DEVELOPMENT OF SUSTAINABLE NUTRIENT MANAGEMENT STRATEGY FOR OIL PALM (*ELAEIS GUINEENSIS* JACQ.) NURSERY: – GREEN-GRO AND POLYFEED EVALUATION

A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SOIL CHEMISTRY AND PLANT NUTRITION

BY

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JUNE, 2008

DECLARATION

I hereby declare that this submission is my own work towards the M.Sc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This dissertation is dedicated to my wife, Beatrice and children Anthony, Gloria and Rosemary, through whose sacrifices my M.Sc. programme has been made successful. Thank you for your cooperation and support and may God richly bless you.

ACKNOWLEDGEMENTS

My sincere thanks go to my supervisors, Mr Andrews Opoku of Crop and Soil Sciences Department, Kwame Nkrumah University of Science and Technology, Kumasi and Dr. B.N. Nuertey of Council for Scientific and Industrial Research-Oil Palm Research Institute (CSIR-OPRI), Kusi for their useful advice in project planning, execution, constructive criticisms and editing. My thanks go to Prof. E.Y. Safo, of Department of Crop and Soil sciences, Kwame Nkrumah University of Science and Technology, for reading through the thesis. My profound gratitude goes to Dr. T.E.O. Asamoah, Director, CSIR-OPRI and the entire management of the CSIR-OPRI, Kusi for allowing me to use their facilities.

My thanks go to Dr. F.M. Tetteh and the technicians of the Soil Research Institute, Kumasi for assisting in the physical and chemical analyses of the soil and leaf samples; Dr. Mochia of Crop Research Institute, Kumasi for assisting in the statistical analyses of data. I thank all the Agronomy staff of CSIR-OPRI, Kusi and SAPCOE, Okyinso workers for assisting me on the field work and data collection.

Finally, I am grateful to the management of Ministry of Food and Agriculture for granting me the study leave to undertake this study.

May Almighty God richly bless you all.

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ABSTRACT

The performance of oil palm seedlings grown in a compost-soil mixture (green-gro) medium and topsoil with the application of three different formulations of fertilizer was evaluated. The study was conducted for a period of eight months at the Sapcoe President's Special Initiative (PSI) oil palm nursery located at Okyinso near Kade. Green-gro, a propagation medium was introduced for application by nursery operators participating in the production of oil palm seedlings under the PSI on oil palm programme. The trial consisted of eight treatments replicated three times in a randomised complete block design. Both media were characterized before the experiment and analysis conducted during and after the experiment for physical and chemical properties and microbial biomass (N, P and C).

Growth parameters measured over the experimental period were butt circumference, plant height, number of leaves, frond dry weight, leaf area and leaf area index. Destructive measurement was conducted at the end of the experiment. Plants were analysed for total nitrogen, phosphorus, potassium, calcium and magnesium at bimonthly intervals. Nutrient use efficiencies were computed and agro-economic appraisal calculated for all the treatments.

Plant nutrients and organic matter accumulated more in green-gro medium than the topsoil during and after the experiment. pH increased rapidly in the topsoil treatments than in the green-gro medium treatments. Vegetative growth in seedlings planted in bags filled with ordinary topsoil was generally better than their counterparts planted in the green-gro medium. Higher accumulation of total nitrogen, phosphorus, potassium and calcium were observed in seedlings planted in bags filled with top soil than those planted in green-gro medium. Seedlings planted in topsoil produced more dry shoot to root ratio than their counterparts planted in green-gro medium, However, seedlings planted in green-gro medium produced more dry root to shoot ratio than their counterparts planted in the topsoil. Seedling mortality rate was low among seedlings planted in bags filled with green-gro medium. Generally, nutrient recovery rate was low for phosphorus and potassium. The recovery rate was high for nitrogen in treatments with N P K Mg and Polyfeed + Mg fertilization and high for magnesium in treatments with Polyfeed fertilization irrespective of the media. The cost of using green-gro medium was extremely higher than the use of topsoil for nursery establishment and was aggravated when Polyfeed was used for fertilization. The quality of topsoil is an important determinant for seedling growth and survival and should be properly managed to reduce cost of production.

CHAPTER ONE

1.0 INTRODUCTION

Oil palm (*Elaeis guineesis* Jacq.) is the second most important cash crop in Ghana after cocoa. It has contributed substantially to poverty alleviation and economic growth in the oil palm belt of the country (Anon, 1990). The crop is robust and can thrive under adverse soil and climatic conditions (Hartley, 1988). It is therefore not surprising that its cultivation over the years has replaced cocoa in the areas where cocoa plantations were devastated by swollen shoot and bush fires.

The potential industrial uses of palm oil are so huge that concerted efforts are being made by the Ghana government to raise the national palm oil output from 100,000 to 200,000 tons per annum by 2012 (Anon, 2006). To realize this vision a total land area of 350,000 hectares is expected to be cultivated which will require raising of about 57,000,000 healthy seedlings.

Propagation medium used in raising seedlings in polyethene bags are usually collected from refuse dumps generally referred to a "black soil". Of late there has been a problem of getting adequate quantities of this "black soil" due to its contamination with non-degradable polyethene waste. The quantity of the "black soil" needed to meet the huge demand of nursery operators cannot be attained. The oil palm nursery operators have therefore resorted to the use of any topsoil and even sub-soil as propagation medium. Clayey top soil is mixed with sand in a ratio of 2:1 to make it loamy enough for seedling production. According to Abner and Foster

(2006), good quality topsoil, high in organic matter enhances oil palm seedling growth and development. It is increasingly becoming scarce to come by the quality topsoil for nursery operations. This has necessitated the use of soil additives to enrich the available topsoil.

With the introduction of the President Special Initiative on Oil Palm in Ghana, many Commercial Business entities have flooded the market with many of these soil additives. Green-gro is one of such soil additives. It is made from compost of shredded coconut husk, cocoa bean husk, chicken litter and aerating material "palm shell" this is to be mixed with topsoil for use. Polyfeed, a fertilizer formulation for oil palm nursery, is another new introduction into the Ghanaian market.

The general objective of this study was to evaluate these soil additives along side the standard practice in the system.

The specific objectives were to:

(i) compare the effects of green-gro and sole topsoil on oil palm seedling growth and development.

(ii) compare Polyfeed (19:19:19:1) with the standard formulation, N: P: K: Mg (1:1:1:2) on the performance of oil palm seedlings.

(iii) evaluate the effects of the different combinations of propagation media and fertilizer formulations on soil microbial biomass Carbon (C), Nitrogen (N) and Phosphorus (P).

(iv) appraise the agro-economic benefits of the introduced soil additives and the standard practice on oil palm nursery enterprise.

Hypothesis

The above objectives were formulated to test the null hypothesis that different propagation media and fertilizer formulations do not affect the performance of oil palm seedlings and soil health.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sustainable nutrient management

2.1.1 Definition

In agriculture, sustainability describes farming systems that are capable of maintaining their usefulness to the society indefinitely. Such systems must be resource conserving, socially supportive, commercially competitive, and environmentally friendly (Duesterhaus, 1990). Parr *et al.* (1993) define sustainable agriculture as the one that for the foreseeable future will be productive, competitive and profitable, conserve natural resources, protect the environment, and enhance public health, food quality and safety. Marra and Kaval (2000) provided a similar definition of sustainability, describing it as fewer negative environmental impact from agricultural production, coupled with sufficient net returns for grower to continue farming. The FAO (1993) listed four criteria for sustainable land management: (1) production should be maintained, (2) risk should not increase, (3) soil and water quality should be maintained and (4) systems should be economically feasible and socially acceptable.

2.1.2 Nutrient management concept

To manage nutrient sustainably requires integration of plant nutrients in a manner to harness their full benefits. A sustainable integrated nutrient management system offers the most promising approach to arrest the unprecedented degradation of the environment. The basic concept underlying the system is the maintenance or adjustment of soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefit from all possible sources of plant nutrient in an integrated manner (FAO, 1993). Such a system entails the use of combinations of mineral fertilizers, animal manures, green manures, crop residues and compost.

2.1.3 Constraints to sustainable nutrient management

To know the threshold values or critical limits for the proposed soil quality indicators is an important determinant of the constraints to sustainable nutrient management. The threshold value or the critical limit is defined by Arshad and Martin (2002) as the desirable range of values for a selected soil indicator that must be maintained for normal functioning of the soil ecosystem. Within this critical range the soil performs its specific functions in natural ecosystems. For example, to grow most crops the pH must be 6.5-7.0 and soil depth must be 50cm or more.

The selection of critical limits for soil quality indicators poses several difficulties. The ability of soil to supply moisture, nutrients and physical rooting support in the absence of toxic substances can be affected by many physical, chemical and biological parameters. A detrimental change in any of these can reduce the soil quality, but the quantitative values beyond which a further reduction in these properties is limiting depends strongly on the crop. For example, a pH below 6.5 reduces the yield of alfalfa, but pH must drop below 4.0 before critical yield reduction occurs in blueberries (Doll, 1964) and pH < 5.0 is accepted in oil palm (CIRAD/IRHO, 1979).

2.1.4 Indicators for assessing nutrient management

2.1.4.1 Soil physical indicators

Soil physical properties that affect plant nutrient management include texture, structure, bulk density and aeration. Hammond *et al.* (1986) and Rajan *et al.* (1996) discovered that soil texture affects the rate and amount of dissolution of phosphate rock which consequently affect oil palm phosphorus uptake in soil. Soil texture and structure which affect drainage and infiltration have direct effect on water availability to the plants. The water-holding capacity of soil is related to soil texture. Soil aggregation plays an important role in an array of soil properties such as soil erodibility, organic matter protection, soil fertility, and soil productivity (De Gryze *et al.*, 2005; Bronick and Lal, 2005). According to Six *et al.* (2002), aggregate stability is often used as an indicator of soil structure.

2.1.4.2 Soil chemical indicators

Soil chemical properties such as soil organic matter, soil mineral particles and soil plant nutrients are important soil chemical indicators that are used to assess nutrient management.

2.1.4.2.1 Soil organic matter

Soil organic matter (SOM)-related properties have been shown to serve as a good soil quality indicator (Arshad and Coen, 1992; Islam and Weil, 2000; Kenedy and Papendick, 1995; Larson and Pierce, 1994; Wander and Bollero, 1999). In the oil palm, avenues exist for reducing the inorganic fertilizer bills through the recycling of nutrients from organic materials derived from the production system. Such organic materials include leguminous cover crop, oil palm parts after felling, fronds from annual pruning, empty fruit bunches and waste from the processing of fresh fruit bunch (FFB) (Omoti, 1989).

Depletion of soil organic carbon can have implications for the long-term productivity of soil. For example, losses of organic carbon (OC) from the soil can result in loss of structure, nutrient retention, water holding capacity and biological processes associated with nutrient cycling (Oades, 1984; Elliott and Coleman, 1988; Carter *et al*., 1997).

Soil organic matter is known to have a strong relationship with aggregate formation and stabilization (Tisdall and Oades, 1982; Zhang *et al*., 1996; Six *et al*., 2002). The organic fraction of manure can significantly increase soil aggregation, infiltration, microbial activity, structure, and water-holding capacity and can reduce soil compaction and erosion (Gilley and Risse, 2000; Haynes and Naidu, 1998).

Organic matter is predicted to reduce heavy metal availability through the increase of cation exchange capacity and its ability to adsorb metal into stable form by longhand bond (Elliot *et al*., 1986).

Several studies have shown that organic materials and their decomposition products can reduce phosphorus fixation in soils (Mnkeni and MacKenzie, 1985; Sibanda and Young, 1986; Iyamuremye *et al*., 1996; Kwabiah *et al*., 2003). Most of these studies attributed the reduction in P fixation to the complexation of Al and Fe by organic acids, competition between organic acids and orthophosphate for adsorption sites and release of P by organic material during decomposition.

