaged and 5 million hectares (0.5 %) utterly destroyed that is now unusable for agriculture (FAO, 1993). The productivity of 190 million hectares (19 %) has diminished substantially (Oldman and Boone, 1989).

2.5 Causes of soil fertility degradation

2.5.1 Land clearing and tillage techniques

The clearing of vegetation for agriculture in the humid forest regions without appropriate soil conservation measures has resulted in the exposure of soil to the impact of rainfall and high temperatures. These have often led to heavy nutrient losses, rapid mineralization of organic matter, disturbance of soil physical condition, reduced water infiltration and erosion hazards (Lal, 1982). Physical soil degradation actually starts with the clearing of vegetation for agricultural development.

Under the shifting cultivation farming system, land clearing techniques have little direct effect on soil compaction since the implements used are very simple (hoe and cutlass). The slope of the land, the intensity of clearing and the exposure of land after clearing however influence the degree of soil erosion. Modern trends in large scale clearing projects involve the use of heavy machinery, increased use of heavy tillage machinery as well as surface traffic in farm operations. All these result in soil compaction. Compaction of soils causes a reduction in soil pore space. This reduces the rate at which water can infiltrate and drain through the soil.

It also reduces the available space for oxygen in the plant root zones. For this reason, some of the major consequences of compaction are poor drainage, poor aeration, and hard pan surfaces which cause runoff. Repeated cultivation of some soils leads to a breakdown of soil structure and this also increases the likelihood of compaction.

The use of inappropriate heavy machinery has also resulted in the direct removal of the top fertile soil layer including organic matter (ACS, 2009). Land clearing methods and tillage systems also affect the chemical properties of soil. Lal (1982) reported that six years after clearing a secondary forest on an Alfisol in Nigeria, soil pH had declined from a precultivation value of 6.1 to 5.8 with no tillage and 4.4 when land was ploughed. Major decline in exchangeable Ca^{2+} and Mg^{2+} were also reported, the effect being more pronounced with ploughing. Agboola (1987), showed that apart from loss of soil organic matter, phosphates and the basic cations, bulldozing or poor land clearing methods bring about loss of micronutrients such as zinc, copper and boron.

2.5.2 Depletion of soil organic matter

Soils occurring under rainforest in humid tropics often have relatively high contents of organic matter but when the forest is cleared and cultivation commenced, Soil Organic Matter (SOM) levels are drastically reduced (Lal, 1982). Because of the predominance of low activity clays in soils of the humid forest zones, the only alternative source of cation exchange capacity is the soil organic matter (Agboola, 1987). Many physical, chemical and biological properties of the surface horizons depend largely on the SOM content (Feller, 1993). Soil organic matter could therefore be referred to as the nerve centre of the sustenance of soil fertility and crop production on these soils. Jekinson and Ayanaba (1977), reported that SOM decomposition rate in the humid tropical environment of Ibadan, Nigeria with annual mean temperature of 26 ^{0}C was about four times faster than in the temperate zone with annual mean temperature of about 9 ^{0}C. Adepetu *et al*. (1979), observed a drop of 58 % in SOM level during the first seven year of continuous cropping on an Alfisol cleared from a secondary forest in Southern Nigeria. Yield decline with continuous and intensive cropping (which has become inevitable in most parts of the humid tropic owing to pressure on land) is often observed even with high level of fertilizer inputs. Such yield decline has been attributed to decrease in SOM and pH, depletion of nutrients not supplied in the applied fertilizers,

imbalance in fertilization and to a degradation of soil physical properties. SOM management is needed in humid tropical soils especially for its effects on change characteristics. Results obtained from a long term trial on a Ferric Lixisol in Ibadan, Nigeria (Vanlauwe, 2000) confirm the overruling role of SOM on ECEC of the top soil.

2.6 Management of nutrient degraded soil

Loss of soil fertility is manifested through using dung and crop residues as household fuels and animal feeds, low use of chemical fertilizers, declining fallow periods, soil and organic matter burning and soil erosion. Although people practice mixed farming, but the nutrient flows between the two are predominantly one sided, with feeding of crop residues to livestock but little or no dung being returned to the soil. The deficiency of plant nutrients causes different changes in the physiological and biochemical processes within plant cells resulting in a reduction of growth, delay of development and quantitative and qualitative decrease of yield (El – Hady *et al.*, 2001; Wahba, 2004). With increase depletion of soil nutrients and the need to feed the growing African population, the addition of fertilizers and other soil amendments to improve soil productive capability should be accorded the needed priority attention. Recent interest in agro ecosystem research has been focusing on the introduction of sustainable management practices in agriculture, including crop rotations and fertilizer application systems to maintain soil quality and productivity and to minimize the negative effects of agriculture production on the environment (Lalfakzuala *et al.*, 2008).

2.6.1 Soil nutrient management using inorganic fertilizers

Judicious use (i.e. lower rates, split application, banding) of inorganic fertilizers is needed on infertile Kaolinitic and oxides soils, to sustain high crop yield and maintain an optimum balance of nutrients. Because of scarcity and high cost, most small holder farmers in tropical African and Latin American rarely use inorganic fertilizers on food crops. Nutrient inputs from inorganic fertilizers are needed to replace nutrients which are exported and lost during cropping, to maintain a positive nutrient balance sheet. Continuous use of inorganic fertilizer can have detrimental effects on soil properties. In temperate region, continuous mono-cropping of cereals with optimum fertilizer use can sustain crop yield on fertile soil such as Mollisols and Alfisols with high activity clays (Jekinson, 1989; Oldman and Boone,

1989). But on the strongly weathered, poorly buffered soils of the tropic (e.g. Kaolinitic, Alfisols, Ultisols and Oxisols) continuous monoculture of cereals, using inorganic fertilizer as the main source of nutrients, can lead to a significant decline in yields after only a few years of cropping because of soil acidification and compaction (Kang and Juo, 1986). Acidification occurs mainly through the loss of exchangeable bases in leaching (Ca, Mg, and K) and acid production during Al hydrolysis and nitrification. For example, in a long term experiment conducted on a Kaolinitic Alfisols in Nigeria, Juo *et al*. (1995), reported that the rate of decline in soil pH and exchangeable Mg under three cropping systems with application of inorganic fertilizer (NPK) were: continuous maize with NPK without residues > continuous maize with residue mulch > maize/cassava intercropping. Without a residue mulch, soil pH (measured in water) dropped from 6.0 to about 4.5 after ten years (Juo *et al*., 1995).

While fertilizer is needed to maintain soil productivity, it must always be used in conjunction with management practices that help maintain soil organic matter, such as return of residues or other organic materials to the soil and minimum tillage. Fertilizer management especially the type of nutrient and the application rate is best based on site specific experiments and farmers' experience.

Advantages of inorganic fertilizer

- It is possible to cultivate the land throughout the year.
- Collecting materials, processing, transporting and applying compost require large amounts of labour. Applying inorganic fertilizer reduces this requirement.
- It has made white coloured soils productive which compost by itself could not accomplish.
- It increases yield in a short period of time. This is of particular interest to tenant farmers.
- It is easy to apply, one can learn by observation or simple instruction from other farmers.

Disadvantages of inorganic fertilizer

- It makes the soil hard, dry and difficult to plough
- It increases the labour requirement for ploughing and breaking clods
- It reduces the moisture retention capability of the soil.

- It sucks the organic material out of the soil and makes it available to the plant in a very short time. This process of extracting slowly kills the soil.

2.6.2 Soil nutrient management using organic manures / fertilizers

Organic manures are usually derived from plant or animal sources and may be classified as bulky organic manures and concentrated organic manure (Yayock and Awoniyi, 1974). Bulky organic manures consist of farmyard manure, compost, green manure, night-soil and sewage. Concentrated organic manures contain higher percentage of nitrogen, phosphorus and potassium, compared with bulky organic manure. The common concentrated organic manures are oil cakes, blood meal, fish manure, meat meal and cotton and wool wastes (Yayock and Awoniyi, 1974). It is a well known fact that productivity of tropical soils can be sustained under continuous land use if soil erosion is controlled and soil organic matter and soil physical and nutritional characteristics are maintained at a favourable level. The various ways of maintaining favourable levels of soil organic matter are green manure, residue mulching, farmyard manure and compost.

Manure is understood to mean the refuse from stables and barnyards, including both excreta and straw or other bedding materials. Depending on the point of view, by-products generated from animal operations can be described as problems or a resource. Either can be correct but both require proper management to avoid becoming an environmental concern. The potential harm from the mismanagement of manure and dead animals can be eliminated, turning the by-products into a valuable source of plant nutrients, soil amendments and livestock feeds. Large amounts of manure produced by livestock have value in maintaining and improving soil because of the plant nutrients, humus, and organic substances contained in it. Farm animals void most of the nitrogen, phosphorus, and potassium that is present in the food they eat and this constitutes an excellent fertility resource. The use of animal manure is a common practice particularly among vegetable growers because it provides considerable amounts of plant nutrients and many other beneficial effects for crop growth (Wijewardena and Gunaratne, 2004). Manure can be applied as a liquid or a solid but must be carefully managed so as to derive the optimum benefit from it. The main benefits of manure are indirect; it supplies humus, which improves the soil physical character by increasing its capacity to absorb and store water, by enhancement of aeration, and by favouring the

activities of lower organisms (EB, 2010). Manure incorporated into the topsoil will help prevent erosion from heavy rain and slow down evaporation of water from the surface. In effect, the value of manure as a mulching material may be greater than its value as a source of essential plant nutrients (Oyedele *et al.,* 2006).

Animals in confined feeding operations including poultry are often times made to produce tonnes of manure. The manure produced by confined animals could be valuable source of crop fertilizer. Guisquiani *et al*. (1995), stated that poultry manure is rich in nitrogen, phosphorus and organic matter and the studies showed that livestock and poultry manures influence crop production and they also improved soil physical properties. Pelleted poultry litter contains nitrogen, phosphorus, potassium and small quantities of micronutrients (Mozaffari *et al.,* 2004). High crop yields are recorded by the application of organic fertilizer as poultry manure (Malak-Ramadan and Emad, 2007). Soil acidity and acidification constrains the productivity of most tropical soils (Uexkull, 1986; Manna *et al.,* 2007). Although conventional liming materials such as calcium carbonate, quicklime, slaked lime and magnesium carbonate are available to ameliorate acidity and acidification, animal manure has been demonstrated to have great potential for ameliorating soil acidity (Busari *et al.,* 2008). Increase in pH of soils amended with poultry manure has also been related to the addition of basic cations (Cavallaro *et al.,* 1993; Kingery *et al.,* 1994; Ano and Agwu, 2005; Melero *et al.,* 2006). Similarly, Ano and Agwu (2005), declared that animal manures have a high capacity for increasing soil pH. With liming and the proper use of organic amendments, marginal lands can be restored to high productivity (Hornick and Parr, 1987).

In humid areas, the practice of green manuring can improve yield and soil qualities. A green-manure crop is grown and ploughed under for its beneficial effects, although during its growth it may be grazed. These green crops are usually annuals, either grasses or legumes whose roots bear nodule bacteria capable of fixing atmospheric nitrogen (EB, 2010). Among the advantages of green-manure crops for typical African soils are the addition of nitrogen to the soil; increase in general fertility level, reduction of erosion, improvement of physical condition, and reduction of nutrient loss from leaching.

Compost, peat, and sludge are used in agriculture and gardening as soil amendments rather than as fertilizers, because they have a low content of plant nutrients. They may be incorporated into the soil or mulched on the surface. Compost or synthetic manure is basically

a mass of rotted organic matter made from waste-plant residues. Addition of nitrogen during decomposition is usually advisable (EB, 2010). The result is a crumbly material that when added to soil does not compete with the crop for nitrogen. When properly prepared, it is free of obnoxious odours. The nitrogen of compost becomes available slowly and never approaches that available from inorganic sources. This slow release of nitrogen reduces leaching and extends availability over the whole growing season. Composts are essentially fertilizers with low nutrient content, which explains why large amounts are applied. The maximum benefits of composts on soil structure (better aggregation, pore spacing, and water storage) and on crop yield usually occur after several years of use. In areas where commercial fertilizers are expensive, with cheap labour and availability of simple implements, composting is the logical practice that meets the needs of an average farmer. Peat improves the water-storage capability of soils and gives better structure to fine soils (EB, 2010). Sewage sludge is the solid material remaining from the treatment of sewage. Its value for soil improvement depends on the method used for treating the sewage. Activated sludge, which results from aerobic (oxygen) treatment, contains 5 to 6 percent nitrogen and 1 to 3.5 percent of phosphorus (EB, 2010). After suitable processing, it is sold as fertilizer and soil amendment for use on lawns, parks, and golf courses.

2.6.3 Soil nutrient management by organo – mineral fertilizer

Agboola and Odeyemi (1972), reported that the best fertilizer mixture for humid and tropical soil is a mixture of organic and inorganic fertilizers. Organic manures are excellent sources of organic matter but relatively low in nutrients. Manure is not a balanced fertilizer, being especially deficient in phosphorus (Yayock and Awoniyi, 1974). Therefore there is need to complement its use. Considerable studies have shown that combinations of organic and mineral fertilizers perform better on crop yield than when each of them is solely used (Agboola and Obigbesan, 1975; Sikora and Enkiri, 2000; Sridhar and Adeoye, 2003). Titiloye *et al.* (1985), reported that maize yields obtained from treatments with combination of wastes and NPK fertilizers had better yields than ones obtained from treatments in which waste material or inorganic fertilizer was applied alone. In addition, Dempsey (1963), stated that liberal amounts of chemical fertilizer and manure should be used to produce a good crop of kenaf.

From the greenhouse and field trial conducted by the research group, the rate of application of organo-mineral fertilizer was shown to be between 2 - 2.5 t/ha (Grade A) and 6.0 – 6.5 t/ha (Grade B). This application rate has yielded better crops as compared to those grown on inorganic fertilizers such as N.P.K formulations alone. A variety of crops such as yams, cassava, maize, amaranth, sunflower, a variety of beans, and horticultural crops were grown with the organo-mineral fertilizer (Omueti *et al*., 2000). Much work has not been done on kenaf production using organo-mineral fertilizer; which justify the need for this study.

2.7 Mycorrhiza: types and distribution

Botanically, mycorrhiza is the mutualistic symbiosis between soil-borne fungi and roots of higher plants. Two main types of mycorrhiza are distinguished: ectomycorrhiza and endomycorrhiza. Arbuscular mycorrhiza (AM) is probably the most widespread terrestrial symbiosis. It is formed between obligate biotrophic fungi of the phylum Glomeromycota (Schuβler *et al*., 2001) and roots of around 80 % vascular plants (Smith *et al*., 2003). Arbuscular mycorrhiza has three important components: the root itself, the fungal structure within the cells of the root and extra radical mycelium in the soil. Arbuscular mycorrhizal fungi (AMF) are ecologically significant because of the symbiotic relationships in and on the roots of a host plant where host plant provides the fungus with soluble carbon sources, and the fungus provides the host plant with an increased capacity to absorb water and nutrients from the soil (Allen *et al*., 2003; Miyisaka and Habte, 2001).

Some of the important genera of AMF are *Glomus*, *Paraglomus*, *Gigaspora*, *Acaulospora*, *Entrophospora* and *Scutellospora*. Four orders, seven families and eight genera of AM fungi have been recognized (Schuβler *et al*., 2001). The number of AM fungal species is unknown, and has been suspected to be much larger than 150, based on selectivity between fungal and plant species and the high proportion of total AM fungal diversity commonly detected in natural communities, compared to the number of plant species (Helgason *et al*., 2002). In an experiment carried out in humid forest zone, Atayese *et al*. (1993), reported that of all the AM present, *Glomus mosseae* is the most prominent / abundant. As a result, *Glomus mosseae* was used in this study.

2.8 Functions of mycorrhiza in crop production

2.8.1 Arbuscular mycorrhizal colonization and nutrient uptake of plants

The principal function of mycorrhiza is to enhance the efficiency of nutrient uptake from the soil solution. When plants receive a higher amount of nutrients as compared to what they can get on their own, the biomass, both above and below the ground increases. Evidences indicate that AM colonized plants absorb and accumulate more phosphorus (P) compared to non-colonized plants when plants are grown in soils that are low in P (Smith and Read, 1997; Harrier and Watson, 2003; Azcon *et al*., 2003). Smith and Read (1997), reported that influx of P in roots colonized by AMF fungi could be 3 to 5 times higher than in non-colonized roots. Enhanced P uptake through AM fungi have been observed in crops such as cassava, potatoes, cocoyam and yam (Howeler, 1990; Duffy and Cassells, 2000).

Not only the uptake of P is enhanced by AM colonization of plant roots, the uptake of other macro and micronutrients like N, K, Ca, Mg, S, Cu, Fe, Zn and B have also been enhanced (Allen *et al*., 2003; Hodge, 2003). Several studies have demonstrated the transportation of inorganic N by AM fungi (Hawkins *et al*., 2000; Blanke *et al*., 2005). Enhancements in the acquisition of K, Ca and Mg are often observed in AM fungi colonized plants grown on acidic soils than neutral or alkaline soils (Harrier and Watson, 2003). Zinc and Cu have been taken up by mycorrhiza in a deficient condition to increase plant yield (Kucey and Jarzen, 1987). There is evidence that AM fungi can inhibit Zn and manganese (Mn) uptake at toxic concentration in soil thus reducing adverse effect on the host (Dueck *et al*., 1986). Some heavy and often toxic metals (Cd, Ni, Sr, Cs) and some non-nutritional anions (Br, I) are known to be taken up and transported to the host by AM fungi, phytotoxicity through increased uptake of these elements was found to fluctuate and was often compensated by increased and more balanced absorption of macronutrients (Sieverding, 1991).