2.1.4.2.2 Soil mineral particles

High clay content in soil serves as binding agent between soil colloids and plant nutrients. This prevents nutrients from being leached easily and makes the nutrients utilized by the plants from the soil. According to Van Veen *et al.* (1985) and Parton *et al.* (1987), the finer fractions of the soil matrix, mostly the clay fraction provide a protective capacity to microbial biomass and organic matter.

Alluvial soils with greater content of 2:1 montmorillonitic clay are high in available magnesium and do not need supplementary source from applied fertilizer if used for oil palm cultivation (Mohd, 2005).

2.1.4.2.3 Soil plant nutrient

Soil fertility is the capacity of a soil to provide plants with nutrients- nitrogen (N), phosphorus (P) and potassium (K) in adequate and balanced amounts (Jansen *et al.*, 1990). The potential supply of N, P and K from the soil is estimated from a set of chemical properties of the soil. Subsequently, a nutrient limiting yield is determined on the basis of the actual uptake of that nutrient. An agricultural practice with high external inputs results in positive soil nutrient balances whilst agricultural practices with low external inputs as commonly found in tropical countries may result in the depletion of soil nutrient stock which seriously threaten the future of agricultural production (Stoorvogel and Smaling, 1990).

According to Stoorvogel and Smaling (1990), the soil nutrient balance is quantified by the estimation of different nutrient flows. Five major inputs and five major outputs of nutrients were identified. The net soil nutrient budget can be determined by calculating the net difference between the input and output of the nutrients. The net nutrient input parameters are added mineral fertilizers, organic fertilizers, wet and dry depositions, nitrogen fixation and sedimentation while the net nutrient output includes crop products, crop residues, leaching, gaseous losses and soil erosion.

2.1.4.3 Soil biological indicators

2.1.4.3.1 Microbial biomass

Recently, microbial biomass has even been proposed as a sensitive indicator of soil quality and soil health (Karlen *et al.,* 1997; Sparling, 1997). A microbially active carbon fraction although a small component of the total soil organic matter plays a particular important role in maintaining soil quality (Weil, 1992).

According to Lynne *et al.* (2003), the potential benefits of increased microbial biomass and activity are numerous. They include increased soil aggregate formation and stability, enhanced plant litter decomposition, increased nutrient cycling and transformations, slow-release storage of organic nutrients, and pathogen control. Additionally, microbial plant symbionts such as mycorrhizal fungi directly improve plant nutrient supply, stress tolerance, and productivity.

Soil microbial biomass is intimately linked to nutrient transformations in soil, acting as both a sink and a source of nutrients (Jenkinson and Ladd, 1981; Singh *et al*., 1989). Seasonal changes in soil microbial biomass are important in controlling the turnover of carbon (C) and associated nutrients (e.g. nitrogen (N), phosphorus (P) and sulfur (S)), which in turn regulate nutrient availability for plant uptake (He *et al*., 1997; Chen *et al*., 2003).

Turco *et al.* (1994) stated that larger stable microbial population and greater activity may indicate greater soil quality while Smith and Paul (1990), postulated that soil microbial biomass acts as a reservoir of critical nutrients and is a major determinant for governing the nutrient availability and resource base for nutrient release, which finally reflect soil fertility levels.

2.1.4.4 Plant performance indicators

2.1.4.4.1 Fertilizer Nutrient recovery

Blair (1993) defined nutrient efficiency as the ability of a genotype/cultivar to acquire nutrients from growth medium and/or to incorporate or utilize them in the production of shoot and root biomass or utilizable plant material (seed, grain, fruits, forage).

Higher nutrient use efficiency by plants could reduce fertilizer input costs, decrease the rate of nutrient losses, and enhance crop yields. Genetic and physiological components of plants have profound effects on their abilities to absorb and utilize nutrients under various environmental and ecological conditions. Genetic, morphological, and physiological plant traits and their interactions with external factors such as soil moisture and temperature, light, best management practices, soil biological, and fertilizer materials need to be more thoroughly evaluated to improve the nutrient use efficiency in plants.

Zhu (2000) reported that fertilizer nitrogen efficiency in field crops is estimated at 30 to 50%. According to Baligar and Bennett (1986a and 1986b) the recovery of applied inorganic fertilizers by plants is low in many soils. According to them estimates of overall efficiency of these applied fertilizers have been about 50% or lower for N, less than 10% for P, and close to

40% for K. These lower efficiencies are due to significant losses of nutrients by leaching, run-off, gaseous emission and fixation by soil.

2.1.4.4.2 Relative Agronomic Effectiveness

The application of animal manures has been found to lead to a higher level of exchangeable cations and this increase is attributed to mineralization from the manure (Eneji *et al*., 2002). Soil management and cultivation can affect OC storage in soils and change the mechanisms of OC stabilization. Conversion from natural ecosystems to artificially regulated ecosystems (e.g., grass into arable lands) is often accompanied by drastic changes in soil properties (Houghton, 1990; Lemenih and Itanna, 2004; Puget and Lal, 2005; Teklay *et al*., 2006; Hoyos and Comerford, 2005; Templer *et al*., 2005). Williams *et al*. (2005) suggested that conventional tillage caused decreases in the quantity and quality of soil organic matter (SOM) and declines in aggregate stability, total SOC, and particulate organic matter carbon (POM-C) as compared to grassland. However, organic amendment can increase POM-C and aggregate stability (Li *et al*., 2004).

Chemical properties improved by manure application include cation exchange capacity and soil buffering potential (Tisdale *et al*., 1993). Improvement and maintenance of a good supply of organic matter (OM) through recycling in soil is a precondition for efficient recycling of nutrients. Castillo *et al*. (2003) reported that when manures are managed properly, they become valuable soil amendments ~~and their~~ application to agricultural land receives considerable attention because of their natural value, liming effect, and environmental friendly behavior. The land application of manure can produce crops similar to those obtained using inorganic fertilizers (Eghball and Power, 1999).

2.1.4.5 Socioeconomic indicators

The major challenge ahead of Ghana agriculture is to produce adequate food to feed the ever growing population. The present rate of population growth has put pressure on farm lands which has reduced fallow period from 8-15 years to 2-3 years after 1-3 years of farming. Sustainable farming involves appropriate and rational utilization of the soil.

Under the present socio-economic conditions of Ghanaian small holder farmer, dependency of mineral fertilizer alone will accelerate the rate of nutrient mining. It is therefore important to place special emphasis on the concept of integrated plant nutrient systems using all available sources. Mineral as well as organic sources namely farm yard manure, green manure, cover cropping, compost, agroforestry, biological nitrogen fixation and crop-livestock integration.

The major problems associated with integrated plant nutrient management strategy are availability, and affordability. For instance, Ahenkora *et al.* (1973) attempted to develop a suitable potting medium made up of cocoa bean shell mixed with soil but encountered the problem of reliable supply of sufficient quantities of the materials. Only few rich farmers can afford transporting large quantities of farm yard manure or compost to their farms. However, there is a gain not only in yield increased but also land improvement in the application of integrated plant nutrient management.

2.2 Role of mineral nutrients in growth and development of oil palm

2.2.1 Nitrogen

Martin and Prious (1972) have shown that application of nitrogen in the form of urea significantly improved the girth of young palms up to the age of 18 months, but the effect subsequently dropped off. However, bunch production does not increase rigorously with nitrogen fertilization from the start of production to 18 years. Nevertheless, the nitrogen content of leaf number 17 significantly improved for certain years. According to them, ammonium sulphate markedly depresses magnesium nutrition, especially when it already has a tendency to drop naturally from the age of 8 years onwards.

There is an insignificant increase in growth, leaf area and production in adult palms with nitrogen fertilization and nitrogen content of the palms receiving no nitrogen are above critical (Pacheco *et al.,* 1985).

2.2.2. Phosphorus

Phosphorus (P) is an essential plant nutrient. However, it is fertility constrain in tropical soils (Sale and Monkwunye, 1993). Most Ghanaian soils are inherently deficient in P because they are highly weathered and have low levels of mineral apatite (Nye and Bertheux, 1957; Acquaye and Oteng, 1970). Oil palm has been found to respond to different sources of phosphorus. Adebayo *et al.* (2006) observed that without addition of P the number of leaves per plant and butt circumference of oil palm seedlings were much lower. Similar response of oil palm to P fertilization had been observed in Nigeria (Ataga, 1978) and in Malaysia (Zaharah *et al.*, 1997). Work done by Adebayo *et al.* (2006) showed that without added P, leaf nutrient content of oil palm seedlings was very low. P fertilizer applications irrespective of source or rate significantly increase the P as well as the magnesium, calcium and zinc content of the plants. Obigbesan *et al*. (2002) observed that root growth was inhibited at low P supply.

Lucas *et al*.(1979) and Menon and Chien (1990) showed that there were significant increase in leaf P content of oil palm seedlings treated with different P sources. They found that doubling the application rate (15.12g P_2O_5 /palm) increased the nutrient content of the leaf more than the recommended rate of 7.56g P_2O_5/palm. This agrees with the work of Agboola and Obigbesan (1974) that affirmed the high correlation between P rate and P uptake in crop plants. However, on soils with very high clay content, recommended application rate of 7.56g P_2O_5/palm was better than the double dose.

2.2.3. Potassium

Potassium has been found to be one of the most essential nutrients of oil palm. Ochs *et al*. (1991) discovered that for leaf potassium content (L17) of 1% or more, further addition of potassium by fertilizer application produce no measurable improvement in production. Between 0.9 and 1%, expected production decreased by 5% and therefore placed a mean critical leaf potassium level at 0.95%. Where as IRHO (1960) recommended 1% of oil palm leaf potassium as the critical level.

Foster *et al.* (1987) reported of depressive effect of muriate of potash (KCl) fertilizer on the oil to bunch ratio. They explained ~~that it is~~ most likely due to a reduction in Mg uptake. From their findings, leaf Mg when expressed as a percentage of total leaf bases was higher and therefore if not reduced to a limiting level by the KCl fertilizer, the potassium constituent of the fertilizer was able to increase mesocarp production and hence raised the oil to bunch ratio.

2.2.4 Magnesium

Magnesium (Mg) plays a vital function in the formation of chlorophyll in plants. It is required in the activation of enzymes concerned with carbohydrate metabolism, fatty acids or oil biosynthesis, and is prominent in the citric acid cycle which is important to cell respiration. It is associated with phosphorus in the formation of phospholipids in oil and related with sulphur in the synthesis of oil (Tayeb, 2005). He found that continuous use of potassium antagonize magnesium uptake by oil palm and continuous use of nitrogen fertilizer lead to the suppression of magnesium uptake by the direct effect of ammonium ions and acidification of the soil. Addition of magnesium to the sulphur further enhances the production of oil (Venema, 1962). Ochs and Ollagnier (1977) reported a positive effect of Mg (in kieserite form) on oil content. Foster *et al.* (1987) explained the depressive effect of KCl fertilizer on oil to bunch in Malaysia which seemed most likely to be due to the reduction in Mg uptake.

Chan and Rajaratnam (1976) reported that profitable response to Mg was rare and that application of kieserite of more than 1-1.5 kg/palm/year had no effect on yield. Ahmed *et al.* (1985) reported that an average rate of 2kg kieserite/palm/year is generally most economic in early years, but responses gradually decline with time and no more than 1kg /palm/year of kieserite is generally required in later years.

Dubos *et al.* (1999) reported that when leaf content Mg is above 0.2 - 0.24%, yield does not usually respond to Mg fertilizer application, irrespective of the rate applied. Whereas response does occur for values below 0.15%, even with low application rate and significant gains of 10 to 40% can be obtained with application of Mg fertilizers.

According to Prabowo and Foster (1998), when soil is deficient in Mg and K, mature oil palm respond positively to Mg during the third and forth year after the treatments, showing significant increase in fresh fruit bunch due to increase in bunch number. They observed that the frond dry weight, leaf area, leaf production and yields were smaller in palms with acute Mg deficiency. A positive linear correlation between Mg content in frond 17 and oil to bunch was obtained when Mg was in the range of marginal supply. Correcting Mg deficiency resulted in an increase in the mesocarp: fruit ratio and an increase in the mesocarp oil content. These results were explained by a reduction in starch accumulation in storage organs when Mg deficiency results in impair carbohydrate transport.

2.3 Impact of nutrient management techniques on performance of oil palm

2.3.1 Effect of propagation medium

Hartmann and Kester (1990) enumerated the characteristics of a good propagation medium as:

a. being sufficiently firm and dense to hold seedlings in place.

b. being sufficiently porous that excess water drains away permitting adequate aeration.

c. being free from weeds.

d. free from nematodes and various noxious disease organisms.

e. having low salinity levels.

f. having sufficient plant nutrient to promote faster seedling growth especially as in the case of oil palm where the plants ~~are to~~ remain in the nursery for longer period.

2.3.1.1 Topsoil

A good quality topsoil high in organic matter gives good results in oil palm nursery but is unsustainable practice since it depletes the area from which it is collected (Abner and Foster, 2006). Karlen *et al.* (1997) defined soil quality as the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. CIRAD and IRHO recommended that a suitable soil for oil palm production should contained at least 15 to 30% fine element (fine sand + loam +clay) in the top 0 to 20cm depth and critical level of various mineral elements are shown in the Table 2.1.

Table 2.1 Critical levels of soil mineral elements for oil palm

Mineral element	Critical level
C (%)	1.00
N (%)	0.10
Available (Olsen) P mg/kg	30.00
Exchangeable cations (cmol/kg)	
K	0.20
Mg	0.40
Ca	-
pH (H_2O)	<5.00

Source: CIRAD/IRHO (1979)

2.3.1.2 Propagation medium made from composted materials

The waste product from oil palm mill, such as empty fruit bunches, fibre, shell and liquid waste (POME) contain appreciable amount of NPK and Mg nutrients. Thus using compost made from these materials has the potential to replace not only the soil but also fertilizer used in the nursery (Abner and Foster, 2006).

Traditionally, residues such as urban solid wastes, sewage sludge and even green wastes were considered as non-desirable or with little value. Currently, numerous studies have demonstrated that these organic residues, after proper composting, can be used with very good results as growth media (Verdonck, 1984, 1988; Raviv *et al.*, 1986; Chen *et al.*, 1988; Bugbee and Frink, 1989; Piamonti *et al.*, 1997; García-Gómez *et al.*, 2002).

Several studies have shown that use of municipal solid waste (MSW) compost in agriculture has many benefits to soil, crops and environment (Hortenstine and Rothwell, 1973; Maynard, 1995; Hicklenton *et al.*, 2001; Rodd *et al.*, 2002). Iglesias-Jimenez and Alvarez (1993) studied the effect of city refuse compost as a P source to overcome the P-fixation capacity of sesquioxides-rich soils and found it to be effective in diminishing the fixation process by providing equivalent amounts of soil labile-P as di-potassium hydrogen orthophosphate, which significantly increased P concentration of plant tissue.

Hue *et al.* (1994) also reported similar findings using yard-waste compost and attributed this to the release of P during the decay process and the competition between organic anions (released by compost) and P for adsorption sites in the soil complex. Meanwhile, Giusquiani *et al.* (1988) reported that addition of urban-waste compost increased soil P solubility. They postulated that the increase in soil P solubility was caused by the formation of phosphohumic complexes that minimise immobilisation process, anion replacement of P by the humate ion, and coating of sesquioxide particles by humus to form protective cover.

Literature shows great variability between pH values, electrical conductivity, or nutrient contents among these types of compost (Hegberg *et al.*, 1991; Hartz *et al.*, 1996; Spiers and Fietje, 2000; Benito *et al.*, 2000), but all conclude that they must be considered as good quality plant growth substrates.

2.3.2 Effect of organic fertilizers

Sireger *et al.* (2002) found that compost made from empty fruit bunch (EFB) over 8-9 weeks could replace inorganic fertilizer in oil palm nursery if applied at a rate 7.5kg per poly bag. Compost made from EFB, Palm Kernel Cake and Palm Oil Mill Effluent (POME), over a 36 weeks period gave excellent oil palm seedling growth (Lord *et al.*, 2002), whilst Chong (2005) found compost made from only EFB and POME over 10 weeks also gave good growth performance in the oil palm nursery.

The use of compost made from oil mill waste over 6 and 12 weeks mixed with soil in different proportions with or without additional 25% standard fertilizer applied from 8 month is reported to improve growth of oil palm seedlings (Abner and Foster, 2006).

According to Caliman *et al.* (2001), empty fruit bunch (EFB) of oil palm can be used as compost for fertilization of oil palm fields but caution that when left on the milling floor or edge of the field prior to the spreading for longer period, it undergoes substantial leaching of plant nutrients. They found that there is rapidity of nutrient release from EFB when returned to the field and if delayed for one week causes N P K Mg loses of 9%, 10%, 18% and 8% of the original contents respectively with 33mm rainfall.

2.3.3 Effect of inorganic fertilizer

Pacheco *et al.* (1985) have shown that nitrogen fertilizer is only useful in young palms to improve the vigor of the young plants and nitrogen fertilization should be limited to first and second years after planting. They indicated that, this fertilizer recommendation is not fundamental; the cheapest form per unit of nitrogen should be used. They also reported that potassium chloride significantly increases the average weight of the bunches, but not the number of bunches. Hence the overall result in improvement in weight of bunches per tree. Adebayo *et al.* (2006) reported that phosphate rock treated oil palm seedlings had superior effect compared to seedlings treated with triple super phosphate. However, Obigbesan and Mengel (1981) and Fayiga (1998) discovered that rock phosphates are useful fertilizers in acidic soils. They also showed that solubility of single super phosphate is much better in more neutral soils compared with acidic soils. Thus, phosphate ions released from it are probably strongly adsorbed by sexquioxides and thus become less soluble than rock phosphate. This could be responsible for its low performance.

According to Pacheco *et al.* (1985), phosphate fertilizer is capable of doubling the yield of young palms and almost quadrupling it at around 15 years old from 7 to 23.7 tons/ hectare/year. Ochs and Ollagnier (1977) observed a significant increase in the oil to bunch ratio due to application of magnesium sulphate.

2.4 Influence of fertilizer application on soil microbial biomass

2.4.1 Effect of compost on microbial biomass

Composted organic materials are substrates for proliferation of soil microorganisms. Consequently, soil microbial biomass increases with increasing input of plant biomass into the soil (Collins *et al*., 1992).

According to Brookes and Mc Grath (1984), organic matter additives can directly increase microbial biomass unless these are contaminated by heavy metals or adversely affected by soil pH.

According to Collins *et al.* (1992), if the inputs of plant biomass in the soil are great, the soil microbial biomass also increase. Application of organic amendments and farmyard manure to soil increases microbial biomass. Ghosal and Singh (1995) measured a 50% increase in microbial biomass in a rice and lentil cropping system when farmyard manure was applied at the rate of 20 t/ha for 4 years. Application of 40kg nitrogen/ha/year with farmyard manure increased microbial biomass carbon from 200 to 350mg /kg soil. Similar increase was measured for microbial biomass nitrogen while microbial biomass phosphorus increased more than two folds.

Marschner *et al*. (2003) observed that even though organic and inorganic fertilizers are used primarily to increase nutrient availability to plants, they can affect the population, composition, and function of soil microorganism. Organic fertilizers usually increase soil microbial biomass (Peacock *et al*., 2001; Parham *et al*., 2002; Kaur *et al*., 2005).

2.4.2 Effect of mineral fertilizer on microbial biomass

In Ultisol, it was observed that microbial biomass carbon decreased due to the application of 80kg nitrogen/ha/year for 8 years to wheat or including legume in cereal cropping presumably due to lowering of soil pH (Ladd *et al*., 1994). Carter (1986) also found that addition of gypsum to an acidic soil reduced microbial biomass by decreasing soil pH, while addition of lime increased microbial biomass.

Hopkins and Shiel (1996), Parham *et al*. (2002), Parham *et al*. (2003) and Plaza *et al*. (2004) found that inorganic fertilizers had relatively less effect on soil microbial biomass and activities than organic fertilizers. While Ruppel and Makswitat (1999), Wardle *et al*. (1999) and Marschner *et al*. (2003) found that fertilization results in microbial community shifts in soils.

However, numerous studies reported of the decreased microbial biomass by mineral N fertilizer (Ladd *et al*., 1994; Hopkins and Shiel, 1996; Simek *et al*., 1999; Sarathchandra *et al*., 2001; Bittman *et al*., 2005), which was attributed to direct toxicity and reduced pH because of ammonium-based fertilizers (Hopkins and Shiel, 1996). Cereal cropping with nitrogen fertilizer applications also appears to increase microbial biomass carbon and nitrogen in soil (Singh and Singh, 1993).

Literature review Summary

Sustainability in agriculture is defined as a fewer negative environmental impact from production coupled with sufficient net returns for the grower to continue farming. In oil palm nursery enterprise, any good top soil rich in organic matter gives better seedlings performance but not sustainable and deplete the area from which it is collected. The addition of plant nutrients in the form of organic and inorganic fertilizers is important to maintain high level of plant nutrients in any available friable soil.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of the study area

The study was carried out at the Sarpcoe oil palm nursery site at Okyinso near Kade in the Eastern Region of Ghana.

Plate 3.1 Site of the study area

3.2 Climate of the study area

The study area falls within the semi deciduous forest zone of Ghana. The area is characterized by bi-modal rainfall distribution. The major rainfall season begins from March to July and minor rainfall season starts from September to November. The mean annual rainfall is

1,800mm. Day temperatures are normally high, ranging from a mean minimum of 20°C to a mean maximum of 31°C

3.3 Experimental design and treatments

The randomised complete block design (RCBD) was used with 8 treatments in 3 replications. Two potting media and three fertilizer formulations were used. The media were sole topsoil and green-gro and the fertilizer formulations were $(NH_4)_2SO_4$+TSP+MOP+Kieserite (1:1:1:2) (commonly referred to as N: P: K: Mg 1:1:1:2), Polyfeed (N: P: K: Mg 19:19:19:1) and Polyfeed + magnesium (1:1). The treatment details were:

T1. Topsoil + N: P: K: Mg (1:1:1:2) - OPRI recommandation

T2. Topsoil + polyfeed (19:19:19:1)

T3. Topsoil + polyfeed + Kieserite (1:1)

T4. Green-gro + N: P: K: Mg (1:1:1:2)

T5. Green-gro + polyfeed (19:19:19:1)

T6. Green-gro + polyfeed + Kieserite (1:1)

T7. Topsoil only

T8. Green-gro only

3.4 Green-gro Preparation

Green-gro is a mixture of grow-plenty (compost) (15%) and topsoil (85%). Grow plenty was prepared with 40% chicken litter, 30% shredded cocoa bean husk, 30% shredded coconut husk. These materials were thoroughly mixed with top soil in a ratio of 15% green-gro: 85%. The topsoil was from Kokofu series (Ferric Plithic Acrisol-FAO/UNESCO, 1976).

3.5 Filling of polyethene bags

Polyethene bags of size 30 × 18 cm lay flat and gauge 150 microns were perforated on the sides. A 9 kg of topsoil and the green-gro were used to fill the bags to three quarters (3/4) of its length

3.6 Field layout, Pegging and Arrangement of the polyethene bags

The field was laid in a gentle sloped land area. The area was cleared and freed from debris and stumps. The plots were laid with each plot covering a total land area of 9.8 m^2. The field was pegged 70 cm ×70 cm triangular. The black polyethene bags were arranged in 10 per row and 3 rows per plot. This gives a total of 30 plants per plot.

3.7 Transplanting of seedlings

A 10 cm diameter auger was used to bore holes in the polyethene bags. Four months old pre-nursed D×P (tenera) oil palm seedlings of uniform size were transplanted in the holes. The pre-polyethene bags were carefully removed without disturbing the ball of earth around the roots.