The mechanism of P uptake by AM fungus has widely been attributed to its hyphae extending beyond the root depletion zone and increasing the volume of bulk soil that the plant roots can explore (Harrier and Watson, 2003; Cardoso *et al*., 2006). These hyphae absorb P, translocate it rapidly to AM structures within the roots (intercellular hyphae, intracellular coils, and highly branched intracellular arbuscules), from where it is released to the interfacial apoplast adjacent to root cortical cells (Smith and Smith, 1996; Smith *et al*., 2003).

Propositions that P uptake in mycorrhizal plants may have resulted from the activity of the mycorrhizal fungi have been made. Increased phosphatase activity in the soil rhizosphere of mycorrhizal may be linked to fungal phenomenon (Harrier and Watson, 2003). While plant roots and mycorrhizal hyphae affect chemical changes and P solubility in the (mycorrhiza) rhizosphere differently, higher P affinity or lower P threshold concentration in the fungal hyphae may also influence P uptake of mycorrhizal plant (Cardoso *et al*., 2006).

Mechanism influencing the uptake of other nutrients could be an indirect effect of enhanced P which may result in increased growth rate and biomass yield. It has also been demonstrated that the extra-radical hyphae of AM fungi have the capacity to transport some nutrients (Johansen *et al*., 1992).

2.9 *Malvaceae* and arbuscular mycorrhiza

Kenaf, *Hibiscus cannabinus*, belongs to the plant family *Malvaceae*, the same family to which okra, cotton and many others. One of the major constraints of crop production in the tropical soil is the declining soil fertility. Mineral fertilizers although increase yield of crops, their continuous and excessive use may be detrimental on the long run. The current interest in agriculture is to minimize the use of mineral fertilizers and focus attention on eco-friendly techniques in farming. In this context, the use of biofertilizers, which are pollution free, low cost input material and which can improve the soil conditions without causing any harmful effect is quite imperative to reduce the heavy dependence on mineral fertilizers.

Mycorrhizal symbiosis is one of the sustainable methods for enhancing soil nutrient availability to most plants grown on soils of low fertility. The symbiotic association increases the availability and uptake of immobile nutrients such as Phosphorus (P), Copper (Cu) and Zinc (Zn) (Kothari *et al*., 1991; Smith and Read, 1997; Clark and Zeto, 2000), uptake and transport of N (Hamael and Smith, 1991; Johansen *et al.*, 1992; Hodge, 2003) as well as optimal function of root (Liu, 2003).

It has been reported that root of cotton was highly colonized by arbuscular mycorrhiza and the inoculation significantly stimulated cotton growth in a phosphorus deficient soil (Lynn *et al*., 1981). Sieverding (1991), classified cotton as facultative mycotrophic plant (which can survive and grow without mycorrhizae at some level of soil fertility). Run-Jin (2004), similarly reported that arbuscular mycorrhiza was able to infect all the cotton varieties

and reduced the incidence and disease indices of *Verticillium* wilt of cotton during the whole growth phase. Cotton seedling growth was promoted, flowering was advanced, the numbers of flowers and bolls were increased and this resulted in an increase in the yield of seed cotton. Nematodes are viewed in some areas as the most serious constraint to kenaf production. In cotton growing areas, the root-knot nematode / fusarium wilt complex is expected to limit yield potential for both cotton and kenaf, and will create crop rotation challenges due to the common susceptibility of the two crops. Nematode disease which causes great reduction in the yield of kenaf has been reported to be suppressed by arbuscular mycorrhiza (Talavera *et al*., 2001). Seed-borne pathogens such as *Fusarium species* and *Rhizoctina solani* that cause diseases in kenaf have been suppressed by AM in other crops (Talavera *et al*., 2001). Inoculation of peanut (*Arachis hypogeae* L.) with *Glomus mosseae* decreased the abundance of *Rhizoctina solani* and *Fusarium species* (Abdalla and Abdel-Fattah, 2000)

With the immense scope of mycorrhiza in crop production and protection, the role of mycorrhiza in the productivity of kenaf has not received enough attention. Although report has shown that roots of kenaf form symbiotic association with mycorrhiza forming fungi (Bunvong *et al*., 1999). Information on the root colonization of different varieties of kenaf by arbuscular mycorrhiza is lacking. Such information is important for sustainable production of kenaf in a nutrient degraded tropical soil.

2.10 Crop production using arbuscular mycorrhiza with other soil amendment

Nitrogen is one of the most limiting elements for plant production in tropical soils. Nitrogen is the most frequently applied fertilizer in the tropics and often the only fertilizer element added to the soil. In the tropics, the most common N fertilizer source is urea. In the soil, urea is converted to ammonium. Hayman (1987) stated that increasing levels of nitrogen fertilizers may inhibit AM fungi formation and may negatively affect the AM population. However, the effects of nitrogen applications on AM are not constant (Sieverding, 1991). They vary from one soil site to another and may depend on the availability of P.

Increasing NPK fertilization did not alter AM in field-grown pasture legumes at Carimagua (Sieverding, 1991). In more fertile soils of the Cauca Valley, Sieverding (1991), found a negative effect of higher NPK applications on AM spore density in sugarcane fields; the decrease was attributed to the inhibiting effect of higher NPK levels on spore formation of

Glomus mosseae, a highly effective AM fungus under those soil conditions. High amount of soil available P and total N may lower AM colonization (Treseder and Allen, 2002; Johnson *et al*., 2003). Application of inorganic fertilizer with mycorrhizal inoculation does not improve soil physical properties (Celik *et al*., 2004).

Liming of acid tropical soils is both recommended and necessary to reduce aluminium saturation below toxic levels for certain crops and to supply Ca and Mg to the soil (Sanchez and Salinas, 1981). Lime application of 0.5 – 4.0 t/ha, either as dolomitic lime or calcitic lime, increased root colonization ratings of cassava, but not significantly, in different fields of the Mondomo area (Inceptisols) and in Carimagua (Oxisols) (Sieverding, 1991). Arbuscular mycorrhiza root colonization ratings of several pasture legumes and pasture grasses were not markedly altered by increasing lime applications (Sieverding, 1991). In contrast to root colonization, the AM fungal spore density decreased significantly due to increasing lime applications to pastures (Sieverding, 1991). This was also found with cassava grown in a similar Oxisol at Carimagua (Sieverding, 1991).

Sieverding (1991), described the importance of humus and composted organic matter for sustainable agricultural production in the tropics. He related the improved productivity of tea, coffee, sugarcane, cotton, banana, cacao, tropical legumes and grasses, and fruit trees after compost application to the increased activity of AM fungi. From field observation, he reported the positive effect of compost on soil aeration which resulted in improved root and AM development. Howard (1943) cited in Sieverding (1991) observed that cassava roots were more intensively colonized by AM fungi when compost was applied. In contrast to lime application, amendment by compost did not alter the diversity of AM fungal species in the soil and had no effect on the relative spore composition of the AM fungal community (Sieverding, 1991). However, placed great emphasis on the correct preparation of composts; the mixture of plant residues with manure apparently is the key to the effectiveness of the organic fertilizer. It was confirmed by Guttay (1983) that the quality of the compost is important for optimum AM formation. Brechelt (1990), studied the effect of increasing amounts of manure, of composted manure and of composted plant residues on AM fungi in greenhouse experiments. She found that fresh manure may decrease AM colonization ratings of *Capsicum annuum* and *Vigna unguiculata* (cowpea) when applied in doses of 5 to 30 t/ha. This decrease may be attributed to the high NH_4 component in fresh manure, and NH_4

nitrogen is known to inhibit AM formation. On the other hand, composted manure and composted plant residues increased colonization ratings of plants at all application levels (Brechelt, 1990). Dry matter production also increased with increasing levels of composted materials when plants were associated with effective AM fungi. Compost application with mycorrhizal inoculation improve soil physical properties (Celik *et al*., 2004). Soils with an abundance of organic matter remain loose and airy, hold a greater amount of moisture and nutrients, promote the growth of beneficial soil organisms and provide a healthier root system (EP, 2011).

Mulching has several effects on physical soil conditions which may positively reflect upon the microbial activity of the soil. Soil temperature is lower in the upper soil horizon, the diurnal fluctuations in soil temperatures are smaller and the water content is higher under mulch. Sieverding (1991), observed a positive influence of plant residue return (weeds and prunings from tea) on AM root colonization in tea plantations. A significant positive effect of plant residue return on AM spore population has been reported from pasture fields in Carimagua (Sieverding, 1991). Straw mulch applied in amounts of 5 – 30 t/ha in greenhouse experiments considerably increased AM root colonization ratings of cowpea and green pepper (Brechelt, 1990).

Reports have shown that inorganic fertilizer application increased the bast and core yield of kenaf (Ogunbodede and Adediran, 1996; Agbaje *et al*., 2009). Bunvong *et al*. (1999), also stated that roots of kenaf form symbiotic association with mycorrhiza forming fungi. Information on the influence of AM inoculation with fertilizers application for kenaf production is lacking and such information is important for sustainable production of kenaf in a nutrient degraded Alfisols.

CHAPTER 3

MATERIALS AND METHODS

Screenhouse and field experiments were conducted in year 2004 and 2005 respectively. Residual effect of the treatments applied on the field was also determined in the year 2006.

3.1 Description of the study area, plot and planting materials

Both the screenhouse and field experiments were carried out at the Institute of Agricultural Research and Training (IAR&T) Moor Plantation, Ibadan on Latitude 7 ° 22.5 ′ N and Longitude 3 ° 50.5 ′ E in the rainforest of South-Western Nigeria. The climate is humid tropical with bimodal rainfall extending from March to October. The average annual rainfall in Ibadan is about 1230 mm with annual average temperature of 27 ^{0}C (FAO, 1993). It has about five months (November – March) of dry season each year with slight irregularity in the rainfall distribution pattern. The soil, which is classified as Oxic Paleustalf derived from gneiss and schist parent material (Ojo – Atere *et al*., 1990). Rainfall distribution of the site was obtained from the Meteorological Station of IAR&T.

The plot where the screenhouse soil was collected and the experimental plot for field experiment have been under continuous cultivation with the continuous application of inorganic fertilizer over ten years.

Two types of market waste-based fertilizers (produced by Pacesetter Organic Fertilizer Company, Bodija, Ibadan, Oyo State) namely: organo-mineral Grade A fertilizer (composted Bodija market waste fortified with superphosphate and urea) and organic Grade B fertilizer (purely composted at Bodija market waste without any additive). Prior to application, the two fertilizers were taken to the laboratory for proximate analysis. However, N.P.K. 20:10:10 fertilizer at recommended rate of 60 kgN/ha was also used (Ogunbodede and Adediran, 1996).

Mycorrhizal inoculum (*Glomus mosseae*) consisting of chopped roots of the trapping plant, hyphae, spores and soil was collected from the Soil Microbiology Laboratory, Department of Agronomy, University of Ibadan, Ibadan.

Two high yielding varieties of kenaf Cuba 108 and Tiannug 1 (IAR&T, 1997) suitable for different agro-ecological zones in Nigeria were collected from IAR&T, Ibadan.

3.2 Effects of fertilizers and mycorrhizal inoculation on the growth, yield and mycorrhizal colonization of Cuba 108 and Tiannug 1

This experiment was conducted in a screenhouse at IAR&T Ibadan between the months of April and July, 2004

3.2.1 Experimental Design

A 2 × 12 × 2 factorial experiment in a Randomized Complete Block Design (RCBD) with three replicates was carried out to assess the effects of two levels of mycorrhiza (with and without) and twelve levels of fertilizers: 0, NPK 20:10:10 (60 kgN/ha), organic (20, 40, 60, 80 and 100 kgN/ha) and organo-mineral (20, 40, 60, 80 and 100 kgN/ha) on the AM colonization, growth and fibre yield of Cuba 108 and Tiannug 1.

3.2.2 Soil sample collection and analysis

Representative topsoil (0 – 15 cm) samples were collected from research farm of IAR&T, Ibadan. Sub-samples were taken, air dried and crushed in agate mortar and passed through a 2 mm sieve to determine the physical and chemical properties: particle size, field capacity, pH, total nitrogen, available phosphorus, exchangeable calcium, magnesium, sodium and potassium of the soil before planting.

Five grams of 2 mm sieved soil sample was weighed in clean sample bottle. It was mixed with 50 ml of distilled water. The mixture was shaken using mechanical shaker for 30 minutes at revolution of 200 / min. Soil pH was determined using a glass electrode pH meter (Rent Model 720) in distilled water (Thomas, 1996).

Particle size was determined by the hydrometer method (Bouyoucous, 1951). Fifty grammes of 2 mm sieved and air-dried soil sample was weighed into a conical flask. Fifty millilitres of sodium hexametaphosphate solution was added and the mixture was stirred with stirrer for 10 minutes using electric stirrer. The mixture was then washed into 1000 ml measuring cylinder, made up to mark with distilled water and thoroughly shaken. Hydrometer and thermometer readings were then taken immediately and after two hours.

Soil organic carbon was determined by the chromic acid digestion method of Walkley and Black as reported by Sparks (1996). A 0.5 g of 0.5 mm sieved and air-dried soil sample was weighed and transferred to 250 ml conical flask. Ten millilitres of 1 N $K_2Cr_2O_7$ solution

was pipetted into the flask and swirled gently to disperse the soil sample. Twenty millilitre of concentrated H_2SO_4 was immediately added. The flask was swirled until the soil compost and reagent were mixed and allowed to stand for 30 minutes. One hundred ml of distilled water was then added, followed by the addition of 4 drops of Ferroin indicator and titrated with 0.5 N Ferroin sulphate solutions until the colour changes to maroon colour. Blank titration was also carried out in the same manner without soil sample.

Determination of sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg) by using Helmke and Sparks (1996) method. Five grammes of 2 mm sieved and air-dried soil sample was weighed into plastic bottle and 30 ml of 1 N ammonium acetate (NH_4OAC) was added and shaken with mechanical shaker for two hours. The cleared supernatant of the mixture was decanted into a 100 ml standard volumetric flask. Another 30 ml of 1N NH_4OAC solution was added to the residue and shaken for another 30 minutes and the supernatant was transferred into the volumetric flask and the solution extract in the volumetric flask was made to mark with 1N NH_4OAC. Potassium and sodium were determined using Flame Photometer (Gallenkamp Model FH 500) and exchangeable Ca and Mg by Atomic Absorption Spectrophotometer (APHA - AWWA - WPCF, 1980).

The percentage nitrogen (N) content in the soil was determined following Bremner (1996) procedure. Five grammes of soil sample was weighed (air-dried sample that sieved with 0.5 mm sieve) into a 500 ml macro-kjeldahl flask. Twenty millilitre of distilled water was added and the flask was swirled for few minutes. The flask was then allowed to stand for 30 minutes. One tablet of selenium catalyst was added, followed by 10 g of K_2SO_4 and 30 ml of concentrated H_2SO_4 through pipette. The flask was heated continuously at low heat on the digestion stand. When the water has been removed and frothing has ceased, the heat was increased until the digest was cleared. Then, the mixture was boiled for 5 hours. The heat was regulated during this boiling so that the H_2SO_4 condensed about half way up the node of the flask. The flask was allowed to cool and 100 ml of water was added slowly to the flask. The digest was carefully transferred into another clean macro-Kjeldahl flask (750 ml). All sand particles were retained in the original digestion flask because sand can cause severe bumping during Kjeldahl distillation. The sand residue was then washed with fifty millilitres of distilled water four times and the aliquot was transferred into the same flask. Fifty ml H_3BO_3 indicator solution was added into a 500 ml Erlenmeyer flask which was then placed under the

condenser of the distillation apparatus. The end of the condenser was about 4 cm above the surface of the H_3BO_3 solution. The 750 ml Kjekdahl flask was attached to the distillation apparatus. One hundred and fifty millilitres of 10 N NaOH was poured through the distillation flask opening the funnel stopcock. Then, distillation commenced. The condenser was kept cool (below 30 ^{0} C), sufficient cold water was allowed to flow through, and the heat was regulated to minimize frothing and to prevent suck-back. One hundred and fifty millilitres distillate was collected and distillation was stopped. The NH_4-N in the distillate was determined by titrating with 0.01 N standard H_2SO_4 using a 25 ml burette graduated at 0.1 ml intervals. The colour change at the end point was from green to purple pink.

Available phosphorus (P) was determined as described by Kuo (1996). Five grammes of soil sample was measured in an extraction cup and 25 ml of Bray 1 solution was added and stirred for one minute. It was allowed to stand for one minute and then filtered. Eight ml of Bray 1 and 1 – 5 µg/l was pipette in each test tube. Eight millilitre of sample extract was also pipette in another test tube. Five drops of phosphorus B reagent was added and mixed thoroughly. Then, 5 drops of phosphorus C reagent and mixed together (F.S. solution).