3.8 Post transplanting treatments

Watering was done manually as and when necessary. Fertilizers (treatments) were applied monthly at 30g/plant/month for all the eight months. Fertilizer was applied to the base of the seedlings in the polyethene bag. Seedlings were watered immediately after every fertilizer treatment. Weeds in the interrows of the bags were controlled with glyphosate at bi-monthly intervals at the rate of 3l/ha. Weeds that grew in the bags were regularly hand picked as and when necessary. Oil palm bunch spikelets were used to mulch the surface of the media in the polyethene bags. Mulching was done immediately after transplanting. There was no schedule programme for pests and diseases control. Prophylactic Insecticidal (cymethoate 1 l/ha) and fungicidal spraying (dithane 1 kg/ha) were done at bi-weekly intervals to prevent insect pests or diseases incidence. Dried leaves were pruned as soon as they were observed. Pruned leaves were burnt immediately outside the field.

3.9 Vegetative measurements

Vegetative measurements were taken from eight (8) randomly selected and tagged seedlings on every plot. The measurements were done on monthly intervals. The vegetative data taken were: butt circumference, plant height, number of leaves, frond dry weight, leaf area and leaf area index.

3.9.1 Butt circumference

Butt circumference was measured with a pair of vernier calipers. The diameters of the butts were measured in two dimensions from north – south (NS) and east – west (EW).

Calculation:

$$R=\frac{NS+EW}{4}$$

Butt circumference $=\pi 2R$, where R was the radius.

3.9.2 Plant height

Plant height was measured with a ruler. It was measured from the soil level to the tip of the longest leaf.

3.9.3 Number of leaves

It was obtained by counting all the functional leaves that were opened on a seedling.

3.9.4 Frond Dry Weight (FDW)

Frond dry weight was calculated using the formula described by Corley (1971). It was obtained by measuring the width and depth of petiole of the third leaf of the seedlings from the top opened leaf of the plant.

Calculation:

$$FDW_{(kg)} = D \times W \times 0.1023 + 0.2062$$

where D = Depth of the petiole

W = width of the petiole

0.1023 +0.2062 = correction factor

3.9.5 Leaf Area (LA)

Leaf area was calculated with the formula provided by Hardon *et al.* (1969). It was calculated after the plants were five (5) ~~months old~~ after transplanting and had developed leaflets on the third leaf from the top opened leaf. Three (3) leaflets were taken from the centre of each side of a frond. The width and length were measured with a ruler. The width was measured at the centre. The means of the six leaflets were computed to represent a leaflet for calculation of the leaf area.

Calculation:

$$LA = L \times W \times N \times 0.55$$

where L = mean length of the leaflets

W= mean width of the leaflets

N= number of leaflets on the frond

0.55= correction factor

3.9.6 Total leaf area (TLA)

Total leaf area was calculated as a transition to the computation of leaf area index (LAI).

Calculation:

$$TLA = LA \times F$$

where F = number of fronds on the plant.

3.9.7 Leaf area index

Leaf area index was computed by relating the total leaf area to the area covered by the plant (density) The third leaf was used for the measurement.

Calculation:

$$LAI = \frac{TL}{D}$$

where D = density

Density or land area covered by a plant was calculated as

$$\frac{1}{2} \times \text{Planting distance} \times \sqrt{3}$$

3.10 Media characterization

Samples of the media were taken before filling the bags and analysed for:

i. Physical properties: sand, silt and clay (Texture)

ii. Chemical properties: Soil pH, total nitrogen, available phosphorus, available potassium, exchangeable bases (calcium, magnesium, potassium and sodium), exchangeable acidity (H^+ and Al^{3+}), effective cation exchange capacity (ECEC), total exchangeable bases and percentage base saturation

iii. Microbial biomass (carbon, nitrogen and phosphorus)

iv. Organic carbon.

3.11 Analytical Methods

The chemical and physical properties of the media were analysed in the Mineralogy and Analytical Laboratory of Soil Research Institute, Kwadaso – Kumasi. Field moist media samples were used for the microbial biomass nitrogen, phosphorus and carbon analysis. The rest of the samples were air-dried, crushed and passed through 2 mm mesh sieve before analysis.

3.11.1 Media pH

Media pH was determined in a 1:1 suspension of media and water using a HI 9017 micro-processor pH meter. A 25 g media sample was weighed into 100 ml plastic beaker. Twenty five millilitres distilled water was added from a measuring cylinder. The suspension was stirred with a stirring rod for 30 minutes. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the electrode was immersed into the suspension and the pH was read.

3.11.2 Organic carbon

Media organic carbon was determined by a modified Walkley and Black procedure as described by Nelson and Sommers (1982). This procedure involved a wet combustion of the organic matter with a mixture of potassium dichromate and suphuric acid. After the reaction, the excess dichromate was titrated with standard ferrous sulphate solution. A 0.5 g of soil sample was weighed into an Erlenmeyer flask. A reference sample or a blank was included. A 7.5 ml 1.0*N* potassium dichromate solution was added to the soil and the blank flask. Fifteen millilitres of concentrated sulphuric acid was carefully added from a measuring cylinder, stirred and allowed to cool for 30 minutes. Ten millilitres of distilled water and 5 ml of concentrated orthophosphuric acid were added. One milliliter of diphenylamine indicator was added and titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

% Organic Carbon = T × (7.5/ BV) – 7.5 × 0.78

where T = Titre value

7.5 × 0.78 = potassium dichromate correction factor

7.5 ÷ BV = $FeSO_4$ correction factor

3.11.3 Total Nitrogen

Total nitrogen was determined by Kjeldahl digestion and distillation procedure (Soil Laboratory Staff, 1984). A 0.2 g soil sample was weighed into a Kjeldahl digestion flask and 5.0 ml distilled water added to it.

Five millilitres concentrated sulphuric acid, 5 ml distilled water; a Kjeldahl catalyst tablet and a selenium mixture were added and mixed carefully. The sample was placed on a Kjeldahl digestion apparatus for 2 h until a clear digest was obtained. The digest was transferred to the reaction chamber and 10.0 ml of 0.2 *M* of NaOH solution was added followed by distillation. The distillate was collected in a flask containing 2% boric acid and titrated with 0.02 *M* HCl solution with bromocresol green as indicator. A blank distillation and titration was also carried out to take care of traces of nitrogen in the regents as well as the water used.

The percentage total nitrogen was expressed as:

$$\%N = \frac{(T \times BV \times M \times 14.007 \times 100)}{0.2 \times 1000} \times 1.18$$

where BV = Blank value

T = Titre value

M = Moles of HCl/dm^3 used

14.007 = Atomic weight of nitrogen

0.2×1000 = Weight of soil used (grams)

100 = Corrected to %

1.18 = Recovery rate of the instrument.

3.11.4 Available Phosphorus (Bray's No. 1).

The readily acid – soluble form of phosphorus was extracted with HCl : NH_4F mixture called the Bray's number one method as described by Bray and Kurtz (1945) and Olsen and Sommers (1982). Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent.

A 5 g soil sample was weighed into a shaking bottle (50 ml) and a 35 ml of extracting solution of Bray 1 (0.03 *M* NH_4F and 0.025 *M* (HCl) was added along side the blank. This was shaken for 10 minutes in a shaker and immediately filtered through a fine filter paper (Whatman No. 42). Five millilitres of the aliquot was pipetted into a test tube. Ten millilitres of colouring reagent (ammonium molybdate and antimony tartarate solution) was added. A pinch of small quantity of ascorbic acid powder was added into the test tube and stirred. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at 660 nm wavelength on medium sensitivity using the blank to set the instrument to zero.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l was prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in 100 ml volumetric flasks and made to volume with distilled water. Aliquots of 0, 1, 2, 3, 4, 5 and 6 ml of the standard solution were transferred into 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculation:

$$P(mg/kg) = \frac{(a-b) \times 20 \times 6 \times mcf}{s}$$

where

a = mg/l P in a sample extract

b = mg/l P in the blank

s = sample weight in grams

mcf =moisture correcting factor

20 = ml extracting solution

6 = ml final sample solution

3.11.5 Available Potassium (K)

Twenty millilitres of the extract used for available phosphorus was used for available potassium (Bray and Kurtz, 1945). Potassium in the media extract was determined using emission values of a Gallenkamp flame analyzer. A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg K/l was prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg K/l in 100 ml volumetric flasks and made to volume with distilled water. Aliquots of 0, 1, 2, 3, 4, 5 and 6 ml of the standard solution were transferred into 100 ml volumetric flasks and made to the 100 ml mark with distilled water. This was used to obtain a calibration curve for the calculation of the available potassium.

Calculation:

$$K(mg/kg)=\frac{(a-b)\times 20\times 6\times mcf}{s}$$

where

a = mg/l K in a sample extract

b = mg/l K in the blank

s = sample weight in grams

mcf = moisture correcting factor

20 = ml extracting solution

6 = ml final sample solution

3.11.6 Exchangeable cations

Exchangeable bases calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in the media were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1986). A 10 g media were transferred into a leaching tube and leached with 50 ml of buffer 1.0 *M* ammonium acetate (NH_4OAc) solution at pH 7.

3.11.6.1 Determination of calcium (Ca) and magnesium (Mg)

A 12.5 ml aliquot of the extract was transferred into an Erlenmeyer flask and the volume made to 50 ml with distilled water. One millilitre of hydroxylamine hydrochloride, 1.0 ml potassium cyanide, 0.2 ml Eriochrome Black T solution was added. The solution was titrated with 0.01 *M* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. A 20 ml 0.01 *M* magnesium chloride solution was also titrated with 0.01 *M* EDTA in the presence of 25 ml of 0.1 *M* ammonium acetate to provide a standard blue colour for the titration.

3.11.6.2 Determination of calcium only

A 12.5 ml aliquot of the extract was transferred into an Erlenmeyer flask and the volume made to 25 ml with distilled water. Hydroxylamine hydrochloride (1.0 ml), potassium cyanide (1.0 ml of 2% solution) and potassium ferocyanide (1.0 ml of 2%) were added. After a few minutes, 4 ml of 8 *M* potassium hydroxide and a spatula of murexide indicator were added.

The solution obtained was titrated with 0.01 *M* EDTA solution to a pure blue colour. Twenty milliliters of 0.01 *M* calcium chloride solution was titrated with 0.01*M* EDTA in the presence of 25 ml 1.0 *M* ammonium acetate solution to provide a standard pure blue colour.

Calculations:

$$Ca+Mg(cmol/kg)=\frac{0.01\times(Va-Vb)\times100}{0.1\times w}$$

where w = weight in grams of soil.

Va= ml of 0.01 *M* EDTA used in titration.

Vb = ml of 0.01 *M* EDTA used in blank titration.

0.0l = concentration of EDTA used.

0.1 = dividing factor for the weight of soil

$$Ca(cmol/kg)=\frac{0.01\times(Va-Vb)\times100}{0.1\times w}$$

3.11.6.3 Determination of exchangeable potassium and sodium

Exchangeable potassium and sodium in the solution were determined by flame photometer using 10 ml aliquot from the leaching tubes to read the emission values. Standard series of potassium and sodium were prepared by diluting 1 g potassium and sodium to 1 litre of water. This was done by taking a 250 mg portions of each into one 250 ml volumetric flasks and made to volume with distilled water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. A 100 ml portion of 1.0

M NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained were 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelength of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K(cmol/kg)} = \frac{(a-b)\times 250\times mcf}{10\times 39.1\times s}$$

$$\text{Exchangeable Na(cmol/kg)} = \frac{(a-b)\times 250\times mcf}{10\times 23\times s}$$

where :

a = mg/l K or Na in the diluted sample percolated.

b = mg/l K or Na in the diluted blank percolated

s = air dried sample weight of soil in gm

mcf = moisture correcting factor.