3.2.3 Soil preparation and planting

After soil analysis, the soil samples collected were thoroughly mixed together and put in 144 pots (each pot contained 10 kg soil). Organo-mineral (20, 40, 60, 80 and 100 kgN/ha) and organic (20, 40, 60, 80 and 100 kgN/ha) fertilizers were thoroughly mixed with the soil in the pots 24 hours before planting. Sixty kgN/ha of N.P.K. 20:10:10 fertilizer was applied third week after planting by side placement. Twenty grams of mycorrhizal inoculum (*Glomus mosseae*) was applied per pot of those designated as inoculated. The method of application was by filling the pots three-quarter way and then evenly spread the mycorrhiza inoculum on it (Carling *et al*., 1978). The pots were then filled with the rest of the soil and watered to field capacity. Seeds of Cuba 108 and Tiannug I were sown at the rate of 4 - 6 seeds per pot. After germination, the plants were thinned to one per pot.

3.2.4 Crop growth and maintenance

The plants were watered to field capacity every other day through the saucer and left to grow in the screenhouse for three and half months (14 weeks). Growth parameters such as

plant height and stem girth were taken at the sixth week after planting and continued at two weeks interval until harvest (25 % flowering). Plant height (cm) was measured from the soil surface to the tip of the kenaf plant using metre rule. Stem girth (cm) was measured using vernier caliper

The Kenaf plants were protected against insects by spraying with Nuvacron at the sixth week after planting and continued at two weeks interval until harvest (25 % flowering). Weeding was done manually by using hand.

3.2.5 Harvesting and determination of percentage root colonization by AM fungi

Kenaf plants were harvested at 25 % flowering by uprooting the plant and later separated into root and shoot. Soil was carefully removed from the roots by immersing the root system in water with gentle agitation after which roots were retrieved.

Approximately 0.5 g fresh weight of clean roots was taken for each treatment (Kormarnick *et al*., 1980). Any dead root was discarded. Root samples were cut into 1 cm length and stored in 50 % ethanol. Before staining procedure commenced, root samples were rinsed with tap water. Mycorrhizal staining was initiated by heating the root in 10 % KOH for 40 minute at 80 °C (Phillip and Hayman, 1970). Roots were bleached in alkaline H_2O_2 for 10 minute after which they were rinsed in water and soaked in 1 % HCl for 10 minute (Schenck, 1980). The staining solution, chlorazol black E (Brundrett *et al*., 1984), used on the roots contained 0.03 % chlorazol black E, lactic acid (400 ml), glycerol (400 ml) and water (200 ml). Stained roots were destained with 50 % glycerol. The degree of mycorrhizal colonization was assessed by spreading the root sample evenly on a grid plate and observing them under the dissecting microscope at low (× 40) magnification. The total number of roots and infected roots intersecting the grids were counted (Giovanneti and Mosse, 1980). The percentage mycorrhizal colonization was calculated by the ratio between the numbers of intersects with infection and the total number of intersects multiplied by 100.

Retting of the shoot was done at IAR&T for two weeks after which, outer fibre (bast) were separated from inner fibre (core) and weighed separately on pot basis using weighing balance.

3.3 Assessment of residual effects of arbuscular mycorrhiza and fertilizers under screenhouse conditions

This was carried out to determine the residual effect of arbuscular mycorrhiza, organic, organo-mineral and inorganic fertilizers on the root colonization, growth and yield of Cuba 108 and Tiannug 1.

3.3.1 Soil preparation and planting

After harvesting kenaf in the screenhouse experiment, the soil in each pot was thoroughly mixed. Neither fertilizer nor mycorrhiza was applied and kenaf seeds were then planted. Other operations were carried out as in the screenhouse experiment.

3.4 Determination of the optimum fertilizer for Cuba 108 fibre production

The higher yielding variety in the screenhouse experiment (Cuba 108) was used on the field and the field experiment was carried out at IAR&T experimental field between the months of April to July, 2005. Representative soil samples were collected and analysed for physical and chemical properties as described earlier.

3.4.1 Experimental design

The experimental design was split-plot in randomized complete block design (RCBD). Mycorrhizal inoculation (with and without) was the main plot factor and twelve fertilizer levels: 0, NPK 20:10:10 (60 kgN/ha), organic (20, 40, 60, 80 and 100 kgN/ha) and organo-mineral (20, 40, 60, 80 and 100 kgN/ha) as the sub-plot factor. Each treatment was replicated three times.

3.4.2 Field preparation and planting

The experimental field was ploughed with a disc plough and harrowed with a disc harrow after two weeks of plough. Organic and organo-mineral fertilizers were applied by incorporating into the soil after broadcasting using hoe to a depth of 5cm and planting was carried out 24 hours after incorporation (Uhlen and Tveitnes, 1995). Inoculation was done with 20 g inoculum of *Glomus mosseae* (which consisted of soil, AM spores, hyphae and

infected root fragments of maize used to trap and multiply the fungus) by placing the crude inoculum directly under the seeds on the field. Cuba 108 was planted at 50 cm between and 20 cm within rows at the rate of 4-6 seeds per hole. After germination, the plants were thinned to one per stand. Each sub-plot measured 2 m × 0.8 m consisting of five rows and five columns making 25 plants per plot. NPK fertilizer was applied third week after planting by side placement.

3.4.3 Crop growth and maintenance

The plants were left to grow on the field for three and half months (14 weeks). Growth parameters such as plant height and stem girth were taken at sixth week after planting and continued at two weeks interval until harvest (25 % flowering). Plant height (cm) was measured from soil surface to the tip of the kenaf plant using metre rule. Stem girth (cm) was measured using calliper.

The established kenaf plants were protected against insects by spraying with Nuvacron at sixth week after planting and continued at two weeks interval until harvest (25 % flowering). Weeding was done manually by using hoe.

3.4.4 Harvesting and determination of percentage root colonization by AM fungi

Kenaf plants were harvested at 25 % flowering by uprooting the nine plants in central rows (excluding boarder rows) on every plot. The plants were then cut into shoots and roots. Soils were carefully removed from the roots by immersing the root system in water with gentle agitation after which roots were retrieved.

Percentage root colonization was determined as described in 3.2.5.

Retting of the shoot was done at IAR&T for two weeks. After which, outer (bast) fibre was separated from inner (core) fibre and weighed accordingly.

3.5 Residual effects of arbuscular mycorrhiza and fertilizers under field conditions

This was carried out to determine the residual effect of arbuscular mycorrhiza, organic, organo-mineral and inorganic fertilizers on selected soil chemical properties, bast and core yield of Cuba 108.

3.5.1 Field preparation and planting

After harvesting in the field experiment, the experimental field was cleared using hoe and cutlass to avoid mixing up of sub-plot soils (if plougher and harrower were used). Neither fertilizers nor mycorrhiza was applied. Planting and other farm operations were carried out has done on the field experiment. Growth and yield parameters were determined. Arbuscular mycorrhizal colonization and soil chemical properties were determined as described earlier.

3.6 Statistical analyses

Data were analysed using descriptive statistics and analysis of variance (ANOVA). Test of significance of the means was by the standard error. Pearson's correlation coefficient was used to determine the relationship between the soil chemical properties.

CHAPTER 4
RESULTS

4.1 Effects of fertilizers and mycorrhizal inoculation on the growth, yield and arbuscular mycorrhizal colonization of Cuba 108 and Tiannug 1 under screenhouse conditions

4.1.1 Soil characteristics and proximate analysis of fertilizers

The soil used in the screenhouse experiment was sandy loam in texture, with a pH of 6.1 (Table 4.1). Also, the soil organic matter, total nitrogen, available phosphorus and exchangeable potassium were 15.0 g/kg, 1.5 g/kg, 2.1 mg/kg and 0.19 cmol/kg respectively.

The Pacesetter's organo-mineral grade A fertilizer had higher concentrations of primary nutrient such as nitrogen, phosphorus and potassium than organic grade B fertilizer (Table 4.2).

4.1.2 Effects of fertilizer and arbuscular mycorrhizal inoculation on the growth of Cuba 108 and Tiannug 1

Arbuscular mycorrhiza inoculation and fertilizer application rates significantly affected the stem girth of Cuba 108 (Table 4.3) and Tiannug 1(Table 4.4). Inoculated Cuba 108 and Tiannug 1at 0 fertilizer level had higher stem girth than non-inoculated counterpart at 0 fertilizer level throughout the growth period. Increase in the levels of organic and organo-mineral fertilizers without arbuscular mycorrhizal inoculation resulted in the significant ($p < 0.001$) increase in stem girth from 20 to 60 kgN/ha of both organic and organo-mineral fertilizers in the Cuba 108 (Table 4.3) and Tiannug 1 (Table 4.4). Without mycorrhizal inoculation, significantly ($p < 0.001$) higher stem girth was observed at 60 kgN/ha of organo-mineral fertilizer in Cuba 108 and Tiannug 1. On the effects of arbuscular mycorrhizal inoculation and fertilizers application, stem girth of inoculated Cuba 108 was significantly ($p < 0.001$) higher than the non-inoculated counterpart at 60 kgN/ha of NPK, 40 kgN/ha of organic, 40 and 60 kgN/ha of organo-mineral fertilizer from 6 to 14WAP (Table 4.3). However, in Tiannug 1 significant differences were observed at 60 kgN/ha of NPK,

Table 4.1: Soil physical and chemical properties before planting in the screenhouse

Soil properties	Value
Sand (g/kg)	760
Silt (g/kg)	182
Clay (g/kg)	58
Textural class	Sandy loam
pH (H_2O)	6.1
Organic matter (g/kg)	15.0
Total N (g/kg)	1.5
Available P (mg/kg)	2.1
K (cmol/kg)	0.2
Ca (cmol/kg)	1.6
Na (cmol/kg)	0.6
Mg (cmol/kg)	2.1
Exch. acidity (cmol/kg)	0.1
ECEC (cmol/kg)	4.6
Base saturation (%)	97.6

Table 4.2: Proximate analysis of Pacesetter's organo-mineral grade A and organic grade B fertilizers

Parameters	Organic	Organo-Mineral
Nitrogen (g/kg)	10.50	57.50
Phosphorus (mg/kg)	0.95	4.48
Potassium ($cmolkg^{-1}$)	1.00	3.05
Cacium ($cmolkg^{-1}$)	2.12	1.25
Magnesium($cmolkg^{-1}$)	0.85	0.35

Table 4.3: Effect of mycorrhiza and fertilizers on the stem girth (cm) of Cuba 108 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	0.48	0.55	0.70	0.72	0.80
	NPK	0.90	1.02	1.21	1.30	1.32
	Or20	0.50	0.62	0.72	0.78	0.85
	Or40	0.65	0.76	0.90	1.00	1.06
	Or60	0.61	0.75	0.84	0.98	1.03
	Or80	0.55	0.70	0.78	0.90	1.00
	Or100	0.60	0.71	0.80	0.94	1.00
	OM20	0.52	0.65	0.75	0.80	0.90
	OM40	0.98	1.30	1.45	1.65	1.75
	OM60	0.94	1.18	1.36	1.40	1.43
	OM80	0.72	0.85	0.92	1.06	1.10
	OM100	0.75	0.95	1.00	1.11	1.15
Without	0	0.45	0.50	0.55	0.60	0.70
	NPK	0.76	0.96	1.10	1.12	1.25
	Or20	0.50	0.57	0.70	0.78	0.82
	Or40	0.55	0.65	0.75	0.81	0.92
	Or60	0.60	0.74	0.81	0.96	1.03
	Or80	0.55	0.66	0.78	0.82	0.97
	Or100	0.58	0.70	0.79	0.92	1.00
	OM20	0.50	0.64	0.73	0.80	0.90
	OM40	0.70	0.80	0.90	1.02	1.06
	OM60	0.80	1.00	1.12	1.15	1.30
	OM80	0.70	0.80	0.92	1.05	1.08
	OM100	0.75	0.85	0.96	1.10	1.12
SE						
Mycorrhiza (M)		0.0032	0.0023	0.0018	0.0001	0.0023
Fertilizers (F)		0.0079	0.0056	0.0045	0.0001	0.0056
Interaction						
M x F		0.0111	0.0079	0.0064	0.0001	0.0079
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*** represent level of significance at $p < 0.001$

Table 4.4: Effect of mycorrhiza and fertilizers on the stem girth (cm) of Tiannug 1 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	0.40	0.47	0.54	0.65	0.71
	NPK	0.82	0.95	1.08	1.15	1.22
	Or20	0.45	0.60	0.65	0.70	0.75
	Or40	0.62	0.75	0.80	0.90	1.00
	Or60	0.60	0.72	0.80	0.90	1.00
	Or80	0.55	0.65	0.75	0.85	0.90
	Or100	0.60	0.66	0.75	0.87	0.98
	OM20	0.50	0.62	0.68	0.75	0.78
	OM40	0.91	1.14	1.38	1.50	1.52
	OM60	0.85	0.95	1.10	1.18	1.40
	OM80	0.68	0.79	0.88	1.00	1.08
	OM100	0.74	0.88	0.95	1.06	1.10
Without	0	0.30	0.44	0.50	0.58	0.66
	NPK	0.75	0.90	1.00	1.07	1.11
	Or20	0.45	0.58	0.62	0.70	0.72
	Or40	0.54	0.64	0.70	0.78	0.82
	Or60	0.60	0.70	0.76	0.90	1.00
	Or80	0.55	0.65	0.72	0.80	0.85
	Or100	0.60	0.66	0.75	0.86	0.92
	OM20	0.50	0.61	0.65	0.70	0.75
	OM40	0.64	0.75	0.82	0.90	1.01
	OM60	0.78	0.95	1.05	1.10	1.20
	OM80	0.65	0.77	0.85	0.99	1.02
	OM100	0.71	0.84	0.92	1.05	1.08
SE						
Mycorrhiza (M)		0.0001	0.0032	0.0032	0.0025	0.0034
Fertilizers (F)		0.0001	0.0079	0.0079	0.0062	0.0082
Interaction						
M x F		0.0001	0.0112	0.0112	0.0088	0.0116
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*** represent level of significance at $p < 0.001$

40 kgN/ha of organic, 40 and 60 kgN/ha of organo-mineral fertilizer from 6 to 14WAP (Table 4.4). Significantly ($p < 0.001$) higher stem girth was observed at 40 kgN/ha of organo-mineral fertilizer in the inoculated Cuba 108 and Tiannug 1 14WAP compared to other fertilizer levels with and without mycorrhizal inoculation. At 40 kgN/ha of organo-mineral fertilizer, inoculated Cuba 108 had higher stem girth than the inoculated Tiannug 1 at the same fertilizer level.

Plant height of both Cuba 108 and Tiannug 1 were significantly influenced by arbuscular mycorrhizal inoculation and fertilizer application rates as shown in Tables 4.5 and 4.6 respectively. Mycorrhizal inoculation significantly ($p < 0.001$) increased plant height of both Cuba 108 (except 12WAP) and Tiannug 1 at 0 fertilizer level compared to their non-inoculated counterpart also at 0 fertilizer level. Among the various fertilizer levels without mycorrhizal inoculation, 60 kgN/ha of organo-mineral fertilizer had significantly ($p < 0.001$) higher plant height in Cuba 108 (Table 4.5) and Tiannug 1 (Table 4.6) compared to other levels of fertilizer without mycorrhizal inoculation. On the effects of mycorrhizal inoculation and fertilizer application rates, inoculated Cuba 108 and Tiannug 1 had significantly ($p < 0.001$) higher plant height than non-inoculated counterpart at 60 kgN/ha of NPK, 40 kgN/ha of organic fertilizer, 40 and 60 kgN/ha of organo-mineral fertilizer from 6 to 14WAP. Significantly ($p < 0.001$) higher plant heights were observed in the inoculated Cuba 108 and Tiannug 1 at 40 kgN/ha of organo-mineral fertilizer compared to other fertilizer levels with and without mycorrhizal inoculation.