3.11.7 Total exchangeable bases (T.E.B.)

Total exchangeable bases is the sum of all the basic cations (Ca^{2+}, + Mg^{2+} + K^{+} + Na^{+})

3.11.8 Exchangeable acidity

Exchangeable acidity is the sum of aluminium and hydrogen (Al + H). The exchangeable acidity in soil sample was extracted with 1.0 *M* KCl and the sums of Al+H were determined by titration. A 10 g of soil sample was put in a 200 ml plastic bottle and 50 ml of 1.0 *M* KCl solution added. The bottle was capped and shaken for one hour and then filtered into 250 ml Erlenmeyer flask. Twenty five milliliters of the filtrate was taken and 2 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 *M* NaOH until the colour just turned permanently pink. A blank was included in the titration

Calculation:

$$\text{Exchangeable Acidity(cmol/kg)} = \frac{(a\text{-}b) \times m \times 100 \times mcf}{s}$$

where a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

m = molarity of NaOH solution

s = air – dried soil sample weight in grams

mcf = moisture correction factor (100 × % moisture /(100).

3.11.9 Effective cation exchange capacity (ECEC)

Effective cation exchange capacity was determined by the sum of all the exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+}+ H^{+})

3.11.10 Percentage base saturation (% BS)

This is the total exchangeable bases expressed as percentage of the ECEC

$$\%BS=\left(\frac{TEB}{ECEC}\right)\times 100$$

3.11.11 Determination of microbial biomass (phosphorus, carbon and nitrogen)

Microbial biomass was determined by the fumigation and extraction technique as described by Anderson and Ingram (1993). A 15 g fresh soil sample was subjected to chloroform fumigation in desiccators for 5 days to cause cell walls of the microbes to lyse and denature and the cellular contents become extractable. The extraction of unfumigated media samples was done to serve as control.

3.11.11.1 Microbial Phosphorus

A 5 g field moist sample was fumigated with chloroform for 48 h. phosphorus was extracted from the fumigated and unfumigated media using Bray-1 solution. The unfumigated value was subtracted from the fumigated value to obtain the microbial biomass phosphorus

Calculation:

$$\text{Microbial P}(\mu g/g)=\frac{\text{Avail P in fumigated extract-Avail p in unfumigated extract}}{0.4}$$

Where 0.4 is the killing factor for phosphorus.

3.11.11.2 Microbial biomass carbon and nitrogen

A 10 g sample of the fumigated and unfumigated media was put into a shaking bottle (200 ml). A 50 ml of 0.5 *M* K_2SO_4 solution was added and shaken for 30 minutes in a shaker. It was then filtered with No. 42 filter paper.

3.11.11.3 Microbial biomass nitrogen

. Total nitrogen in the extract (from fumigated and unfumigated media samples) was determined by Kjeldahl distillation method.

Calculation:

$$\text{Microbial N}(\mu g/g) = \frac{\text{Total N in fumigated extract-Total N in unfumigated extract}}{0.45}$$

Where 0.45 is the killing factor for nitrogen.

3.11.11.4 Microbial Biomass carbon

Colorimetric method was used for the determination of microbial biomass carbon. The transmittance of an aliquot with spectrophotometer was measured. A standard solution was prepared with 0.2 g sucrose in 1000 ml distilled water. Aliquot of 0, 20, 40, 60, 80 and 100 ml of the solutions were measured into 100 ml flasks and made to mark with distilled water to obtain 0, 20, 40, 60, 80 and 100 mg carbon/litre. The transmittance values of the standards were also measured directly on a spectrophotometer at wavelength of 660 nm at low sensitivity. Calibration curve obtained from standard transmittance provided formula for the calculation of microbial biomass carbon.

Calculation:

Microbial biomass carbon (μg/g) = T × G + S

where T =Transmittance

G = gradient

S = slope

3.11.12 Particle size (Mechanical) analysis

Bouyoucos (1936) or hydrometer method was used to determine the texture of the media. A 50 g media sample was weighed into a graduated cylinder. The media was saturated with distilled water and 100 ml of 10% calgon (sodium hexametaphosphate) and stirred for 10 minutes. The suspension was transferred to a 1000 ml cylinder and filled with distilled water to the 1000 ml mark. Two drops of amyl alcohol were added. The suspension was mixed thoroughly with a plunger and the temperature read. The hydrometer was gently inserted into the suspension. The hydrometer readings were taken at 30 seconds and 3 hours. The texture was obtained by interpolating the sand, silt and clay percentages in a textural triangle.

Calculation:

$$\%Silt = \frac{F1 \times 100}{M}$$

$$\%Clay = \frac{F2 \times 100}{M}$$

%Sand=100 - %Silt - %Clay

Where F1 - first hydrometer reading

F2 -Second hydrometer reading

M -Mass of dry media

3.12 Plant Nutrient Analysis

The nutrient accumulation in the seedlings was determined before transplanting into the polyethene bags in the new site and bimonthly there after. The nutrients analysed were total nitrogen, phosphorus, potassium, calcium and magnesium.

Leaf samples were cleaned thoroughly with cotton wool and distilled water. They were oven dried at 70°c for forty eight hours (48h) to constant weights. Dried leaf samples were ground into powder in a mortar.

3.13 Leaf sampling

Plant samples for nutrient determination were taken at bi-monthly intervals. At the early stages up to the fifth month, a whole leaf was taken from the seedling. It was taken from the third leaf from the top open leaf from 8 randomly selected and tagged seedlings. At six months onwards, when leaflets had developed, leaf samples were taken from leaflets of a third open leaf from the top.

3.13.1 Total plant nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described for the media.

3.13.2 Total plant phosphorus, potassium, calcium and magnesium

A 0.5g of milled leaf sample was ashed in a furnace for 4 hours at a temperature of 450°C. The ash was dissolved in 10 ml concentrated nitric acid and filtered through No. 42 filter paper into a 100 ml conical flask. The filtrate was made up to 100 ml with distilled water. A 50 ml aliquot distillate was used for the determination of calcium and magnesium with the procedure described for the media.

3.13.3 Determination of total plant phosphorus and potassium

A 10 ml of ammonium molybdate (1.0 *M*) and 10 ml of ammonium vanadate (1.0 *M*) were added to 50 ml of the distillate. The solution was made up to 100 ml with distilled water along side the blank. Aliquots were taken for spectrophotometer reading at 440 nm wave length at high sensitivity for total plant phosphorus and flame analyzer reading for total plant potassium.

3.14 Media sampling and analysis

In addition to the initial media characterization, media sampling and analysis were done 4 months after transplanting and ~~at the end~~ of the experiment.

3.15 Sampling procedure

Three (3) plants were randomly selected from each plot and plants removed. The media were thoroughly mixed (with sample of 500 g taken) and sent to laboratory immediately for microbial and nutrient analysis.

3.16 Destructive measurement

The destructive measurement was done at the end of the field work. Three (3) seedlings were taken from each plant. The plants were removed from the soil with their roots, leaves and butts separated. The plant parts were chopped into pieces and enveloped. The materials were dried in an oven at a temperature of 70°C for 48 h. Plates 3.2 to 3.9 show the seedlings of treatments 1 to 8 at the end of the experiment.

Plate 3.2 Seedlings of treatment 1 at month 8

Plate 3.3 Seedlings of treatment 2 at month 8

Plate 3.4 Seedlings of treatment 3 at month 8

Plate 3.5 Seedlings of treatment 4 at month 8

Plate 3.6 Seedlings of treatment 5 at month 8

Plate 3.7 Seedlings of treatment 6 at month 8

Plate 3.8 Seedlings of treatment 7 at month 8

Plate 3.9 Seedlings of treatment 8 at month 8

3.17 Percentage Seedlings Mortality (PSM)

Percentage Mortality of seedlings was calculated on monthly basis and was calculated as

$$PSM = \frac{\text{Total number of dead seedlings in a plot}}{\text{Total seedlings in a plot}} \times 100$$

3.18 Nutrient Use Efficiency (NUE)

NUE refers to the ability of the seedlings to utilize the nutrient resources from the media for dry matter production (Graham, 1984). The common indices of NUE' are Nutrient Efficiency Ratio (NER), Apparent Nutrient Recovery (ANR) and Nutrient Recovery Rate (NRR). These were calculated at the end of the experiment.

3.18.1 Nutrient Efficiency Ratio (NER)

Calculation:

$$NBR = \frac{\text{Total dry matter produced (g)}}{\text{Total nutrient in tissue (g)}}$$

(Baligar *et al.*, 2001)

3.18.2 Apparent Nutrient Recovery efficiency (ANR)

ANR has been used to reflect seedlings' ability to absorb applied nutrient from media.

Calculation:

$$ANR(\%) = \frac{\text{Nutrient uptake F (g)-Nutrient uptake C (g)}}{\text{Quantity of nutrient applied (g)}} \times 100$$

(Baligar *et al.*, 2001)

3.18.3 Nutrient Recovery Rate (NRR)

NRR has been used to express the percentage of the applied nutrients that was utilized by the seedlings and is calculated as

$$NRR(\%)=\frac{\text{Nutrient uptake (g)}}{\text{Quantity of nutrient applied (g)}}\times 100$$ (Baligar *et al.*, 2001)

3.19 Agro-economic appraisal

The cost-benefit analysis of producing a seedling was computed by comparing production cost and the revenue from selling a seedling. The return component was the current price of a seedling. The cost component was computed from the cost of germinated seed nut, polyethene bags, media, fertilizer(s), operational cost and chemicals. The net return was obtained by subtracting the production costs from the revenue. The expenditure equivalent ratio was also calculated.

Net returns = Price of a seedling – Production cost.

$$\text{Expenditure Equivalent ratio}=\frac{\text{Total seedling cost of the control treatment}}{\text{Total seedling cost of the other treatments}}$$

Where total highest cost is treatment that gave highest cost and other cost are cost of other treatments.

3.20 Data analysis

Data were analysed statistically using the analysis of variance (ANOVA) procedures of SAS (1999) statistical package .The treatment means for the measured parameters of each sampling data were compared using Student-Newman-Kuels test (snk). All the parameters were compared at probability level of 0.05.

CHAPTER FOUR

4.0 RESULTS

4.1 Media characterization

4.1.1 Particle size distribution (texture)

Data on particle size distribution (texture) of the media are presented in Figure. 4. The mechanical analysis shows that the topsoil contained 29.06% sand, 60.59% silt and 10.35% clay and it is classified as silty loam. The green-gro medium contained 41.28% sand, 48.35% silt and 10.35% clay and is also classified as loam.

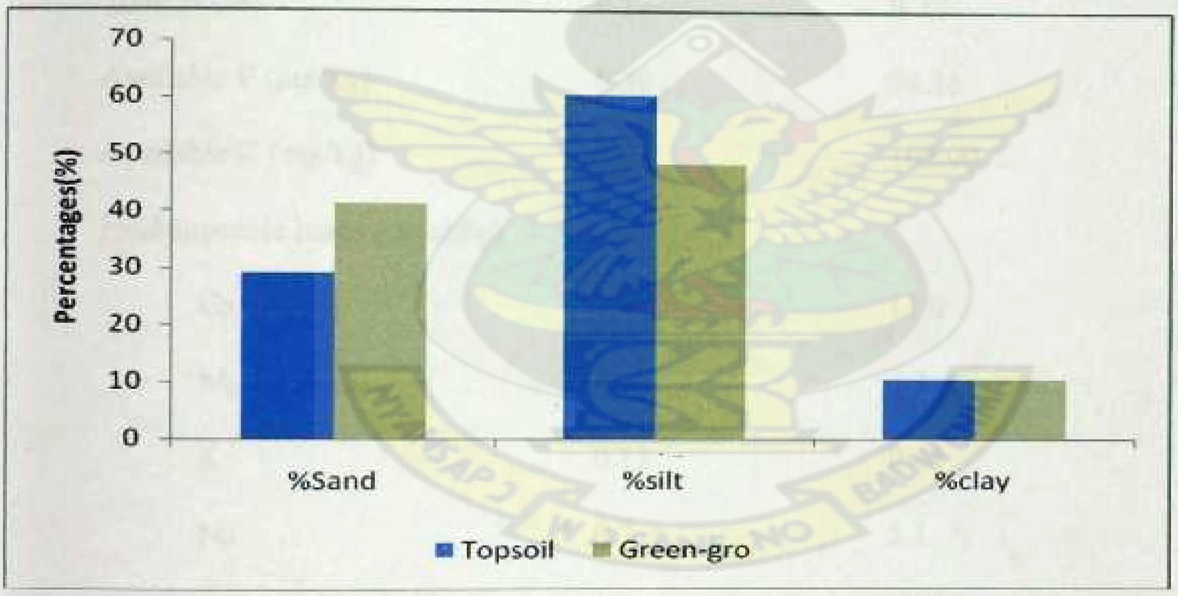

Fig: 4.1 Media characterization for physical properties

4.1.2 Media characterization for chemical properties, organic matter and microbial biomass

Media characterization for chemical properties, organic matter and microbial biomass (C, N and P) are presented in Table 4.1. The results indicated that green-gro medium contained higher content of all parameters analysed except exchangeable magnesium and exchangeable acidity. Available phosphorus content of green-gro medium was about 900% higher than that of top soil. Available potassium content of green-gro medium was about 600% higher than that of topsoil. Even though the topsoil and the green-gro contained variable amounts of exchangeable cations, the base saturation was almost the same in both media.