4.1.3 Influence of fertilizers and arbuscular mycorrhizal inoculation on the colonization, bast and core yields of kenaf

Inoculated Cuba 108 and Tiannug 1 at 0 fertilizer application had significantly ($p < 0.001$) higher bast yield than their non-inoculated counterpart at 0 fertilizer application as shown in Tables 4.7 and 4.8 respectively. Increase in the levels of organic and organo-mineral fertilizer without mycorrhizal inoculation significantly ($p < 0.001$) increased the bast yield from 0 to 60 kgN/ha while at 80 kgN/ha or more, a decline in bast yield occurred in the Cuba 108 (Table 4.7) and Tiannug 1 (Table 4.8). On the other hand, inoculated Cuba 108 and Tiannug 1 had significantly ($p < 0.001$) higher bast yield than the non-inoculated counterpart

Table 4.5: Effect of mycorrhiza and fertilizers on the plant height (cm) of Cuba 108 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	48.30	97.50	100.10	114.17	136.10
	NPK	103.17	156.53	168.03	200.17	236.17
	Or20	69.80	100.10	108.10	125.10	156.10
	Or40	87.27	115.57	127.17	153.17	188.17
	Or60	87.27	115.10	127.17	151.10	188.17
	Or80	78.30	108.10	123.17	145.17	176.10
	Or100	82.27	109.10	126.10	150.17	180.17
	OM20	75.63	105.10	119.80	143.10	167.10
	OM40	123.07	195.17	231.17	265.17	275.17
	OM60	115.23	165.37	203.17	239.17	246.17
	OM80	93.80	121.10	132.17	159.17	194.17
	OM100	96.20	136.17	153.17	185.17	203.17
Without	0	40.80	89.30	93.10	114.10	132.10
	NPK	96.30	144.37	155.17	186.03	207.03
	Or20	63.30	98.30	107.10	121.10	139.10
	Or40	76.27	107.17	120.17	144.10	172.77
	Or60	84.70	112.17	126.17	150.17	183.17
	Or80	76.50	107.37	121.10	144.17	175.10
	Or100	79.70	108.67	125.10	149.17	180.10
	OM20	74.20	100.10	118.10	140.10	165.17
	OM40	88.77	116.57	128.17	155.10	190.10
	OM60	102.67	150.17	166.17	196.17	225.17
	OM80	88.80	117.17	130.10	159.10	190.17
	OM100	96.20	123.30	138.10	177.10	200.10
SE						
Mycorrhiza (M)		0.8394	0.3436	0.0039	0.5731	0.6534
Fertilizers (F)		2.0561	0.8417	0.0096	1.4037	1.6006
Interaction						
M x F		2.9077	1.1903	0.0136	1.9851	2.2636
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*** represent level of significance at $p < 0.001$

Table 4.6: Effect of mycorrhiza and fertilizers on the plant height (cm) of Tiannug 1 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	42.20	84.40	86.10	105.10	133.10
	NPK	101.67	149.17	165.17	185.17	222.17
	Or20	55.60	88.50	91.10	119.10	140.17
	Or40	83.37	110.17	128.10	150.10	180.17
	Or60	75.53	110.10	124.17	150.10	179.17
	Or80	72.67	100.17	117.03	125.10	155.10
	Or100	74.97	105.03	118.17	141.17	160.17
	OM20	61.30	94.20	99.10	120.10	146.10
	OM40	122.87	188.37	218.17	227.17	265.17
	OM60	111.17	151.07	177.17	195.17	244.17
	OM80	90.17	129.10	143.17	167.17	184.10
	OM100	94.40	133.37	150.17	170.17	201.17
Without	0	20.20	40.30	48.10	56.10	95.10
	NPK	94.67	140.17	151.17	178.17	204.03
	Or20	49.40	85.30	90.10	117.10	135.10
	Or40	63.60	98.30	108.10	123.10	147.10
	Or60	74.97	110.10	118.30	143.17	167.10
	Or80	70.67	99.30	112.17	125.10	153.17
	Or100	74.20	103.17	117.17	133.17	156.10
	OM20	60.60	90.10	95.50	119.17	145.10
	OM40	87.37	110.17	128.10	160.03	181.10
	OM60	99.37	142.17	155.17	180.17	220.17
	OM80	89.60	121.17	141.10	160.10	183.17
	OM100	90.67	131.17	149.17	170.17	187.17
SE						
Mycorrhiza (M)		0.4835	0.5730	0.5721	0.7617	0.7037
Fertilizers (F)		1.1844	1.4035	1.4013	1.8658	1.7237
Interaction						
M x F		1.6751	1.9848	1.9817	2.6386	2.4377
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*** represent level of significance at $p < 0.001$

Table 4.7: Influence of mycorrhiza and fertilizers on the colonization, bast and core yield (g/pot) of Cuba 108 under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	Bast	Core	Mycorrhizal colonization (%)
With	0	2.63	5.18	17.27
	NPK60	7.08	14.23	71.30
	Or20	2.92	7.09	19.60
	Or40	4.09	9.64	43.00
	Or60	3.91	9.14	34.63
	Or80	3.51	8.21	24.50
	Or100	3.65	8.44	26.87
	OM20	3.07	7.30	21.67
	OM40	9.55	19.85	79.80
	OM60	8.85	15.48	74.83
	OM80	4.62	10.37	57.63
	OM100	5.18	10.85	63.10
Without	0	1.75	3.81	14.50
	NPK60	5.52	10.39	64.63
	Or20	2.84	6.26	18.93
	Or40	3.41	7.30	23.27
	Or60	3.73	8.24	31.60
	Or80	3.49	7.49	23.30
	Or100	3.61	7.68	24.87
	OM20	2.97	6.50	20.57
	OM40	4.35	9.37	49.03
	OM60	6.24	12.77	67.43
	OM80	4.51	9.47	55.00
	OM100	4.69	9.97	58.70
	S.E.			
	Mycorrhiza (M)	0.0530	0.1646	0.5648
	Fertilizers (F)	0.1298	0.4032	1.3835
	Interaction			
	M × F	0.1836	0.5702	1.9566
	ANOVA			
	M	***	***	***
	F	***	***	***
	Interaction			
	M × F	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer, S.E. = Standard Error,

*** represent level of significance at $p < 0.001$

Table 4.8: Influence of mycorrhiza and fertilizers on the colonization, bast and core yield (g/pot) of Tiannug 1 under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	Bast	Core	Mycorrhizal colonization (%)
With	0	1.98	3.50	15.40
	NPK60	6.67	14.20	65.60
	Or20	2.27	5.24	17.30
	Or40	3.53	8.07	38.43
	Or60	3.36	7.85	29.50
	Or80	3.08	6.62	21.97
	Or100	3.36	7.30	25.37
	OM20	2.50	5.14	18.60
	OM40	8.75	17.09	73.10
	OM60	8.23	14.90	69.33
	OM80	4.26	9.57	52.63
	OM100	4.44	10.31	58.13
Without	0	1.21	2.44	14.40
	NPK60	4.76	10.00	60.30
	Or20	2.13	4.15	16.47
	Or40	2.69	5.14	19.47
	Or60	3.24	7.00	27.23
	Or80	2.99	5.80	20.97
	Or100	3.17	6.15	22.67
	OM20	2.36	4.68	18.27
	OM40	3.74	8.51	44.43
	OM60	5.83	11.70	62.70
	OM80	3.94	8.68	49.93
	OM100	4.35	9.15	55.23
	S.E.			
	Mycorrhiza (M)	0.0533	0.1281	0.5242
	Fertilizers (F)	0.1307	0.3139	1.2841
	Interaction			
	M × F	0.1848	0.4439	1.8160
	ANOVA			
	M	***	***	***
	F	***	***	***
	Interaction			
	M × F	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer, S.E. = Standard Error,

*** represent level of significance at $p < 0.001$

at 60 kgN/ha of NPK, 40 kgN/ha of organic fertilizer, 40 and 60 kgN/ha of organo-mineral fertilizer. Highest bast yield was observed at 40 kgN/ha of organo-mineral fertilizer in the inoculated Cuba 108 (Table 4.7) and Tiannug 1 (Table 4.8). At 40 kgN/ha of organo-mineral fertilizer, bast yield of inoculated Cuba 108 was higher than Tiannug 1 by 9.1 %.

Without mycorrhizal inoculation, significantly ($p < 0.001$) higher core yield was observed at 60 kgN/ha of organo-mineral fertilizer in the Cuba 108 (Table 4.7) and Tiannug 1(Table 4.8). When compared the core yield at 60 kgN/ha of organo-mineral fertilizer without mycorrhizal inoculation, core yield of Cuba 108 was 9.1 % higher than that of Tiannug 1. Core yield of inoculated Cuba 108 without fertilizer application was 48.0 % higher than the core yield of inoculated Tiannug 1 without fertilizer application. Core yield of inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer was 16.1 % higher than that of inoculated Tiannug 1 at the same fertilizer level.

Inoculated Cuba 108 without fertilizer application had higher percentage mycorrhizal colonization than the non-inoculated counterpart without fertilizer application by 19.1 % (Table 4.7). Similarly, inoculated Tiannug 1 without fertilizer application was 6.9 % higher than the non-inoculated counterpart at 0 fertilizer level (Table 4.8). Comparing the response of the two varieties to mycorrhizal inoculation without fertilizer application, percentage colonization of Cuba 108 was 12.1 % higher than Tiannug 1. On the response of the two varieties to fertilizers application without mycorrhizal inoculation, percentage colonization of Cuba 108 was higher than that of Tiannug 1 with percentage range of 7.5 – 14.9 %. Fertilizers application with mycorrhizal inoculation had significantly ($p < 0.001$) higher percentage mycorrhizal colonization than fertilizers application without mycorrhizal inoculation in the Cuba 108 and Tiannug 1at 40 kgN/ha of organic and organo-mineral fertilizer. Comparing percentage mycorrhizal colonization of the two varieties with reference to fertilizers application with and without mycorrhizal inoculation, inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer had higher percentage mycorrhizal colonization than inoculated Tiannug 1 at the same fertilizer level by 9.2 %.

4.2 Residual effects of fertilizers and arbuscular mycorrhizal inoculation on kenaf performance under screenhouse conditions

4.2.1 Residual effects of fertilizers and mycorrhizal inoculation on the growth of kenaf

Stem girth of Cuba 108 (Table 4.9) and Tiannug 1 (Table 4.10) were affected by the residual of mycorrhizal inoculation and fertilizer application rates. Stem girth of inoculated Cuba 108 without fertilizer application was 10.5 % higher than the stem girth of the non-inoculated Cuba 108 without fertilizer application 14WAP. In Tiannug 1, stem girth of inoculated without fertilizer application was higher than the stem girth of the non-inoculated without fertilizer application 14WAP. Stem girth of non-inoculated Cuba 108 and Tiannug 1 significantly ($p < 0.001$) increased as the levels of organic and organo-mineral fertilizers increased from 20 to 100 kgN/ha from 6 to 14WAP. On the residual effect of fertilizer application levels and mycorrhizal inoculation, significantly ($p < 0.001$) higher stem girth were observed between inoculated and non-inoculated Cuba 108 with fertilizers application at 40, 60 and 100 kgN/ha of organic fertilizer, and 60 kgN/ha of organo-mineral fertilizer 14WAP (Table 4.9). Significant ($p < 0.001$) difference were observed between inoculated and non-inoculated Tiannug 1 at 40 and 100 kgN/ha of organic fertilizer; and 40 kgN/ha of organo-mineral fertilizer 14WAP (Table 4.10). Significantly ($p < 0.001$) higher stem girths were observed in the inoculated Cuba 108 and Tiannug 1 at 100 kgN/ha of organic fertilizer 14WAP. Stem girth of inoculated Cuba 108 at 100 kgN/ha of organic fertilizer was higher than inoculated Tiannug 1 at the same fertilizer level by 7.4 %.

Residual effect of mycorrhizal inoculation and fertilizer application levels affected the plant height of Cuba 108 (Table 4.11) and Tiannug 1 (Table 4.12). Inoculated Cuba 108 without fertilizer application had higher plant height than the non-inoculated counterpart without fertilizer application by 15.8 %. However, plant height of inoculated Tiannug 1 without fertilizer application was 12.7 % higher than the plant height of non-inoculated Tiannug 1 without fertilizer application. The higher the levels of organic and organo-mineral fertilizers applied without mycorrhizal inoculation, the higher were the residual effect on the plant height of Cuba 108 and Tiannug 1 with 100 kgN/ha of organic fertilizer having significantly ($p < 0.001$) higher plant height in Cuba 108 (Table 4.11) and Tiannug 1 (Table 4.12) 14WAP.

Table 4.9: Residual effects of mycorrhiza and fertilizers on the stem girth (cm) of Cuba 108 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	0.40	0.50	0.54	0.60	0.63
	NPK	0.41	0.55	0.60	0.65	0.68
	Or20	0.42	0.61	0.65	0.74	0.77
	Or40	0.50	0.65	0.72	0.80	0.83
	Or60	0.50	0.71	0.75	0.90	0.95
	Or80	0.58	0.80	0.87	0.98	1.03
	Or100	0.70	0.90	1.00	1.10	1.16
	OM20	0.42	0.60	0.62	0.71	0.74
	OM40	0.45	0.64	0.70	0.76	0.80
	OM60	0.50	0.70	0.74	0.88	0.93
	OM80	0.52	0.80	0.85	0.95	1.01
	OM100	0.65	0.88	0.90	1.00	1.06
Without	0	0.30	0.50	0.53	0.55	0.57
	NPK	0.40	0.52	0.55	0.63	0.66
	Or20	0.42	0.60	0.65	0.71	0.74
	Or40	0.45	0.64	0.70	0.75	0.79
	Or60	0.50	0.70	0.74	0.84	0.89
	Or80	0.52	0.71	0.80	0.95	1.00
	Or100	0.62	0.88	0.90	1.00	1.05
	OM20	0.42	0.60	0.62	0.69	0.71
	OM40	0.43	0.62	0.67	0.75	0.78
	OM60	0.50	0.70	0.72	0.82	0.86
	OM80	0.51	0.71	0.75	0.94	0.99
	OM100	0.60	0.85	0.90	0.98	1.04
SE						
Mycorrhiza (M)		0.0019	0.0023	0.0027	0.0022	0.0044
Fertilizers (F)		0.0047	0.0056	0.0067	0.0055	0.0108
Interaction						
M x F		0.0067	0.0079	0.0095	0.0077	0.0152
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*** represent level of significance at $p < 0.001$

Table 4.10: Residual effects of mycorrhiza and fertilizers on the stem girth (cm) of Tiannug 1 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	0.35	0.50	0.62	0.67	0.69
	NPK	0.40	0.62	0.65	0.72	0.75
	Or20	0.44	0.65	0.70	0.78	0.81
	Or40	0.45	0.68	0.71	0.85	0.90
	Or60	0.50	0.73	0.77	0.88	0.91
	Or80	0.60	0.76	0.80	0.90	0.96
	Or100	0.62	0.90	1.00	1.02	1.08
	OM20	0.44	0.62	0.65	0.77	0.80
	OM40	0.45	0.66	0.71	0.82	0.87
	OM60	0.50	0.72	0.75	0.86	0.91
	OM80	0.60	0.75	0.80	0.90	0.96
	OM100	0.60	0.85	0.90	0.92	0.97
Without	0	0.31	0.50	0.60	0.66	0.68
	NPK	0.38	0.60	0.64	0.71	0.74
	Or20	0.44	0.63	0.70	0.78	0.80
	Or40	0.45	0.66	0.70	0.80	0.84
	Or60	0.46	0.70	0.75	0.86	0.91
	Or80	0.54	0.75	0.77	0.90	0.95
	Or100	0.60	0.79	0.80	0.92	0.96
	OM20	0.40	0.62	0.65	0.74	0.77
	OM40	0.45	0.65	0.70	0.79	0.83
	OM60	0.46	0.70	0.75	0.85	0.90
	OM80	0.52	0.74	0.77	0.90	0.93
	OM100	0.60	0.76	0.80	0.91	0.96
SE						
Mycorrhiza (M)		0.0019	0.0014	0.0025	0.0028	0.0044
Fertilizers (F)		0.0047	0.0033	0.0062	0.0069	0.0108
Interaction						
M x F		0.0067	0.0047	0.0088	0.0097	0.0153
ANOVA						
M		***	**	ns	ns	ns
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
** and *** represent level of significance at $p < 0.01$ and 0.001 respectively
ns = not significant

Table 4.11: Residual effects of mycorrhiza and fertilizers on the plant height (cm) of Cuba 108 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	40.10	77.17	91.10	101.10	112.37
	NPK	42.17	86.10	98.17	110.17	119.00
	Or20	48.17	96.17	114.10	122.10	132.37
	Or40	58.17	103.10	124.10	142.10	153.37
	Or60	60.17	106.10	130.10	152.17	166.03
	Or80	67.10	112.17	135.17	170.17	182.10
	Or100	76.17	125.17	142.17	200.17	216.43
	OM20	44.17	94.17	110.17	120.10	129.77
	OM40	55.17	100.10	116.10	132.17	143.37
	OM60	60.10	105.10	128.17	152.10	161.77
	OM80	67.10	110.17	135.10	168.17	181.43
	OM100	74.10	120.17	142.17	185.17	201.43
Without	0	36.10	65.10	80.10	92.17	97.03
	NPK	41.10	82.17	92.17	110.17	116.43
	Or20	45.17	95.10	112.10	120.17	129.77
	Or40	51.10	100.10	115.10	132.10	142.43
	Or60	59.10	104.10	128.17	150.17	161.43
	Or80	62.17	107.17	135.10	160.17	174.37
	Or100	70.10	115.17	140.17	184.17	198.10
	OM20	42.17	90.10	100.17	120.10	129.70
	OM40	50.10	98.10	115.10	132.10	142.37
	OM60	58.17	103.17	125.17	145.10	157.03
	OM80	62.10	106.17	132.17	158.10	170.43
	OM100	68.17	113.10	138.10	178.10	194.37
SE						
Mycorrhiza (M)		0.6504	0.7030	0.6494	0.5721	1.3694
Fertilizers (F)		1.5931	1.7219	1.5908	1.4013	3.3544
Interaction						
M x F		2.2530	2.4352	2.2497	1.9817	4.7438
ANOVA						
M		ns	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		**	***	***	***	*

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*, ** and *** represent level of significance at $p < 0.05$, 0.01 and 0.001 respectively
ns = not significant