Table: 4.1 Chemical properties and microbial biomass C, N and P of media

Property	Top soil	Green-gro
pH (1:1 H_2O)	6.4	7.2
Organic C (%)	2.00	2.40
OM (%)	3.45	4.14
Total N (%)	0.18	0.22
Available P (mg/kg)	0.39	34.16
Available K (mg/kg)	1.64	102.00
Exchangeable bases (cmol/kg)		
Ca	7.5	11.0
Mg	4.9	4.3
K	0.13	0.44
Na	0.7	5.1
Exchangeable acidity (cmol/kg)	0.1	0.05
ECEC (cmol/kg)	14.86	20.89
Microbial biomass		
C (µg/g)	43.3	52.2
N (µg/g)	2.48	4.12
P (µg/g)	5.9	177.24

4.2 Media analysis during experiment

4.2.1 Media pH

The media pH was in the range of 5.1 and 7.4 (Fig. 4.2). With the exception of treatment 8, pH of all the media decreased from initial stage of the study to the fourth month. Whereas pH of the green-gro medium treatments increased at the end of the study, it decreased in topsoil treatments. The lowest pH was recorded in treatment 1 (topsoil + N P K Mg 1:1:1:2) in the 4th month and 8th month. The highest pH values were observed in treatment 4 (green-gro + N P K Mg 1:1:1:2) in the 8th month.

Fig.4.2 Effects of treatments on pH in the media at the beginning, during and after the experiment.

4.2.2 Total nitrogen in media

Total nitrogen in the topsoil treatments showed decreasing trend up to the fourth month and increasing trend from the 4th month to the end of the study period (Fig. 4.3). Green-gro medium treatments recorded gradual increase up to the fourth month and a very sharp increase thereafter. Treatments 6 and 8 showed near linear total nitrogen content. The highest total nitrogen content was observed in treatment 6 followed by treatment 8. However significant differences were observed in all the three periods of study with green-gro medium treatments showing significantly higher levels (snk 0.05) throughout the experimental period.

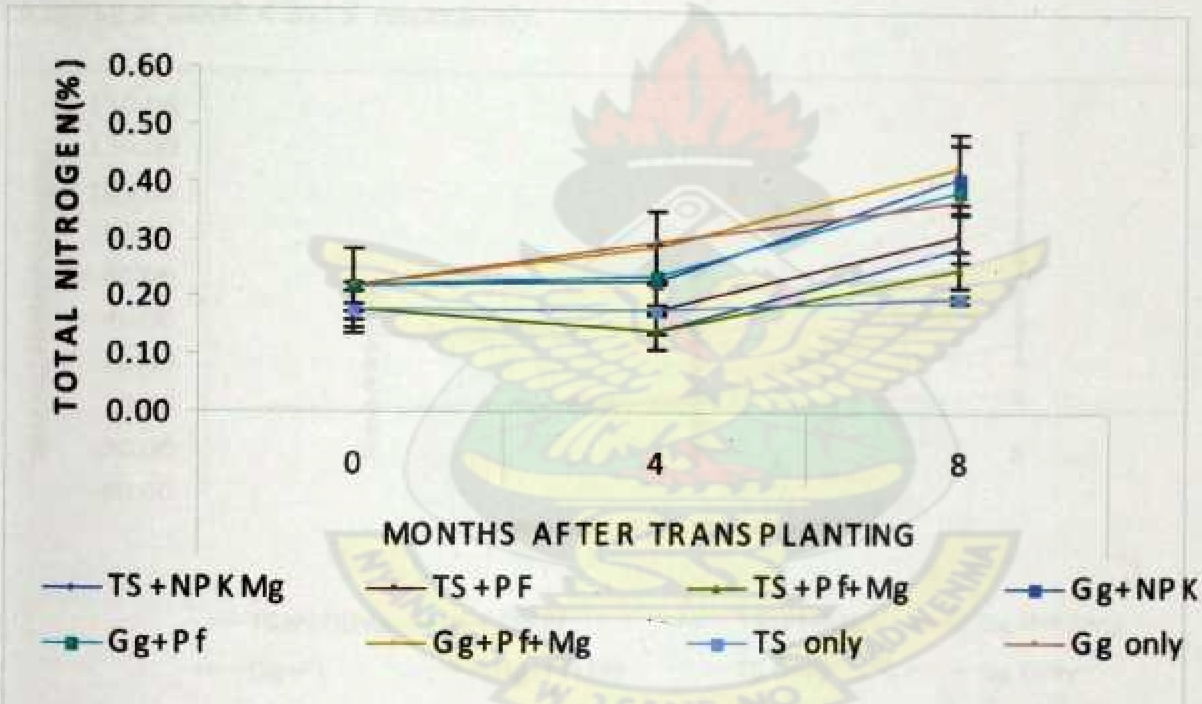

Fig.4.3 Effects of treatments on total nitrogen in the media at the beginning, during and after the experiment.

4.2.3 Available phosphorus in media

The available phosphorus content of green-gro medium treatments with fertilization increased with time after transplanting and were significantly different from the other treatments in all the three sampling periods (Fig.4.4). The available phosphorus in all the media with fertilization increased very sharply from the 4th month to the 8th month. The highest available phosphorus contents were recorded in treatments 5 (green-gro + polyfeed) and 6 (green-gro + polyfeed + Mg) media and were as high as 108.3 and 97.13 mg/kg respectively at the end of the study while the available phosphorus content in treatment 7 medium was as low as 1.0 and 7.6 mg/kg at month 4 and 8 respectively.

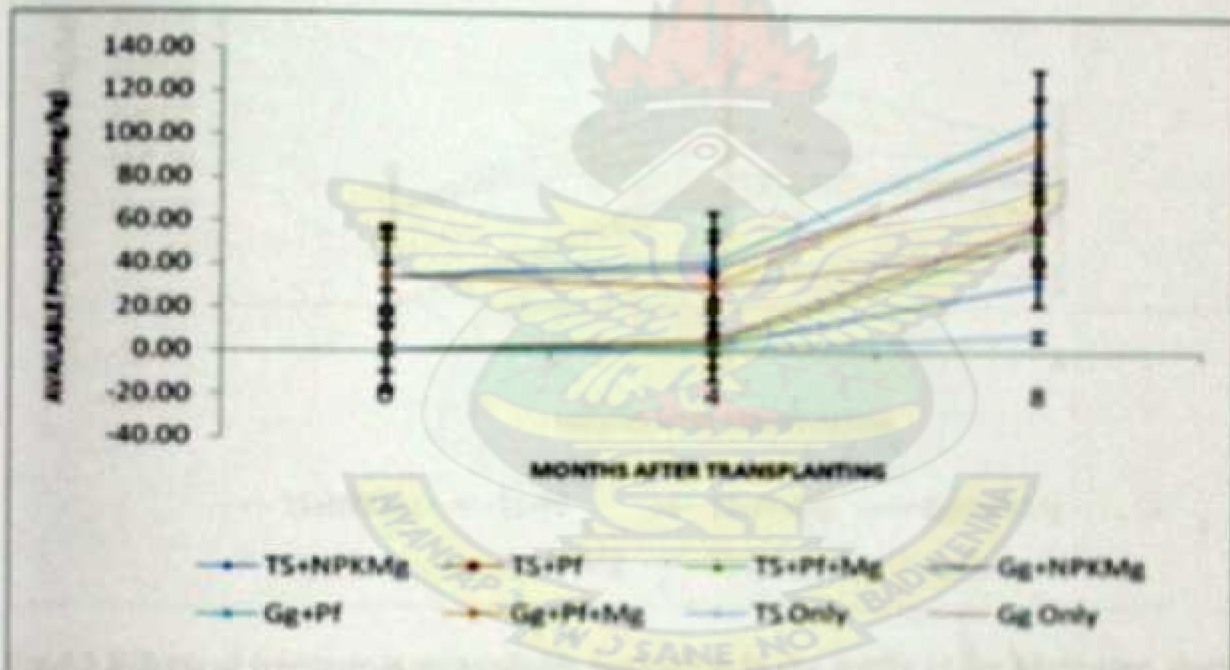

Fig.4.4 Effects of treatments on available phosphorus in the media at the beginning, during and after the experiment.

4.2.4 Available potassium in media

The available potassium content of all treatment media showed sharp increase from start (month 0) of the experiment to the fourth month and abruptly decreased from the fourth month to the end of the eighth month (Fig. 4.5). However, it was significantly higher in Green-gro medium treatments at the fourth month. Available potassium content of T7 medium was significantly lower at fourth and eighth months. Treatment 5 medium recorded significantly higher available potassium content at the end of the experiment.

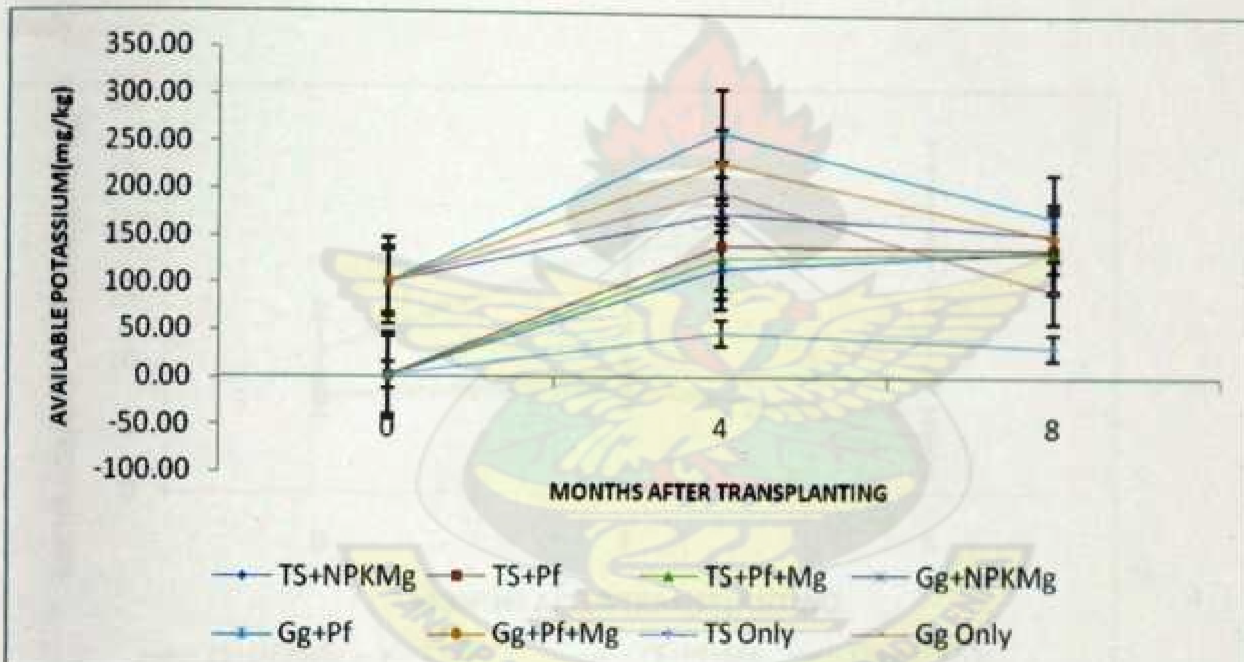

Fig.4.5 Effects of treatments on available potassium in the media at the beginning, during and after the experiment.