Table 4.12: Residual effects of mycorrhiza and fertilizers on the plant height (cm) of Tiannug 1 at different weeks after planting (WAP) under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	37.17	56.10	65.10	70.10	89.00
	NPK	47.17	78.17	92.10	98.10	108.37
	Or20	54.10	95.10	111.10	117.10	126.70
	Or40	58.10	102.17	117.17	130.10	142.43
	Or60	62.10	111.10	126.10	142.17	158.37
	Or80	68.10	114.17	137.17	166.17	177.43
	Or100	80.10	137.10	160.17	193.17	209.43
	OM20	50.10	88.10	98.17	107.17	113.43
	OM40	57.17	100.17	117.10	130.10	141.37
	OM60	60.10	108.10	120.17	142.10	151.77
	OM80	63.17	113.50	136.17	162.17	176.10
	OM100	77.10	130.17	153.17	180.17	196.43
Without	0	30.17	54.10	60.10	65.10	79.00
	NPK	45.10	75.17	82.10	95.10	104.70
	Or20	52.17	90.10	100.10	112.10	123.37
	Or40	54.17	100.17	115.17	120.17	130.37
	Or60	60.10	103.10	120.10	134.10	148.03
	Or80	63.10	113.10	130.17	158.17	168.43
	Or100	74.17	122.17	138.10	178.17	192.10
	OM20	48.10	80.10	95.17	102.17	111.00
	OM40	54.17	97.10	113.10	120.10	129.77
	OM60	58.17	102.17	117.17	132.17	144.03
	OM80	62.17	112.17	130.10	148.17	159.43
	OM100	73.17	120.17	137.17	172.10	188.37
SE						
Mycorrhiza (M)		0.8222	0.6876	0.8413	0.7538	1.1729
Fertilizers (F)		2.0139	1.6843	2.0607	1.8464	2.8731
Interaction						
M x F		2.8481	2.3820	2.9143	2.6113	4.0631
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		*	***	***	**	ns

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*, ** and *** represent level of significance at $p < 0.05$, 0.01 and 0.001 respectively
ns = not significant

On the response of the two varieties to the residual effect of fertilizers application without mycorrhizal inoculation, non-inoculated Cuba 108 had higher plant height than non-inoculated Tiannug 1 with a percentage ranging from 3.1 – 11.2 % 14WAP. Inoculated Cuba 108 with fertilizers application had higher plant height than non-inoculated counterpart with a percentage range of 2.2 to 9.3 %. The percentage range of 3.5 to 9.0 % was observed between inoculated and non-inoculated Tiannug 1 with fertilizers application 14WAP. Plant height of inoculated Cuba 108 with fertilizers application was higher than inoculated Tiannug 1 with fertilizers application with a percentage range of 3.3 to 9.8 % 14WAP.

4.2.2 Residual effects of fertilizers and mycorrhizal inoculation on the yield and mycorrhizal colonization of kenaf under screenhouse conditions

Bast and core yields of Cuba 108 were significantly ($p < 0.05$) affected by the residual effects of mycorrhizal inoculation and fertilizer application rates (Table 4.13). Also, core yield and mycorrhizal colonization of Tiannug 1 were significantly ($p < 0.05$) affected by the residual effects of fertilizer application rates and mycorrhizal inoculation (Table 4.14). Bast yield of inoculated Cuba 108 at 0 fertilizer application was higher than the non-inoculated counterpart at the same fertilizer level by 14.5 %. Inoculated Tiannug 1 at 0 fertilizer level was higher than the non-inoculated counterpart at the same fertilizer level by 10.6 %. Bast yield of inoculated Cuba 108 without fertilizer application was higher than that of inoculated Tiannug 1 under the same fertilizer treatment by 8.2 %. Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation in Cuba 108 and Tiannug 1 resulted in the significant ($p < 0.001$) increase in bast yield at 100 kgN/ha of organic and organo-mineral fertilizers. Bast yield of Cuba 108 was higher than that of Tiannug 1 by 7.0 – 12.9 % when fertilizers were applied without mycorrhizal inoculation. Inoculated Cuba 108 and Tiannug 1 had significantly ($p < 0.001$) higher bast yield than the non-inoculated counterpart at 80 and 100 kgN/ha of organic fertilizer, and also at 100 kgN/ha of organo-mineral fertilizer (Tables 4.13 and 4.14). On the residual effect of organic and organo-mineral fertilizers with mycorrhiza inoculation, significant ($p < 0.001$) increase in bast yield were observed at 60, 80 and 100 kgN/ha of both organic and organo-mineral fertilizer in Cuba 108. While significant ($p < 0.001$) increase were observed at 80 and 100 kgN/ha of both organic and organo-mineral fertilizer in Tiannug 1.

4.13: Residual effects of mycorrhiza and fertilizers on the colonization, bast and core yield (g/pot) of Cuba 108 under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	Bast	Core	Mycorrhizal colonization (%)
With	0	1.58	3.57	14.93
	NPK60	2.01	4.03	16.80
	Or20	2.33	4.49	20.57
	Or40	2.51	5.42	23.37
	Or60	3.10	6.50	33.77
	Or80	3.92	7.85	46.53
	Or100	6.15	11.08	58.50
	OM20	2.21	4.47	19.13
	OM40	2.45	5.18	22.17
	OM60	2.96	6.32	30.73
	OM80	3.50	7.31	43.33
	OM100	4.98	10.22	54.90
Without	0	1.38	3.06	14.10
	NPK60	1.93	3.89	15.83
	Or20	2.27	4.41	19.80
	Or40	2.35	4.98	22.23
	Or60	2.73	5.72	27.80
	Or80	3.27	6.91	40.07
	Or100	4.56	9.38	52.40
	OM20	2.07	4.32	16.93
	OM40	2.37	4.65	21.73
	OM60	2.43	5.57	24.83
	OM80	3.15	6.69	40.63
	OM100	4.27	8.49	49.10
	S.E.			
	Mycorrhiza (M)	0.0468	0.0705	0.4955
	Fertilizers (F)	0.1145	0.1727	1.2138
	Interaction			
	M × F	0.1620	0.2442	1.7165
	ANOVA			
	M	***	***	***
	F	***	***	***
	Interaction			
	M × F	**	*	ns

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of

organo-mineral fertilizer, S.E. = Standard Error,

*, ** and *** represent level of significance at p < 0.05, 0.01 and 0.001 respectively
ns = not significant

Table 4.14: Residual effect of mycorrhiza and fertilizers on the colonization, bast and core yield (g/pot) of Tiannug 1 under the screenhouse conditions

Mycorrhiza inoculation	Fertilizers application	Bast	Core	Mycorrhizal colonization (%)
With	0	1.46	3.31	12.33
	NPK60	1.84	3.95	13.50
	Or20	2.14	4.33	16.10
	Or40	2.38	5.19	20.53
	Or60	2.67	6.27	30.27
	Or80	3.32	6.69	42.53
	Or100	5.27	10.55	56.10
	OM20	2.05	4.07	14.47
	OM40	2.33	4.77	18.70
	OM60	2.56	5.80	27.17
	OM80	2.97	6.61	39.10
	OM100	4.68	8.19	51.57
Without	0	1.32	2.71	11.50
	NPK60	1.71	3.79	12.97
	Or20	1.96	3.95	15.30
	Or40	2.14	4.70	17.63
	Or60	2.40	5.60	23.90
	Or80	2.75	6.52	34.27
	Or100	4.26	7.00	47.97
	OM20	1.85	4.02	13.53
	OM40	2.10	4.49	17.10
	OM60	2.33	5.42	22.47
	OM80	2.67	6.44	33.27
	OM100	3.77	6.76	45.10
	S.E.			
	Mycorrhiza (M)	0.0460	0.0652	0.3965
	Fertilizers (F)	0.1127	0.1597	0.9713
	Interaction			
	M × F	0.1593	0.2259	1.3736
	ANOVA			
	M	***	***	***
	F	***	***	***
	Interaction			
	M × F	ns	***	*

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of

organo-mineral fertilizer, S.E. = Standard Error,

* and *** represent level of significance at $p < 0.05$ and 0.001 respectively
ns = not significant

On the response of the two varieties to the residual effect of fertilizers application and mycorrhizal inoculation, inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had higher bast yield of 16.7 % compared to inoculated Tiannug 1 at the same fertilizer level.

Core yield of inoculated Cuba 108 without fertilizer application was 16.7 % higher than non-inoculated counterpart at the same fertilizer rate (Table 4.13). Inoculated Tiannug 1 at 0 fertilizer level was 22.1 % higher than the non-inoculated counterpart (Table 4.14). Core yield of inoculated Cuba 108 without fertilizer application was 7.9 % higher than the core yield of inoculated Tiannug 1 without fertilizer application. Significant ($p < 0.001$) increase in core yield was observed as the levels of organic and organo-mineral fertilizers increased without mycorrhizal inoculation up to 100 kgN/ha of organic and organo-mineral fertilizer in Cuba 108. Significant ($p < 0.001$) increase was observed up to 80 kgN/ha of organic and organo-mineral fertilizer in Tiannug 1. At 100 kgN/ha of organic fertilizer, core yield of non-inoculated Cuba 108 was 34.0 % higher than the core yield of non-inoculated Tiannug 1 when compared. Inoculated Cuba 108 with fertilizers application had significantly ($p < 0.001$) higher core yield than non-inoculated counterpart at 100 kgN/ha of organic and organo-mineral fertilizers. Similar observation was made between inoculated Tiannug 1 with fertilizers application and non-inoculated counterpart at 100 kgN/ha of organic and organo-mineral fertilizers. At 100 kgN/ha of organic fertilizer, core yield of inoculated Cuba 108 was 5.0 % higher that that of inoculated Tiannug 1 at the same fertilizer level.

Mycorrhizal colonization of inoculated Cuba 108 without fertilizer application was 5.9 % higher than the non-inoculated counterpart without fertilizer application (Table 4.13). In Tiannug 1, without fertilizer application, inoculated was 7.2 % higher than the non-inoculated (Table 4.14). Mycorrhizal colonization of inoculated Cuba 108 without fertilizer application was higher than that of inoculated Tiannug 1 under the same fertilizer application by 21.1 %. When compared the response of Cuba 108 and Tiannug 1 to fertilizers application without mycorrhizal inoculation, non-inoculated Cuba 108 had higher mycorrhizal colonization than the non-inoculated Tiannug 1 with percentage range of 9.2 – 22.1 %. Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation resulted in the significant ($p < 0.001$) increased in the mycorrhizal colonization from 60 to 100 kgN/ha of organic; and 80 to 100 kgN/ha of organo-mineral in both Cuba 108 and Tiannug 1. Non-inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had higher mycorrhizal colonization

compared to non-inoculated Tiannug 1 at 100 kgN/ha of organic fertilizer by 9.2 %. Inoculated Cuba 108 and Tiannug1 at 60, 80 and 100 kgN/ha of organic and organo-mineral fertilizer had significantly ($p < 0.001$) higher mycorrhizal colonization than their non-inoculated counterpart at the same fertilizer level. Mycorrhizal colonization of inoculated Cuba 108 at 100 kgN/ha of organic fertilizer was higher than that of inoculated Tiannug 1 at the same fertilizer level by 4.3 %.

4.3 Determination of optimum fertilizer for fibre production in Cuba 108 under field conditions

The higher yielding variety under the screenhouse, Cuba 108, was planted on the field to determine the optimum fertilizer for fibre production.

4.3.1 Soil characteristics before planting under field conditions

The soil under field conditions was sandy loam in texture, with a pH of 6.2 and low in nutrients like N, P and K (Table 4.15).

4.3.2 Influence of AM inoculation and fertilizers on the growth of Cuba 108

Mycorrhizal inoculation and fertilizer application rates significantly affected both the stem girth (Table 4.16) and plant height (Table 4.17) of Cuba 108. Inoculated Cuba 108 at 0 fertilizer level had higher stem girth than the non-inoculated counterpart at 0 fertilizer level from 8 to 14WAP by percentage range of 5.2 – 7.5 % (Table 4.16). Increase in the levels of organic and organo-mineral fertilizers application without mycorrhizal inoculation significantly ($p < 0.001$) increased stem girth of Cuba 108 from 20 to 60 kgN/ha of both organic and organo-mineral fertilizer from 6 to 14WAP. Among the 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, organo-mineral had significantly ($p < 0.001$) higher stem girth than the organic (from 6 to 14WAP) and NPK (from 10 to 14WAP) fertilizer. On the effect of mycorrhizal inoculation and fertilizers application on stem girth, significant ($p < 0.001$) differences were observed between inoculated Cuba 108 with fertilizers application and non-inoculated Cuba 108 with fertilizers application at 60 kgN/ha

Table 4.15: Soil physical and chemical properties before planting on the field

Soil properties	Value
Sand (g/kg)	780
Silt (g/kg)	170
Clay (g/kg)	50
Textural class	Sandy loam
pH (H_2O)	6.2
Organic matter (g/kg)	13.1
Total N (g/kg)	1.2
Available P (mg/kg)	2.71
K (cmol/kg)	0.18
Ca (cmol/kg)	1.61
Na (cmol/kg)	0.52
Mg (cmol/kg)	2.01
Exch. acidity (cmol/kg)	0.1
ECEC (cmol/kg)	4.42
Base saturation (%)	97.32

Table 4.16: Influence of mycorrhiza inoculation and fertilizers on the stem girth (cm) of Cuba 108 at different weeks after planting (WAP) under field conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	0.43	0.65	0.76	1.00	1.02
	NPK	0.91	1.08	1.51	1.90	1.97
	Or20	0.63	0.71	0.92	1.20	1.23
	Or40	0.80	0.89	1.25	1.50	1.65
	Or60	0.75	0.88	1.20	1.50	1.57
	Or80	0.73	0.82	1.10	1.43	1.48
	Or100	0.75	0.83	1.12	1.45	1.49
	OM20	0.65	0.79	1.06	1.32	1.36
	OM40	1.10	1.22	1.80	2.20	2.27
	OM60	0.98	1.10	1.54	2.01	2.02
	OM80	0.83	0.95	1.31	1.70	1.75
	OM100	0.85	0.99	1.35	1.78	1.83
Without	0	0.40	0.44	0.50	0.94	0.97
	NPK	0.87	1.05	1.41	1.81	1.82
	Or20	0.55	0.65	0.83	1.00	1.03
	Or40	0.70	0.79	1.07	1.42	1.45
	Or60	0.75	0.85	1.18	1.45	1.56
	Or80	0.72	0.82	1.08	1.42	1.47
	Or100	0.73	0.83	1.10	1.43	1.49
	OM20	0.65	0.72	0.93	1.20	1.26
	OM40	0.81	0.90	1.30	1.65	1.68
	OM60	0.89	1.07	1.51	1.86	1.97
	OM80	0.81	0.95	1.31	1.70	1.73
	OM100	0.83	0.98	1.35	1.73	1.76
SE						
Mycorrhiza (M)		0.0028	0.0034	0.0032	0.0031	0.0101
Fertilizers (F)		0.0069	0.0084	0.0077	0.0076	0.0248
Interaction						
M x F		0.0097	0.0119	0.0109	0.0108	0.0351
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer
Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer.
OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer
S.E. = Standard Error
*** represent level of significance at $p < 0.001$

Table 4.17: Influence of mycorrhiza inoculation and fertilizers on the plant height (cm) of Cuba 108 at different weeks after planting (WAP) under field conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	42.47	79.57	89.60	150.10	162.70
	NPK	78.27	125.17	170.17	217.27	233.20
	Or20	44.37	86.90	109.37	158.50	168.10
	Or40	60.17	110.60	150.57	200.27	215.87
	Or60	59.80	110.30	150.10	196.30	210.90
	Or80	52.87	102.60	141.60	173.10	191.97
	Or100	55.97	104.30	147.27	188.50	204.43
	OM20	45.50	95.90	121.70	164.97	181.87
	OM40	83.67	137.27	200.37	240.77	269.77
	OM60	80.27	133.77	180.27	219.57	237.83
	OM80	68.27	118.67	160.00	207.67	219.40
	OM100	75.27	121.87	160.40	210.40	225.93
Without	0	23.60	38.00	68.80	131.90	138.17
	NPK	75.67	122.87	161.30	210.47	226.77
	Or20	43.17	80.80	101.00	157.67	165.93
	Or40	48.30	100.27	134.60	171.07	182.67
	Or60	58.07	108.60	150.00	190.50	206.63
	Or80	51.77	101.90	140.20	171.60	183.37
	Or100	53.30	103.87	141.97	180.70	199.77
	OM20	45.00	89.67	120.77	162.37	176.57
	OM40	62.07	114.37	151.00	200.30	205.90
	OM60	75.67	122.87	164.87	212.67	229.94
	OM80	66.97	118.00	153.30	205.67	218.93
	OM100	70.17	120.47	160.17	210.17	223.60
SE						
Mycorrhiza (M)		0.4831	0.6332	0.5734	2.0200	1.6201
Fertilizers (F)		1.1834	1.5510	1.4045	4.9479	3.9685
Interaction						
M x F		1.6736	2.1935	1.9863	6.9974	5.6123
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	*	**

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer

S.E. = Standard Error

*, ** and *** represent level of significance at $p < 0.05$, 0.01 and 0.001 respectively

of NPK, 20 and 40 kgN/ha of organic and 40 kgN/ha of organo-mineral fertilizer from 6 to 14WAP. Increase in the levels of organic and organo-mineral fertilizers with mycorrhizal inoculation significantly ($p < 0.001$) increased stem girth of Cuba 108 from 20 to 40 kgN/ha of both fertilizers. Significantly ($p < 0.001$) higher stem girth was observed in the inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer compared to other fertilizer levels with and without mycorrhizal inoculation.