4 .2.5 Exchangeable cations in media

4.2.5.1 Exchangeable calcium

The exchangeable calcium content of the topsoil treatments did not compare in any way against that of green-gro medium treatments in all the analysis. Exchangeable calcium in all the green-gro medium treatments except treatment 6 showed increasing trend from the initial stage to the end of the experiment (Fig. 4.6). The topsoil treatments however showed increased trend from initial stage of the study to the fourth month and decreased thereafter to the end of the study.

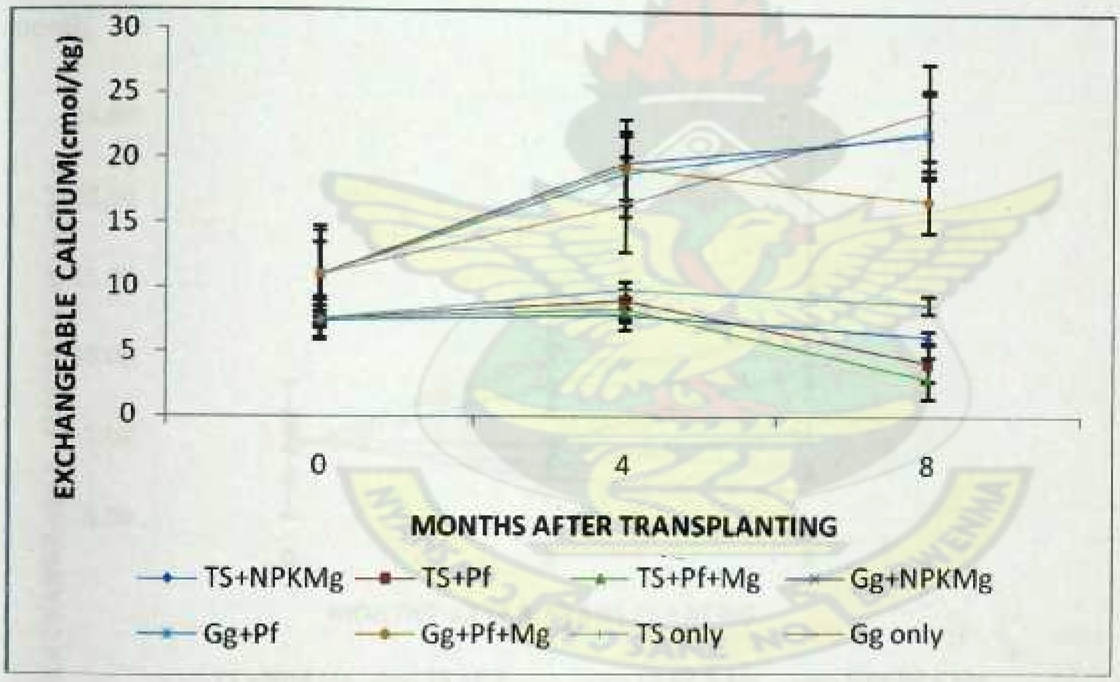

Fig.4.6 Effects of treatments on exchangeable calcium in the media at the beginning, during and after the experiment.

4.2.5.2 Exchangeable magnesium

The exchangeable magnesium content in the topsoil was higher than in the green-gro medium at the initial stage of the experiment. The trend changed in the fourth and eighth months (Fig. 4.7). The green-gro medium treatments showed increasing trend of exchangeable magnesium content from the beginning to the fourth month of the experiment. Decreasing trend was however observed in the topsoil treatments from the beginning to the fourth month. Topsoil and the green-gro media with polyfeed + kieserite fertilization treatments (treatments 3 and 6) showed sharp increase in exchangeable magnesium content from the fourth month to the eighth month.

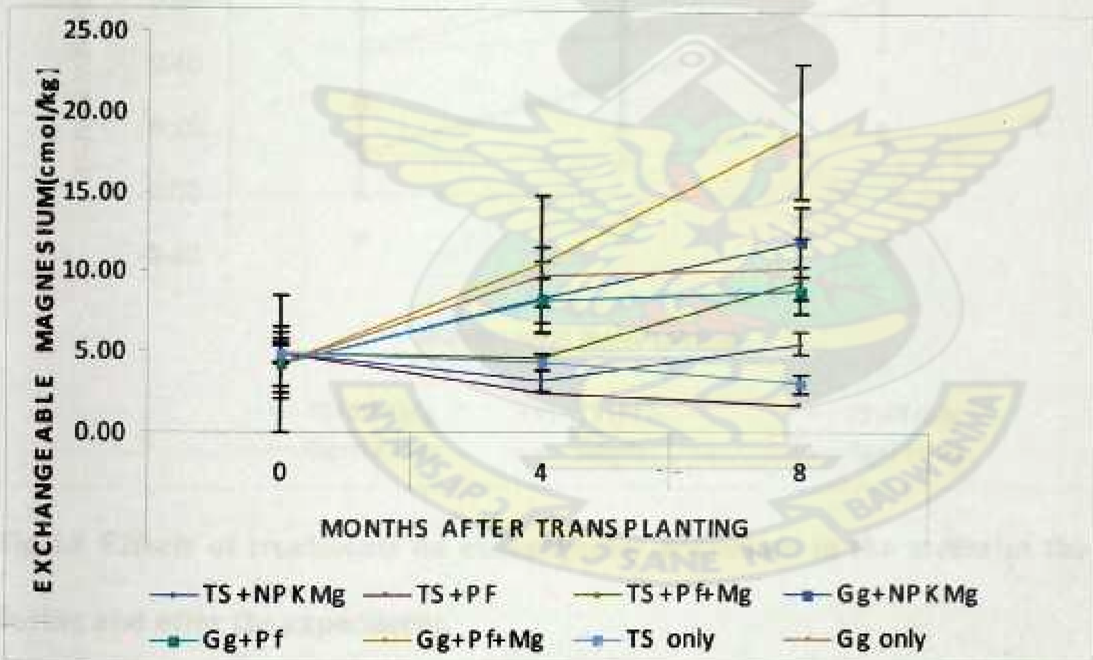

Fig.4.7 Effects of treatments on exchangeable magnesium in the media at the beginning, during and after the experiment.

4.2.5.3 Exchangeable potassium

There was an increasing trend of exchangeable potassium in the media of all the treatments (Fig. 4.8). Green-gro medium treatments showed significantly higher exchangeable potassium content than topsoil treatments at all stages except green-gro only (T8). The exchangeable potassium content of the topsoil treatments were very close to each other at all the stages. The green-gro treatments also showed similar trend except the topsoil and the green-gro (T7 and T8).

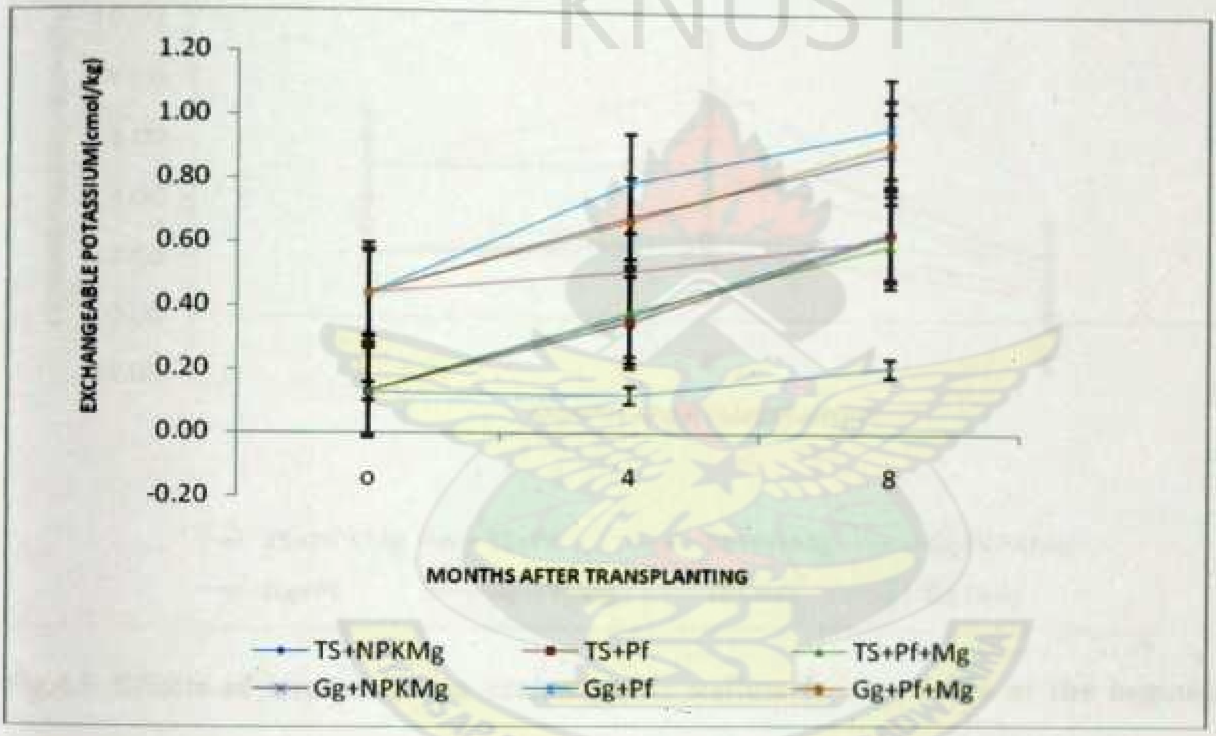

Fig.4.8 Effects of treatments on exchangeable potassium in the media at the beginning, during and after the experiment.

4.2.5.4 Exchangeable sodium

Exchangeable sodium in all the media treatments showed upward trend from the initial to the final stage of the experiment (Fig. 4.9). However, the green-gro medium treatments showed significantly higher exchangeable sodium content in the fourth month than the topsoil treatments. The trend changed with all the treatment media showing pronounced increase of exchangeable sodium at the end of the experiment with the exception of green-gro only (T8).