Mycorrhizal inoculation without fertilizer application significantly ($p < 0.001$) increased plant height of Cuba 108 compared to non-inoculated Cuba 108 at 0 fertilizer application throughout the growth period (Table 4.17). At 14WAP, increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased plant height of Cuba 108 from 20 to 60 kgN/ha of both fertilizers. Among 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, organo-mineral fertilizer had significantly ($p < 0.001$) higher plant height than organic fertilizer. Inoculated Cuba 108 with fertilizers application was higher than non-inoculated Cuba 108 with fertilizers application at 14WAP with percentage increase ranging from 1.3 to 31.0 %. At 14WAP, increase in the levels of organic and organo-mineral fertilizers with mycorrhizal inoculation significantly ($p < 0.01$) increased plant height of Cuba 108 from 20 to 40 kgN/ha. Significantly ($p < 0.01$) higher plant height was observed in the inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer compared to other fertilizer levels with and without mycorrhizal inoculation.

4.3.3 Effects of AM inoculation and fertilizers on the yield and mycorrhizal colonization of Cuba 108 under field conditions

Bast, core and mycorrhizal colonization of Cuba 108 were affected significantly ($p < 0.001$) by mycorrhizal inoculation and fertilizer application rates (Table 4.18). Bast yield of inoculated Cuba 108 without fertilizer application was 38.3 % higher than the bast yield of the non-inoculated counterpart without fertilizer application. Increase in the level of organo-mineral fertilizer significantly ($p < 0.001$) increased the bast yield of non-inoculated Cuba 108 at 60 kgN/ha (Table 4.18). Bast yield of the non- inoculated Cuba 108 at 60 kgN/ha of organo-mineral was 12.7 % higher than the bast yield of non-inoculated Cuba 108 at

Table 4.18: Influence of mycorrhiza inoculation and fertilizers on the colonization, bast and core yield (t/ha) of Cuba 108 under field conditions

Mycorrhiza inoculation	Fertilizers application	Bast	Core	Mycorrhizal colonization (%)
With	0	0.83	1.80	19.63
	NPK60	2.43	6.80	75.93
	Or20	1.33	2.77	23.93
	Or40	1.73	5.10	47.73
	Or60	1.67	4.90	39.47
	Or80	1.53	4.27	32.27
	Or100	1.63	4.63	31.80
	OM20	1.43	3.50	25.87
	OM40	3.78	9.37	85.93
	OM60	3.07	8.05	79.13
	OM80	1.83	5.80	62.60
	OM100	1.93	6.20	67.50
Without	0	0.60	1.63	16.87
	NPK60	2.13	6.37	65.20
	Or20	1.20	2.63	22.63
	Or40	1.33	3.60	26.93
	Or60	1.47	4.67	37.00
	Or80	1.37	3.83	28.50
	Or100	1.40	4.50	29.30
	OM20	1.27	3.40	25.03
	OM40	1.57	5.47	57.13
	OM60	2.40	6.97	72.60
	OM80	1.70	5.60	60.13
	OM100	1.80	5.70	64.03
	S.E.			
	Mycorrhiza (M)	0.05	0.09	0.50
	Fertilizers (F)	0.12	0.23	1.23
	Interaction			
	M × F	0.16	0.33	1.74
	ANOVA			
	M	***	***	***
	F	***	***	***
	Interaction			
	M × F	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer, S.E. = Standard Error,

*** represent level of significance at $p < 0.001$

60 KgN/ha of NPK fertilizer. Inoculated Cuba 108 at 40 and 60 kgN/ha of organo-mineral fertilizer had significantly ($p < 0.001$) higher bast yield than their corresponding non-inoculated Cuba 108. At all levels of fertilizers application with and without mycorrhizal inoculation, significantly ($p < 0.001$) higher bast yield was observed in the inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer.

Core yield of inoculated Cuba 108 without fertilizer application was higher than that of non-inoculated counterpart without fertilizer application by 10.4 % (Table 4.18). Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased core yield from 20 to 60 kgN/ha. After 60 kgN/ha of the two fertilizers, core yield started decreasing by 21.9 and 21.3 % in organic and organo-mineral fertilizer respectively. When compared core yield with reference to fertilizers application without mycorrhizal inoculation, 60 kgN/ha of NPK and organo-mineral fertilizers had significantly ($p < 0.001$) higher core yield than organic fertilizer. Core yield of the 60 kgN/ha of organo-mineral fertilizer was higher than that of NPK by 9.4 %. Inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer had significantly ($p < 0.001$) higher core yield than the non-inoculated counterpart at the same fertilizer level. Increase in the levels of organic and organo-mineral fertilizers with mycorrhizal inoculation significantly ($p < 0.001$) increased the core yield from 20 to 40 kgN/ha. Thereafter, core yield decreased by 19.4 and 61.6 % in organic and organo-mineral fertilizer respectively. Inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer had significantly ($p < 0.001$) higher core yield compared to other fertilizer levels with and without mycorrhizal inoculation.

Mycorrhizal colonization of inoculated Cuba 108 at 0 fertilizer level was higher than the non-inoculated counterpart at the same fertilizer level by 16.4 % (Table 4.18). Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased mycorrhizal colonization from 20 to 60 kgN/ha. Declining in percentage mycorrhizal colonization started at 80 kgN/ha of the two fertilizers. Significantly ($p < 0.001$) higher mycorrhizal colonization was observed at 60 kgN/ha of organo-mineral compared to other fertilizer levels without mycorrhizal inoculation. Inoculated Cuba 108 at 60 kgN/ha of NPK, 40 kgN/ha of both organic and organo-mineral fertilizer had significantly ($p < 0.001$) higher mycorrhizal colonization than their corresponding non-inoculated Cuba 108. Increase in the levels of organic and organo-mineral

fertilizers with mycorrhizal inoculation significantly ($p < 0.001$) increased mycorrhizal colonization from 20 to 40 kgN/ha of both organic and organo-mineral fertilizers. Inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer had significantly ($p < 0.001$) higher mycorrhizal colonization compared to other fertilizer levels with and without mycorrhizal inoculation.

4.3.4 Soil chemical properties after harvesting Cuba 108

Soil chemical properties were significantly affected by mycorrhizal inoculation and fertilizer application rates except pH, nitrogen (N) and sodium (Na) (Table 4.19). Soil of the inoculated Cuba 108 without fertilizer application had significantly ($p < 0.001$) lower organic matter, phosphorus (P), potassium (K) and calcium (Ca) than the soil of non-inoculated Cuba 108 without fertilizer application. Fertilizers application without mycorrhizal inoculation significantly ($p < 0.001$) increased soil pH (except 60 kgN/ha of NPK), organic matter, N (except 60 kgN/ha of NPK), P, K, Ca and magnesium (Mg) (except 60 kgN/ha of NPK, 20 and 40 kgN/ha of both organic and organo-mineral fertilizers) compared to the 0 fertilizer level without mycorrhizal inoculation (Table 4.19). Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased soil organic matter, P, N (except 40 kgN/ha of organic fertilizer, 60 and 100 kgN/ha of organo-mineral fertilizer), K, Ca and Mg. Among the 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, organic fertilizer had significantly ($p < 0.001$) higher soil organic matter, N, P, K and Ca followed by the organo-mineral and NPK fertilizers. Soil of the inoculated Cuba 108 with fertilizers application had significantly lower soil organic matter ($p < 0.05$), P ($p < 0.001$), K ($p < 0.001$) (except 40, 80 and 100 kgN/ha of organo-mineral fertilizer) and Ca ($p < 0.001$) compared to the soil of the non-inoculated Cuba 108 with fertilizers application. Increase in the levels of organic and organo-mineral fertilizers with mycorrhizal inoculation significantly increased soil organic matter ($p < 0.05$), P ($p < 0.001$), K ($p < 0.001$) and Ca ($p < 0.001$) from 20 to 100 kgN/ha. Considering the fertilizers application with and without mycorrhizal inoculation, soil of the non-inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had significantly higher soil organic matter ($p < 0.05$), P ($p < 0.001$) and Ca ($p < 0.001$).

Table 4.19: Selected soil chemical properties after harvesting Cuba 108

Mycorrhiza inoculation	Fertilizers application	pH	Organic matter (g/kg)	N (g/kg)	P (mg/kg)	K	Ca (cmol/kg)	Mg	Na
With	Control	5.90	10.40	0.40	2.93	0.14	2.92	0.26	0.02
	NPK	5.73	11.40	0.40	3.40	0.16	4.07	0.29	0.02
	Or20	6.23	15.90	0.50	4.13	0.20	5.52	0.27	0.03
	Or40	6.33	17.80	0.50	4.31	0.23	6.12	0.29	0.02
	Or60	6.37	18.70	0.50	5.55	0.30	6.47	0.34	0.02
	Or80	6.43	24.00	0.70	6.02	0.35	7.72	0.37	0.02
	Or100	6.40	24.90	0.70	6.35	0.39	9.42	0.39	0.03
	OM20	6.20	15.10	0.40	4.11	0.18	5.47	0.25	0.03
	OM40	6.30	16.30	0.40	4.31	0.24	5.67	0.27	0.02
	OM60	6.40	17.30	0.40	4.61	0.28	6.32	0.30	0.02
	OM80	6.43	21.20	0.60	4.69	0.32	6.37	0.33	0.02
	OM100	6.37	21.80	0.60	5.03	0.37	6.42	0.34	0.02
Without	Control	6.00	11.40	0.40	3.10	0.16	5.07	0.26	0.03
	NPK	5.90	12.40	0.40	3.81	0.19	5.92	0.27	0.03
	Or20	6.33	16.90	0.50	4.37	0.26	6.04	0.26	0.03
	Or40	6.33	18.70	0.50	5.23	0.32	7.07	0.26	0.03
	Or60	6.47	19.70	0.60	6.30	0.38	8.17	0.31	0.03
	Or80	6.50	24.60	0.70	6.35	0.40	8.27	0.34	0.03
	Or100	6.50	25.90	0.80	6.75	0.41	9.62	0.37	0.03
	OM20	6.33	15.90	0.40	4.20	0.21	5.97	0.25	0.03
	OM40	6.40	17.40	0.50	4.94	0.26	6.97	0.25	0.03
	OM60	6.40	18.30	0.50	5.34	0.31	7.12	0.29	0.03
	OM80	6.43	22.30	0.70	5.46	0.34	7.47	0.30	0.03
	OM100	6.43	22.90	0.70	6.19	0.39	8.17	0.34	0.03
	SE								
	Mycorrhiza (M)	0.022	0.002	0.002	0.001	0.002	0.001	0.003	0.002
	Fertilizers (F)	0.054	0.005	0.004	0.003	0.005	0.002	0.007	0.005
	Interaction M x F	0.076	0.006	0.006	0.005	0.008	0.003	0.01	0.006
	ANOVA								
	M	ns	***	ns	***	***	***	ns	ns
	F	***	***	***	***	***	***	***	ns
	Interaction M x F	ns	*	ns	***	***	***	*	ns

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer, S.E. = Standard Error, ns = not significant,

* and *** represent level of significance at $p < 0.05$ and 0.001

4.3.5 Correlation coefficient between soil chemical properties

Positive correlations ($p < 0.05$) were observed between soil organic matter and other soil chemical properties investigated except sodium (where there is no significant correlation) as shown in Table 4.20. However, positive correlation ($p < 0.05$) was found between calcium and sodium.

4.4 Residual effects of AM inoculation and fertilizers on the growth, yield and mycorrhizal colonization of Cuba 108 under field conditions

4.4.1 Residual effects of AM inoculation and fertilizers on the growth of Cuba 108 under field conditions

Stem girth (Table 4.21) and plant height (Table 4.22) were significantly affected by the residual effects of mycorrhizal inoculation and fertilizers application. Stem girth of inoculated Cuba 108 without fertilizer application was higher than non-inoculated counterpart at 0 fertilizer application throughout the growth period by percentage range of 1.2 – 10.9 % (Table 4.21). Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation resulted in the significant ($p < 0.001$) increased in stem girth from 20 to 80 kgN/ha of both organic and organo-mineral fertilizers at 14WAP. On the residual effect of mycorrhizal inoculation and fertilizers application, significant ($p < 0.001$) differences were observed between inoculated and non-inoculated Cuba 108 at 60 and 100 kgN/ha of organic fertilizer; and at 60 kgN/ha of organo-mineral fertilizer. Inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had significantly ($p < 0.001$) higher stem girth compared to other fertilizer levels with and without mycorrhizal inoculation.

Inoculated Cuba 108 without fertilizer application had higher plant height than non-inoculated Cuba 108 at 0 fertilizer level with percentage range of 2.4 to 18.8 % from 6 to 14WAP (Table 4.22). Fertilizers application without mycorrhizal inoculation significantly ($p < 0.001$) increased plant height compared to 0 fertilizer application without mycorrhizal inoculation except at 60 and 20 kgN/ha of NPK and organo-mineral fertilizer respectively 14WAP. Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation increased plant height of Cuba 108 from 20 to 100 kgN/ha. On the residual effect of mycorrhizal inoculation and fertilizers application, significantly ($p < 0.05$) higher plant

Table 4.20: Correlation coefficient between soil chemical properties

	pH	OM	N	P	K	Ca	Mg	Na
pH	1.00							
OM	0.85**	1.00						
N	0.67**	0.92**	1.00					
P	0.81**	0.93**	0.86**	1.00				
K	0.79**	0.90**	0.84**	0.86**	1.00			
Ca	0.79**	0.90**	0.84**	0.95**	0.83**	1.00		
Mg	0.49*	0.81**	0.81**	0.76**	0.73**	0.70**	1.00	
Na	0.17	0.13	0.21	0.26	0.16	0.42*	-0.19	1.00

OM = Organic matter
* and ** represent levels of significance at $p < 0.05$ and 0.01 respectively
n = 192

Table 4.21: Residual influence of mycorrhizal inoculation and fertilizers on the stem girth (cm) of Cuba 108 at different weeks after planting (WAP) under field conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	0.60	0.86	0.98	1.02	1.04
	NPK	0.72	0.88	1.00	1.03	1.06
	Or20	0.73	0.95	1.04	1.10	1.13
	Or40	0.75	1.00	1.10	1.13	1.13
	Or60	0.82	1.08	1.21	1.30	1.34
	Or80	0.93	1.15	1.30	1.33	1.39
	Or100	1.09	1.32	1.39	1.48	1.55
	OM20	0.73	0.90	1.02	1.06	1.09
	OM40	0.75	1.00	1.05	1.12	1.17
	OM60	0.81	1.06	1.20	1.27	1.32
	OM80	0.85	1.13	1.29	1.32	1.37
	OM100	0.96	1.32	1.35	1.38	1.44
Without	0	0.55	0.85	0.90	0.92	0.95
	NPK	0.65	0.87	1.00	1.02	1.06
	Or20	0.73	0.93	1.03	1.06	1.11
	Or40	0.75	1.00	1.05	1.10	1.14
	Or60	0.79	1.02	1.12	1.22	1.26
	Or80	0.85	1.10	1.26	1.31	1.37
	Or100	0.95	1.23	1.32	1.35	1.41
	OM20	0.72	0.90	1.02	1.05	1.08
	OM40	0.74	0.95	1.05	1.10	1.13
	OM60	0.75	1.00	1.10	1.15	1.18
	OM80	0.83	1.10	1.23	1.31	1.36
	OM100	0.93	1.16	1.30	1.33	1.40
SE						
Mycorrhiza (M)		0.0019	0.0018	0.0024	0.0014	0.0050
Fertilizers (F)		0.0048	0.0045	0.0059	0.0033	0.0122
Interaction						
M x F		0.0067	0.0064	0.0084	0.0047	0.0172
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		***	***	***	***	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer

S.E. = Standard Error

*** represent level of significance at $p < 0.001$

Table 4.22: Residual influence of mycorrhiza inoculation and fertilizers on the plant height (cm) of Cuba 108 at different weeks after planting (WAP) under field conditions

Mycorrhiza inoculation	Fertilizers application	6	8	10	12	14
With	0	49.40	76.10	110.10	128.10	139.70
	NPK	51.67	79.87	112.10	135.10	147.10
	Or20	53.60	87.17	117.18	147.10	157.37
	Or40	60.17	90.10	126.17	151.17	165.43
	Or60	61.17	93.10	131.17	166.17	178.43
	Or80	70.17	101.17	140.10	180.17	196.37
	Or100	82.97	115.17	181.17	217.17	235.43
	OM20	53.10	82.17	115.17	142.10	154.70
	OM40	59.70	89.17	126.10	150.17	163.43
	OM60	61.17	91.17	130.10	165.10	177.77
	OM80	63.97	100.17	135.17	180.10	187.43
	OM100	78.40	115.17	173.17	204.17	220.10
Without	0	41.60	70.10	107.10	125.10	131.37
	NPK	50.53	77.10	111.10	130.10	145.37
	Or20	53.37	83.10	117.10	145.10	156.03
	Or40	54.90	88.60	125.17	150.10	159.17
	Or60	60.27	90.67	128.17	157.17	168.37
	Or80	63.30	98.17	134.10	174.17	183.43
	Or100	76.17	110.10	145.17	190.17	208.43
	OM20	52.40	81.10	115.10	136.10	147.37
	OM40	54.30	88.53	121.10	147.17	158.77
	OM60	60.17	90.60	127.17	157.10	166.37
	OM80	63.30	95.10	134.10	168.17	179.03
	OM100	73.47	105.17	140.17	183.17	199.10
SE						
Mycorrhiza (M)		0.5724	0.6484	0.5746	0.7616	1.7012
Fertilizers (F)		1.4022	1.5883	1.4076	1.8655	4.1670
Interaction						
M x F		1.9830	2.2463	1.9906	2.6382	5.8930
ANOVA						
M		***	***	***	***	***
F		***	***	***	***	***
Interaction						
M x F		**	***	***	***	*

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM60, OM80 and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer

S.E. = Standard Error

*, ** and *** represent level of significance at $p < 0.05$, 0.01 and 0.001 respectively

height was observed in the inoculated Cuba 108 at 100 kgN/ha of organic fertilizer 14WAP compared to other treatments

4.4.2 Residual effects of AM inoculation and fertilizers on the yield and mycorrhizal colonization of Cuba 108 under field conditions

Residual effects of mycorrhizal inoculation and fertilizer application rates had effect on bast, core and mycorrhizal colonization of Cuba 108 (Table 4.23). Bast yield of inoculated Cuba 108 without fertilizer application was higher than the bast yield of the non-inoculated without fertilizer application by 23.3 % (Table 4.23). Fertilizers application without mycorrhizal inoculation significantly ($p < 0.001$) increased bast yield of Cuba 108 compared to the bast yield of non-inoculated Cuba 108 at 0 fertilizer level except at 60 kgN/ha of NPK fertilizer. Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased bast yield at 100 kgN/ha of both organic and organo-mineral fertilizer. Considering 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, organic fertilizer had the highest bast yield followed by the organo-mineral and NPK fertilizer. Of all the fertilizers application with and without mycorrhizal inoculation, inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had the highest bast yield.

Core yield of inoculated Cuba 108 without fertilizer application was 16.3 % higher than the core yield of non-inoculated Cuba 108 at the same fertilizer level (Table 4.23). Non-inoculated Cuba 108 under fertilizers application had significantly ($p < 0.01$) higher core yield than the non-inoculated Cuba 108 at 0 fertilizer application. Among the 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, organic and organo-mineral had significantly ($p < 0.001$) higher core yield compared to NPK fertilizer; and the core yield of organo-mineral fertilizer was 6.0 % higher than that of organic fertilizer. Highest core yield was observed in the inoculated Cuba 108 at 100 kgN/ha of organic fertilizer.

Mycorrhizal colonization of inoculated Cuba 108 without fertilizers application was higher than that of non-inoculated Cuba 108 at 0 fertilizer level by 9.6 % (Table 4.23). Increase in the level of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased mycorrhizal colonization from 60 to 100 kgN/ha of both

Table 4.23: Residual effects of arbuscular mycorrhiza and fertilizers on the colonization, bast and core yield (t/ha) of Cuba 108 under field conditions

Mycorrhiza inoculation	Fertilizers application	Bast	Core	Mycorrhizal colonization (%)
With	0	0.53	1.43	15.13
	NPK60	0.87	2.23	16.63
	Or20	1.13	2.77	21.13
	Or40	1.23	3.43	26.20
	Or60	1.33	3.67	41.17
	Or80	1.60	4.10	52.57
	Or100	2.68	5.79	68.80
	OM20	0.97	2.83	18.47
	OM40	1.17	3.50	23.83
	OM60	1.30	3.63	37.93
	OM80	1.43	3.87	48.80
	OM100	2.10	4.87	61.03
Without	0	0.43	1.23	13.80
	NPK60	0.80	2.20	15.40
	Or20	0.97	2.60	19.43
	Or40	1.10	3.37	23.03
	Or60	1.20	3.33	31.20
	Or80	1.30	3.80	44.60
	Or100	1.87	4.30	58.17
	OM20	0.90	2.73	17.10
	OM40	1.03	3.10	22.07
	OM60	1.13	3.53	28.07
	OM80	1.20	3.50	42.70
	OM100	1.76	4.07	54.80
	S.E.			
	Mycorrhiza (M)	0.04	0.08	0.47
	Fertilizers (F)	0.10	0.19	1.15
	Interaction			
	M × F	0.14	0.26	1.63
	ANOVA			
	M	***	**	***
	F	***	***	***
	Interaction			
	M × F	ns	ns	*

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of

organo-mineral fertilizer, S.E. = Standard Error, ns = not significant

*, ** and *** represent level of significance at $p < 0.05$, 0.01 and 0.001

organic and organo-mineral fertilizers. At 60 kgN/ha of the fertilizers applied, organic and organo-mineral fertilizer had significantly ($p < 0.001$) higher mycorrhizal colonization compared to the NPK fertilizer. Inoculated Cuba 108 with fertilizers application had significantly ($p < 0.05$) higher mycorrhizal colonization than non-inoculated Cuba 108 with fertilizers application at 60, 80 and 100 kgN/ha of both organic and organo-mineral fertilizers. Increase in the levels of organic and organo-mineral fertilizers with mycorrhizal inoculation significantly ($p < 0.05$) increased percentage mycorrhizal colonization at 60, 80 and 100 kgN/ha of both organic and organo-mineral fertilizers. Significantly ($p < 0.05$) higher mycorrhizal colonization was observed in the inoculated Cuba 108 at 100 kgN/ha of organic fertilizer compared to other fertilizer levels with and without mycorrhizal inoculation.

4.4.3 Residual effects of AM inoculation and fertilizers on soil chemical properties after harvesting

Soil chemical properties were affected by the residual effects of mycorrhiza inoculation and fertilizers application (Table 4.24). Soil of the inoculated Cuba 108 without fertilizer application had significantly lower soil organic matter ($p < 0.001$), N (($p < 0.01$), K ($p < 0.001$) and Mg ($p < 0.05$) than the soil of the non-inoculated Cuba 108 without fertilizer application. Fertilizers application without mycorrhizal inoculation significantly ($p < 0.001$) increased soil pH (except 60 kgN/ha of NPK), organic matter, N (except 60 kgN/ha of NPK, 20, 40 and 60 kgN/ha of organo-mineral), P (except 60 kgN/ha of NPK), Ca, Mg (at 60, 80 and 100 kgN/ha of both organic and organo-mineral) and K compared to the non-inoculated without fertilizer application. Increase in the levels of organic and organo-mineral fertilizers without mycorrhizal inoculation significantly ($p < 0.001$) increased soil organic matter, P (at 40 and 60 kgN/ha of organic; and also at 80 kgN/ha of organo-mineral) and Ca. Among the 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, organic fertilizer had significantly ($p < 0.001$) higher soil organic matter, N, P and Ca followed by the organo-mineral and NPK fertilizer. Fertilizers application with mycorrhizal inoculation had significantly lower soil organic matter ($p < 0.001$) (except 80 kgN/ha of organic fertilizer), N ($p < 0.05$) (except 60 kgN/ha of organic, 20, 40 and 60 kgN/ha of organo-mineral fertilizer), P ($p < 0.01$) (at 40, 60, and 100 kgN/ha of organic, 80 and 100 kgN/ha of organo-mineral

Table 4.24: Residual effects of arbuscular mycorrhiza and fertilizers on soil chemical properties after harvesting kenaf

Mycorrhiza inoculation	Fertilizers application	pH	Organic matter (g/kg)	N (g/kg)	P (mg/kg)	K	Ca	Mg	Na
						(cmol/kg)			
With	0	5.60	7.20	0.20	1.83	0.12	1.32	0.15	0.02
	NPK	5.43	8.70	0.20	2.05	0.14	3.08	0.22	0.01
	Or20	6.16	10.90	0.30	2.42	0.18	4.09	0.17	0.02
	Or40	6.20	11.90	0.30	2.52	0.20	4.72	0.26	0.02
	Or60	6.23	12.30	0.40	3.13	0.28	5.17	0.27	0.02
	Or80	6.30	15.00	0.40	3.29	0.32	6.52	0.28	0.02
	Or100	6.30	15.30	0.50	3.54	0.37	8.32	0.28	0.02
	OM20	6.13	10.50	0.30	2.41	0.15	3.97	0.15	0.02
	OM40	6.20	11.40	0.30	2.48	0.22	4.28	0.17	0.02
	OM60	6.23	11.70	0.30	2.73	0.25	5.11	0.20	0.02
	OM80	6.30	13.60	0.40	3.11	0.31	5.22	0.27	0.02
	OM100	6.33	13.90	0.40	3.45	0.33	5.37	0.28	0.02
Without	0	5.80	8.70	0.30	1.97	0.14	3.57	0.16	0.02
	NPK	5.77	9.20	0.30	2.26	0.17	4.82	0.17	0.02
	Or20	6.23	11.40	0.40	2.54	0.23	4.30	0.16	0.02
	Or40	6.26	12.30	0.40	2.97	0.30	5.57	0.18	0.02
	Or60	6.33	12.80	0.40	3.50	0.35	6.77	0.27	0.02
	Or80	6.33	14.40	0.50	3.53	0.36	6.97	0.30	0.02
	Or100	6.43	16.10	0.60	3.87	0.39	8.49	0.32	0.02
	OM20	6.17	10.70	0.30	2.48	0.18	4.57	0.16	0.02
	OM40	6.23	11.70	0.30	2.77	0.24	5.67	0.18	0.02
	OM60	6.23	12.10	0.30	3.01	0.28	5.92	0.26	0.02
	OM80	6.33	14.20	0.50	3.63	0.32	6.37	0.30	0.02
	OM100	6.37	15.40	0.50	3.83	0.38	7.14	0.31	0.02
	SE								
	Mycorrhiza (M)	0.026	0.002	0.001	0.034	0.045	0.002	0.001	0.002
	Fertilizers (F)	0.063	0.005	0.003	0.082	0.109	0.006	0.002	0.005
	Interaction M x F	0.090	0.007	0.004	0.117	0.155	0.008	0.002	0.006
	ANOVA								
	M	ns	***	**	*	***	ns	*	***
	F	***	***	***	***	***	***	ns	***
	Interaction M x F	ns	***	*	**	***	***	ns	***

NPK60 = 60 kgN/ha of NPK (20:10:10) fertilizer

Or20, Or40, Or60, Or80 and Or100 = 20, 40, 60, 80 and 100 kgN/ha of organic fertilizer

OM20, OM40, OM 60, 80OM and OM100 = 20, 40, 60, 80 and 100 kgN/ha of organo-mineral fertilizer, S.E. = Standard Error, ns = not significant

*, ** and *** represent level of significance at $p < 0.05$, 0.01 and 0.001

fertilizer) and Ca ($p < 0.001$) than the non-inoculated with fertilizers application. When compared the fertilizers application with and without mycorrhizal inoculation, soil of the non-inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had significantly ($p < 0.001$) higher soil organic matter and Ca compared to other fertilizer levels with and without mycorrhizal inoculation.

CHAPTER 5

DISCUSSIONS

Sustainable agricultural production on a fragile tropical soil requires the use of biological materials such as organic fertilizer and beneficial microorganism. Cuba 108 and Tiannug 1 varieties of kenaf have been recommended for cultivation in different agro-ecological zones of Nigeria (IAR&T, 1997). Inorganic fertilizer has been identified to increase yields of both Cuba 108 and Tiannug 1 (Ogunbodede and Adediran, 1996; Agbaje *et al*., 2009). In this study, the understanding of AM association with organic, inorganic and organo-mineral fertilizers provides a basis for achieving sustainable kenaf production through root colonization by AM fungi for enhanced nutrient acquisition in nutrient deficient soil.

Screenhouse experimental soil was low in nutrients compared to the soil fertility rating classes in Nigerian (FPDD, 1990). Low fertility status of the soil might be due to the continuous cultivation of the land with continuous application of inorganic fertilizer in the past. LAWOO (1994), stated that inorganic fertilizer sucks the organic material out of the soil and makes it available to the plant in a very short time and this process make the soil degraded in nutrient over a period of time. Adepetu *et al*. (1979), also stated that continuous use of mineral fertilizer can have detrimental effects on soil properties.

In the screenhouse experiment, Cuba 108 showed a higher degree of responsiveness to mycorrhizal inoculation than Tiannug 1. Variation in response to mycorrhizal inoculation has been obtained in different species and genotypes of other crops (Krishna *et al*., 1985; Sieverding, 1991; Dare *et al*., 2008). However, inoculation increased the growth, AM colonization, bast and core yield of both Cuba 108 and Tiannug 1 compared to the non-inoculation counterpart. These better growth exhibited by the inoculated kenaf plants might be due to a better uptake of nutrients, which in turn can be directly attributed to AM inoculation. This might also be due to the effectiveness of *Glomus mosseae* inoculated to absorb plant nutrient from soil solution for the growth and yield of the plant. Sieverding (1991) stated that mycorrhiza enhanced the efficiency of nutrient absorption from the soil solution by increasing the soil volume explored for nutrient uptake. Among the factors that influence the plant response to mycorrhizal inoculation are soil fertility, the number of indigenous mycorrhizal fungi, the competitiveness and effectiveness of the introduced

mycorrhizal fungus compared with indigenous mycorrhizal fungi (Bowen, 1985). However, Sieverding (1991), stated that root colonization increased by increasing AM concentrations in the soil. Increase in the levels of the fertilizers applied with mycorrhizal inoculation significantly ($p < 0.001$) increased mycorrhizal colonization, bast and core yield from 20 to 40 kgN/ha of both organic and organo-mineral fertilizer. Nitrogen is one of the most limiting elements in tropical soils and most frequently applied fertilizer in the tropics and often the only fertilizer element added to the soil but increasing levels of nitrogen fertilizers may inhibit AM formation and may negatively affect the AM population (Hayman, 1987). This observation is consistent with the study of the mycorrhiza project on cassava where increasing in the N levels, P and K were added at constant rate, clearly inhibited the root colonization ratings of cassava (Sieverding, 1991). In more fertile soils, Sieverding (1991), found a negative effect of higher N.P.K. applications on AM spore density in sugarcane fields; the decrease was attributed to the inhibiting effect of higher N.P.K. levels on spore formation of *Glomus mosseae*, a highly effective AM fungus under those soil conditions. High amount of soil available P and total Nmay lower AM colonization (Treseder and Allen, 2002; Johnson *et al*., 2003). For most of the levels of fertilizers application with or without AM inoculation, Cuba 108 had higher stem girth, plant height, percentage AM colonization, bast and core yields than Tiannug 1. This observation is consistent with the findings of Ogunbodede and Adediran (1996), where Cuba 108 had higher bast and core yield than Tiannug 1.

On the residual effect of AM inoculation and fertilizers application, percentage AM colonization, growth and yield parameters increased from 20 kgN/ha to 100kgN/ha of both organic and organo-mineral fertilizers. Organic had better yields than organo-mineral fertilizer. This might be due to the gradual release of nutrients by the organic fertilizer which make it to have better residual effect among the fertilizers used. Agboola (1982), indicated that maintenance of soil fertility and productivity with continuous application of farmyard manure is possible. Comparisons between organic and inorganic fertilizers had shown better results from the farmer (Djokoto and Stephens, 1961), which was attributed to the slow release of balanced nutrient reserves during decomposition. On the strongly weathered, poorly buffered soils of the tropic (e.g. Kaolinitic, Alfisols, Ultisols and Oxisols) continuous monoculture of cereals, using chemical fertilizer as the main source of nutrients, can lead to a

significant decline in yields after only a few years of cropping because of soil acidification and compaction (Kang and Juo, 1986).

On the field experiment, similar observations were made on the influence of AM inoculation and fertilizers application on growth, AM colonization, bast and core yield of kenaf as obtained in the screenhouse experiment. Inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer that had significantly ($p < 0.05$) higher percentage AM colonization also had higher stem girth, plant height, bast and core yield. This observation is consistent with Atayese *et al*. (1993), who stated that the higher the intensity of AM colonization, the greater the cassava tuber yields at the top and the base of the slope. Dare *et al*. (2008), also reported that inoculation with AM is highly beneficial to the yield and nutrient uptake of yam. Comparing the 60 kgN/ha of the fertilizers applied with and without inoculation, organo-mineral fertilizer had highest AM colonization, bast and core yield followed by the N.P.K and organic fertilizer. This might be due to nutrient availability in the soil throughout the crop growing period in case of organo-mineral fertilizer and unlike N.P.K. fertilizer which provide large doses of nutrients at early stage of plant growth which plant may not be able to effectively utilize and organic fertilizer which release nutrients slowly in a continuous way. Combination of organic and inorganic fertilizers performs better on crop yield than when each of them is solely used (Sridhar and Adeoye, 2003).

On the residual effect of the fertilizers and AM inoculation, growth and yield parameters increased from 20 kgN/ha to 100 kgN/ha with organic fertilizer greater than the organo-mineral fertilizer. When compared, the 60 kgN/ha of the fertilizers, organic had the highest growth and yield parameters followed by the organo-mineral and NPK fertilizer. Agboola and Obigbesan (1975), observed that cowpea grown on a field which had been previously cropped continuously for ten years, yielded significantly better when inorganic fertilizer P was applied together with farmyard manure (FYM) than when either of them was applied alone. The response was attributed partly to the liming effect of organic manure. This result is also in agreement with Sieverding (1991) where AM inoculation with rock phosphate had higher cassava yield than AM inoculation with triple supper phosphate in the second year of cropping. Dempsey (1963), stated that liberal amounts of chemical fertilizer and manure should be used to produce a good crop of Kenaf. However, percentage mycorrhizal colonization increased from 20 kgN/ha to 100 kgN/ha of both organic and organo-mineral

fertilizer. This might probably be due to the ability of the two fertilizers to supply organic material to the soil. Soils with an abundance of organic matter remain loose and airy, hold a greater amount of moisture and nutrients, promote the growth of beneficial soil organisms and provide a healthier plant root system (EP, 2011). Percentage mycorrhizal inoculation decreased in the residual compared to the screenhouse and field experiments. Inoculation method (by placing inoculum under the seed) might be responsible for this. Enough inoculum should be applied (300 – 500 ml / stake of cassava) to obtain spatial distribution and if possible, half of the inoculum should be applied under the planting material and half in side bands (Sieverding, 1991). This is the most efficient method; if the inoculum is only applied under the plant, it may be necessary to repeat the AM inoculation the second year to get higher colonization.

Soil chemical properties such as pH, organic matter, total nitrogen, available phosphorus, potassium and calcium, after harvesting kenaf from the field experiment and residual, increased from 20 kgN/ha to 100 kgN/ha of both organic and organo-mineral fertilizers. For all the fertilizer treatments, non-inoculated soils had higher percentage of the soil chemical properties than the inoculated soils. This might result from the effectiveness of *Glomus mosseae* inoculated to absorb nutrient from soil solution. However, the principal function of mycorrhiza is to increase the soil volume explored for nutrient uptake and to enhance the efficiency of nutrient absorption from the soil solution (Sieverding, 1991).

After harvesting the first and second cropping, soil of the non-inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had highest pH followed by the non-inoculated Cuba 108 at 100 kgN/ha of organo-mineral fertilizer and the inoculated Cuba 108 at 100 kgN/ha of organic fertilizer. Comparing the fertilizers at 60 kgN/ha without mycorrhizal inoculation, organic fertilizer had the highest pH (greater then the pH before planting) followed by the organo-mineral (also greater than before planting) and N.P.K. (20:10:10) fertilizers (lower than before planting). This might be attributed to the composition of the fertilizers used. Organic fertilizer was made from market wastes while the N.P.K fertilizer was made by making use of chemicals. Kang and Juo (1986), stated that acidification occurs mainly through the loss of exchangeable bases in leaching (Ca, Mg and K) and acid production during Al hydrolysis and nitrification. Tamang (1993), stated that soil acidification is being made worse by the introduction of chemical fertilizers, particularly ammonium sulphate and

urea whose application increases soil acidity. Juo *et al. (*1995), also reported that the rate of decline in soil pH and exchangeable Mg under three cropping systems with application of chemical fertilizers (NPK) were continuous maize with NPK without residues > continuous maize with residue mulch > maize/cassava intercropping. Without a residue mulch, soil pH (measures in water) dropped from 6.0 to about 4.5 after ten years. The market wastes in organic fertilizer might serve as liming material to the soil which might be responsible for the increased in the soil pH in the case of organic and organo-mineral fertilizers soils. Adetunji (2005), suggested that for soil quality maintenance, liming of acid soils should be done to a pH that gives optimum fertilizer efficiency, nutrient uptake, and aluminum saturation. Soils that receive significant amounts of organic material tend to maintain (buffer) soil pH values for longer period (Adetunji and Okeleye, 2001; Okeleye and Adetunji, 1999).

Concerning the soil organic matter after harvesting, non-inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had highest soil organic matter followed by the non-inoculated Cuba 108 at 100kgN/ha of organo-mineral fertilizer and the inoculated Cuba 108 at 100 kgN/ha of organic fertilizer. At 60 kgN/ha of fertilizers applied, organic had highest soil organic matter content (higher than before planting soil organic matter) followed by the organo-mineral fertilizer (also greater than soil organic matter before planting) and N.P.K. fertilizer (lower than soil organic matter before planting) and this was reflected in the bast and core yield. Also, at 60 kgN/ha of the fertilizers without mycorrhizal inoculation, organic fertilizer had the highest soil organic matter followed by the organo-mineral and N.P.K fertilizers with their bast and core yield followed the same trend. This might occurred as a result of the low rate of mineralization of organic fertilizer compared to the chemical fertilizer (which releases nutrients instantly) and the beneficial effect is what we observed in soil organic matter content which may be responsible for the highest yield of organic fertilizer in the second cropping. Yield decline with continuous and intensive cropping (which has become inevitable in most parts of the humid tropics owing to pressure on land) is often observed even with high levels of chemical fertilizer inputs and such yield decline has been attributed to decrease in soil organic matter and pH, depletion of nutrients not supplied in the applied fertilizers, imbalance in fertilizer application and to a degradation of soil physical properties (Oluwatoyinbo, 2001). Also, chemical fertilizer is an agent that sucks the organic material out of the soil and makes it available to the plant in a very short time. One of the

conditions for stable soil productivity in the tropics is the necessity to maintain and improve soil organic matter levels. This is because organic matter has some specific beneficial effects that cannot be provided by inorganic fertilizers for instance, the high cation exchange capacity of organic matter improves nutrient utilization efficiency of crops in soils; this is very important because of the low-activity-clays (LAC) that characterize Nigerian soils (Adepetu, *et al*., 1979). Also, organic matter maintains good aggregate stability and the general macro-structure of tropical soils (Adeoye, 1985). The application of compost is a proven way of improving soil properties by supplying organic matter and micronutrients (Sridhar and Adeoye, 2003). However, the total nitrogen, available phosphorus and exchangeable potassium followed the same trend with organic matter content. At 60kgN/ha of the fertilizers applied without mycorrhizal inoculation, organic fertilizer had the highest total nitrogen, available phosphorus and exchangeable potassium followed by the organo-mineral and N.P.K. fertilizer. Control had the least total nitrogen, available phosphorus and exchangeable potassium.

The positive correlation coefficient between organic matter, total nitrogen and available phosphorous might be due to the source of nitrogen and phosphors which is likely to be soil organic matter. Adetunji (2005), stated that organic matter is probably the most vital indicator of soil quality and influences the physical, chemical and biological indicators of soil quality and soil nitrogen is inextricably tied to the soil organic matter content because the bulk of soil nitrogen is in organic combination. Prasad and Power (1997), also reported that soil organic matter increase the water-holding capacity of soils and is a source of several essential plant nutrients, especially N, S and P. Non-inoculated soil at 100 kgN/ha of organic fertilizer had highest exchangeable potassium and calcium. At 60 kgN/ha of the fertilizers applied, organic fertilizer had significantly highest K and Ca followed by the organo-mineral and N.P.K fertilizer. While in exchangeable Mg and Na, no significant difference among the fertilizer types and levels (including 60kgN/ha of fertilizers applied). This could probably be due to the exchangeable bases content of the fertilizers applied, for instance organic fertilizer contain more of Ca and K than organo-mineral fertilizer while the two fertilizers had little Na and Mg. In many tropical soils, organic matter is the major source of cation exchange capacity (Agboola and Corey, 1973). Also, Agboola (1987), reported that because of the predominance of low activity clays (LAC) in soils of the humid forest zones, the only alternative source of

cation exchange capacity is the soil organic matter. In addition, organic manures release nutrient slowly and this apparently ensures a continuous supply of nutrients to crops at nearly all growth phases (Janic, 1986). Azeez and Adetunji (2005) reported that significant increase in K level of the soil is more pronounced as the rate of fertilizer application increases. The levels of exchangeable Ca, Mg, Na and K decreased further after second cropping probably as a result of uptake and leaching. Although mycorrhizae are particularly important for the uptake of immobile nutrients, in highly competitive situations like agroforestry, the uptake of more mobile nutrients like K may be a direct result of mycorrhizal association (Bowen, 1985). Awotoye *et al*. (2003), also reported that uptake of N, P, and K were significantly increased by mycorrhizal inoculation likewise the uptake of Ca and Mg under *Gliricidia species.*

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CHAPTER 6

SUMARY AND CONCLUSIONS

The two varieties of kenaf namely Cuba 108 and Tiannug 1 recommended for different agro-ecological zones in Nigeria were highly responsive to arbuscular mycorrhizal inoculation. The percentage of arbuscular mycorrhizal colonization varied with varieties of kenaf investigated with Cuba 108 having higher percentage colonization compared to Tiannug 1. Percentage root colonization varied with fertilizer types. Organic base fertilizer had higher percentage mycorrhizal colonization than the NPK (20: 10: 10) fertilizer. In the organic and organo-mineral fertilizer, percentage root colonization decreased as the nitrogen level increased in the screenhouse and field experiments for the two varieties of kenaf. The higher the percentage root colonization, the higher were the growth (stem girth and plant height) and yield (bast and core) parameters with inoculated kenaf greater than the non-inoculated. In both the screenhouse and field experiments, inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer had significantly higher mycorrhizal colonization, bast and core yield compared to the recommended 60 kgN/ha of NPK (20: 10: 10). At 60 kgN/ha of the fertilizers applied without mycorrhizal inoculation, higher bast and core yield were observed in the organo-mineral fertilizer followed by the inorganic and organic fertilizer in the screenhouse and field experiments.

On the residual effects of fertilizers application and mycorrhizal inoculation, inoculated Cuba 108 at 100 kgN/ha of organic fertilizer had significantly higher mycorrhizal colonization, bast and core yield compared to other treatments with and without mycorrhizal inoculation. On the other hand, non-inoculated Cuba 108 at 60 kgN/ha of organic fertilizer had higher mycorrhizal colonization, bast and core yield compared to the non-inoculated Cuba 108 at the recommended rate of 60 kgN/ha of NPK (20: 10: 10). Organic base fertilizer at 60 kgN/ha had higher soil chemical properties such as organic matter, pH, nitrogen, phosphorus and potassium compared to the inorganic fertilizer at 60 kgN/ha with and without mycorrhizal inoculation.

Since significantly higher bast and core yield were obtained in the inoculated Cuba 108 at 40 kgN/ha of organo-mineral fertilizer compared to the recommended rate of 60 kgN/ha of NPK (20: 10: 10), there is need to manage indigenous mycorrhiza to reduce input

of fertilizer. However, there is need to manage organic matter content of the soil through the application of organic material for sustainable kenaf production.

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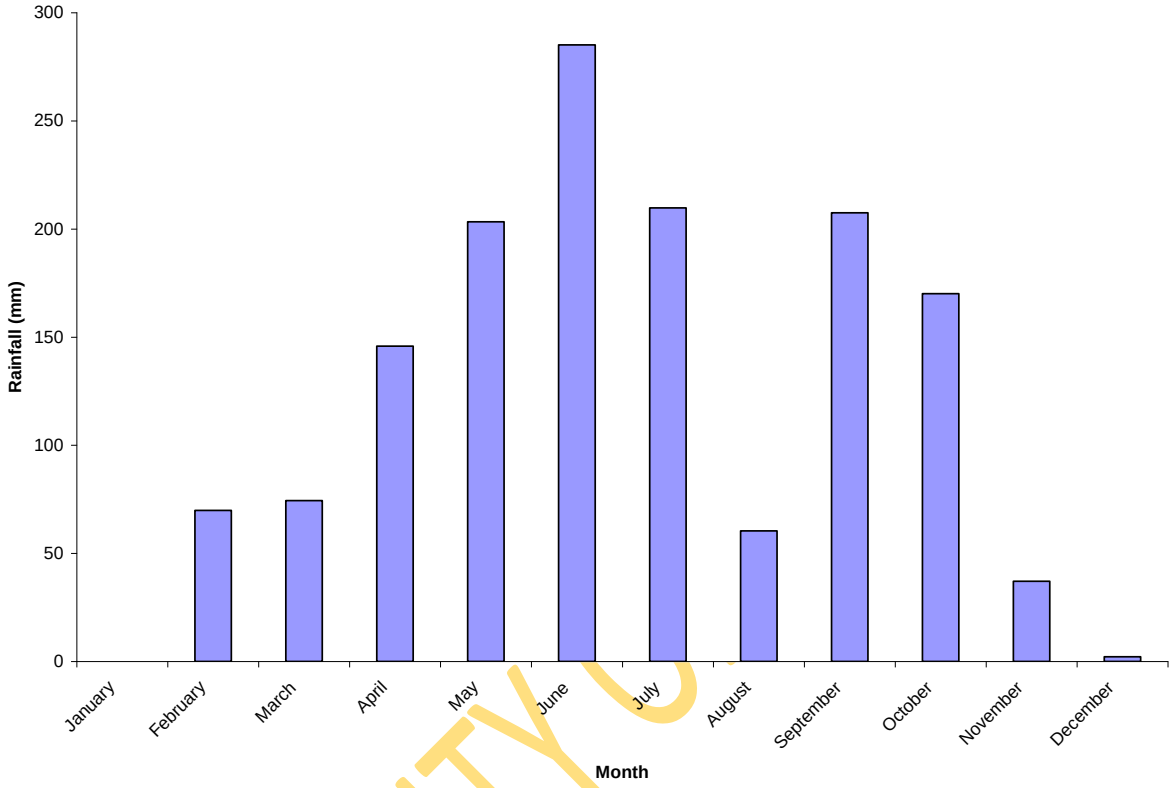
Appendix 1

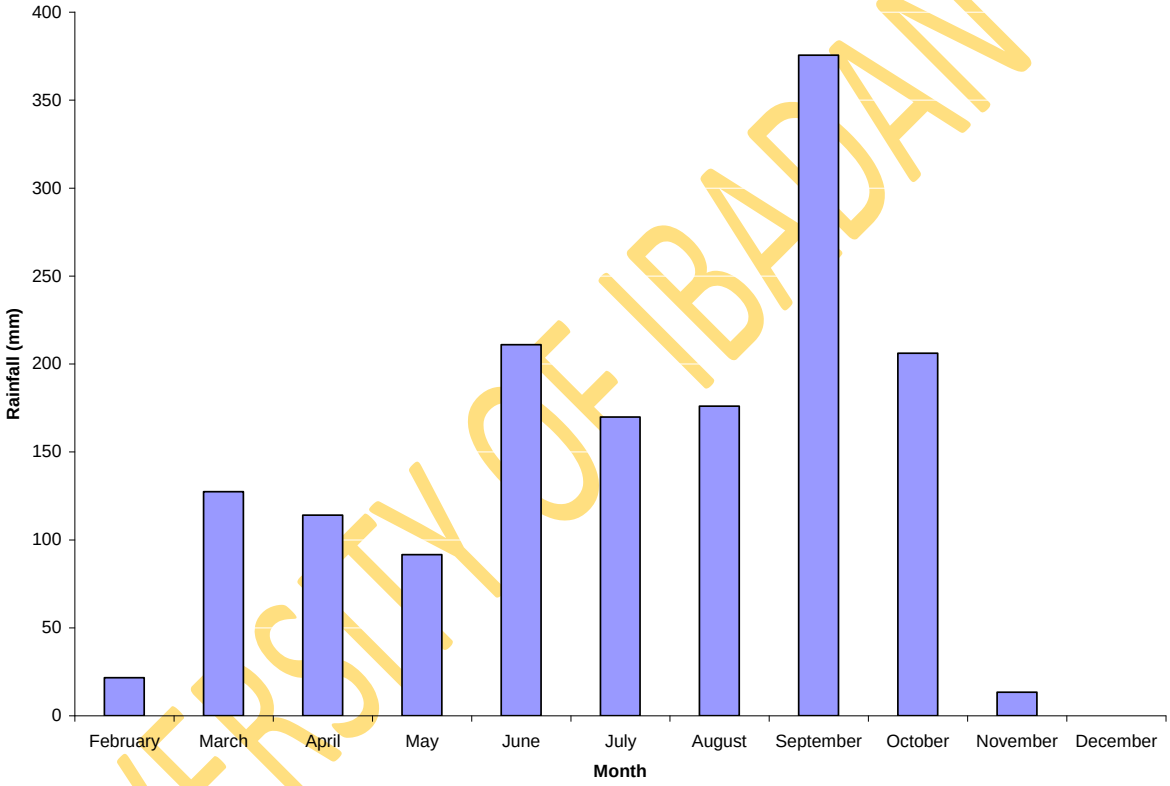
Nutrient ratings for soil fertility classes in Nigeria.

Rating	Total Nitrogen (g/kg)	Phosphorus (g/kg) Bray-l-p	Exch. K (cmol/kg)	Organic Matter (g/kg)
Low	< 1.5	< 8	< 0.20	< 20
Medium	1.5 – 2.0	8 - 20	0.20 - 0.40	20 - 30
High	> 2.0	> 20	> 0.40	> 30

FPDD (1990)



Appendix 2: Monthly rainfall distribution in Ibadan in 2005



Appendix 3: Monthly rainfall distribution in Ibadan for 2006