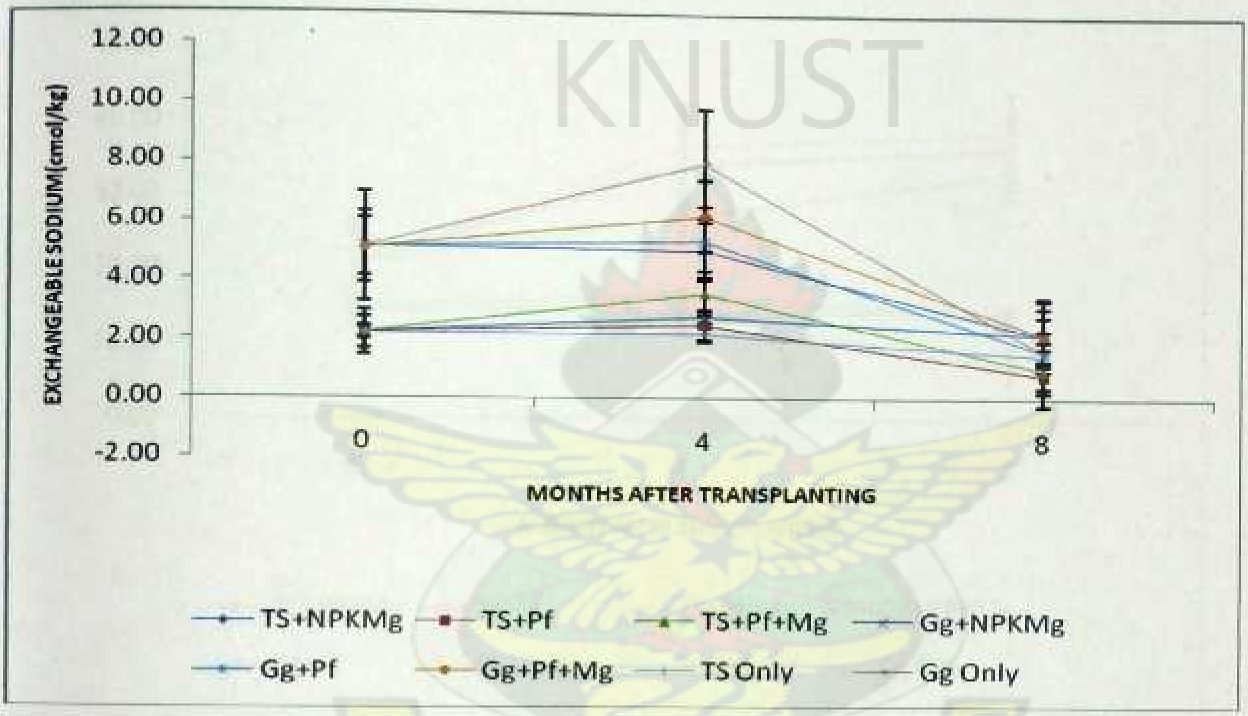

Fig.4.9 Effects of treatments on exchangeable sodium in the media at the beginning, during and after the experiment.

4.2.6 Total exchangeable bases (TEB) in media

Total exchangeable bases in all the media showed increasing trend from the initial stage to the end of the experiment (Fig. 4.10). The increases were all near linear. The green-gro medium treatments recorded significantly higher total exchangeable bases contents than topsoil treatments. However the total exchangeable bases of topsoil treatments and green-gro medium treatments were closer to each other at all stages of the experiment except the controls.

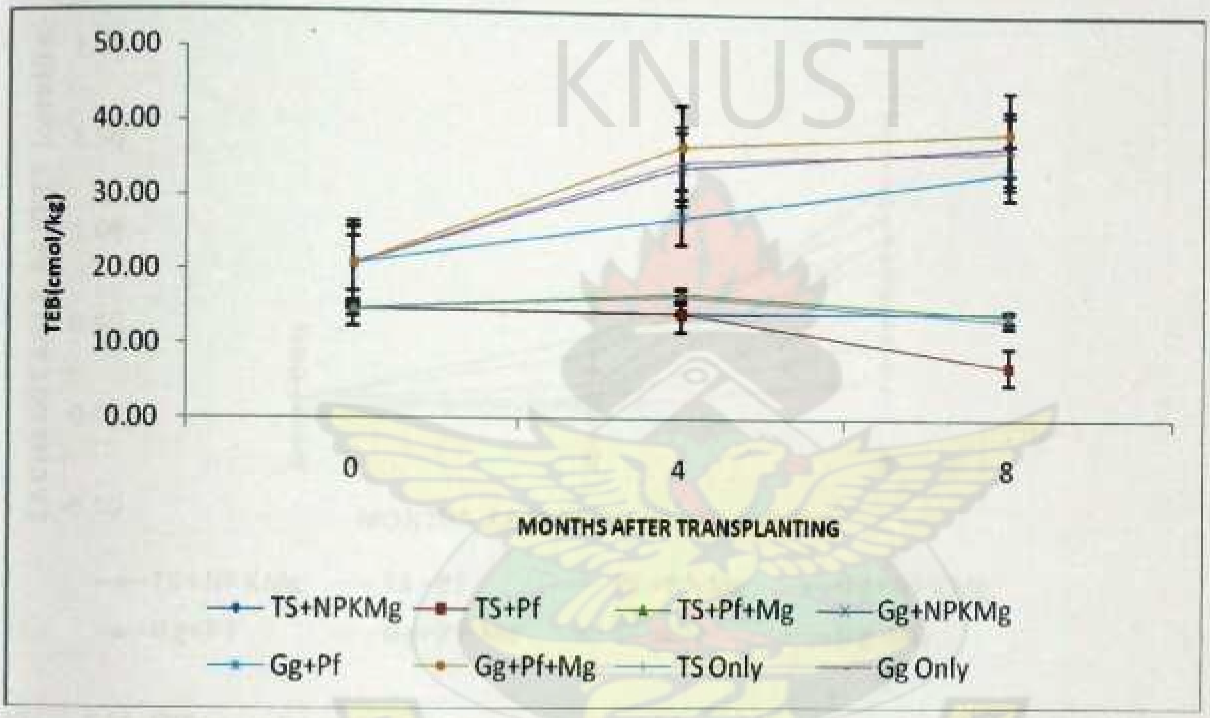

Fig. 4.10 Effects of treatments on total exchangeable bases in the media at the beginning, during and after the experiment.

4.2.7 Exchangeable acidity in media

The change in the media exchangeable acidity was more pronounce in topsoil treatments as compared to the green-gro medium treatments (Fig. 4.11). Even though the exchangeable acidity was high in the topsoil than in the green-gro medium initially, the increase in topsoil treatments was very pronounced in the fourth and eighth month.

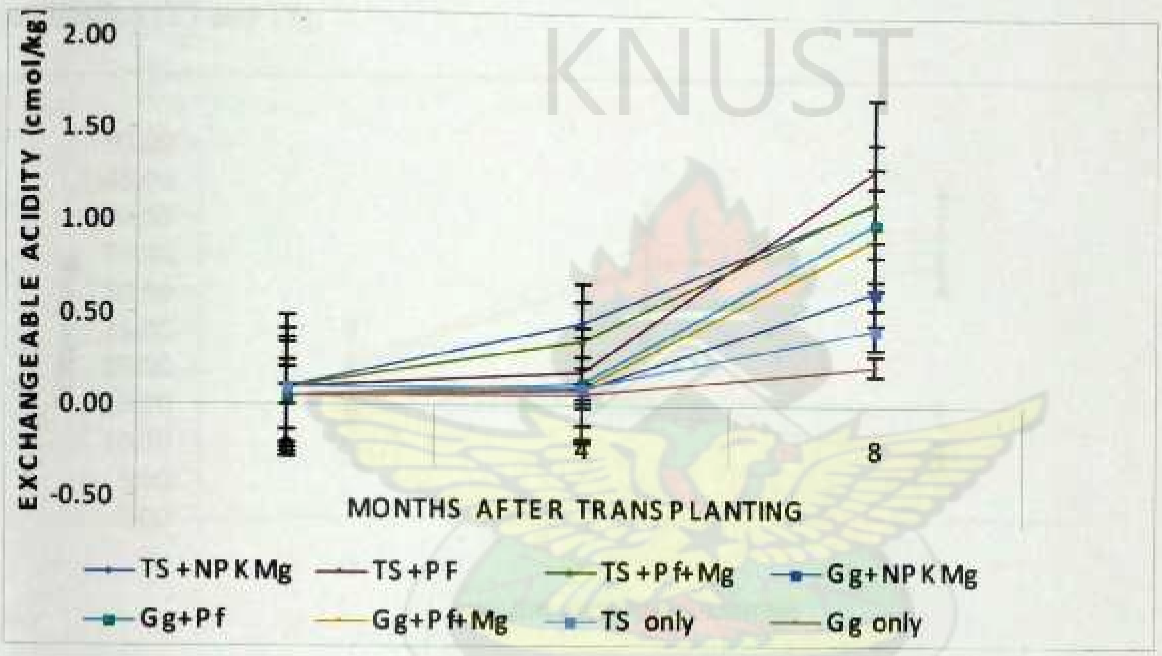

Fig. 4.11 Effects of treatments on exchangeable acidity in the media at the beginning, during and after the experiment.

4.2.8 Effective cation exchange capacity (ECEC) of media

The effective cation exchange capacity in all the media showed increasing trend from the beginning to the end of the experiment (Fig. 4.12). The increase in effective cation exchange capacity was linear. The green-gro medium treatments recorded significantly higher effective cation exchange capacity values than topsoil treatments in all the stages. Moreover the ECEC of the different medium treatments differences were much close except the treatments without fertilization (T7 and T8).

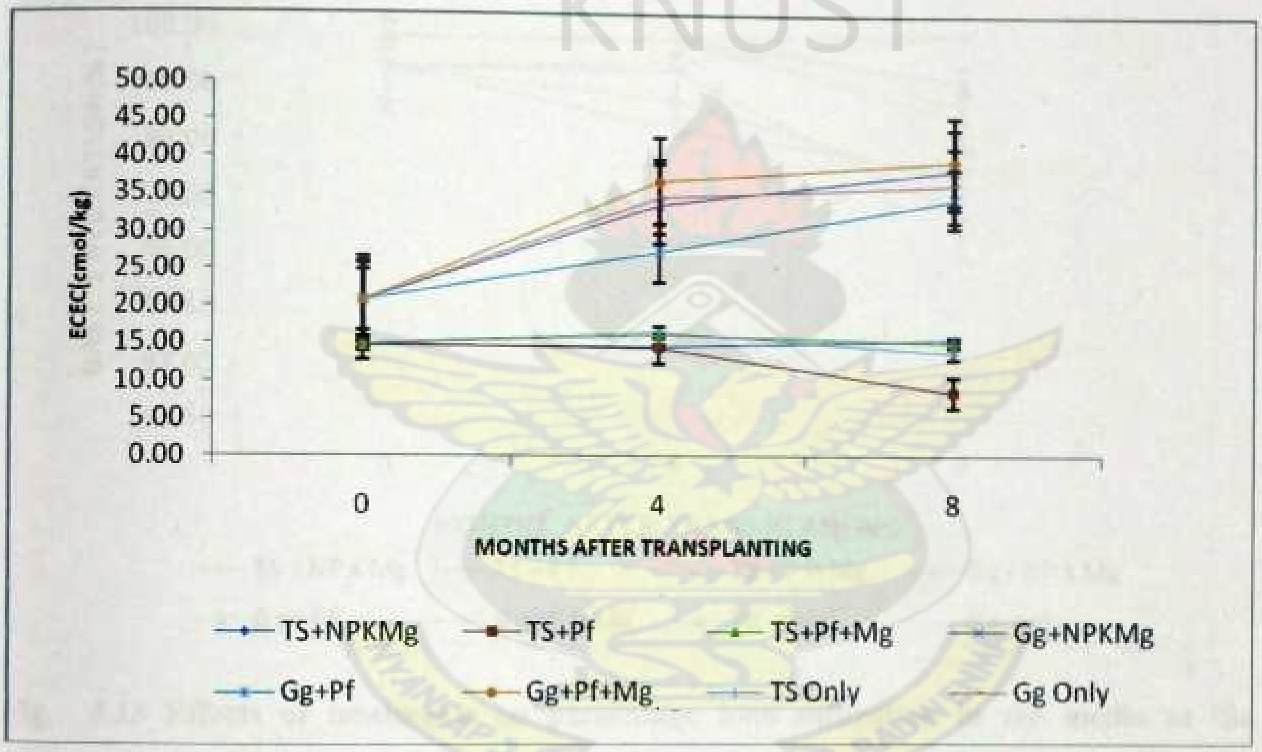

Fig. 4.12 Effects of treatments on effective cation exchange capacity of media at the beginning, during and after the experiment.

4.2.9 Percentage base saturation of media

Percentage base saturation decreased from the beginning to the end of the experiment in all the treatments except the treatments without fertilization (T7 and T8). However, base saturation was always high in the green-gro medium than the topsoil treatments (Fig. 4.13). The lowest percentage base saturation was recorded in Polyfeed fertilization (T2) among topsoil treatments and in poly feed fertilization (T5) among green-gro treatments.

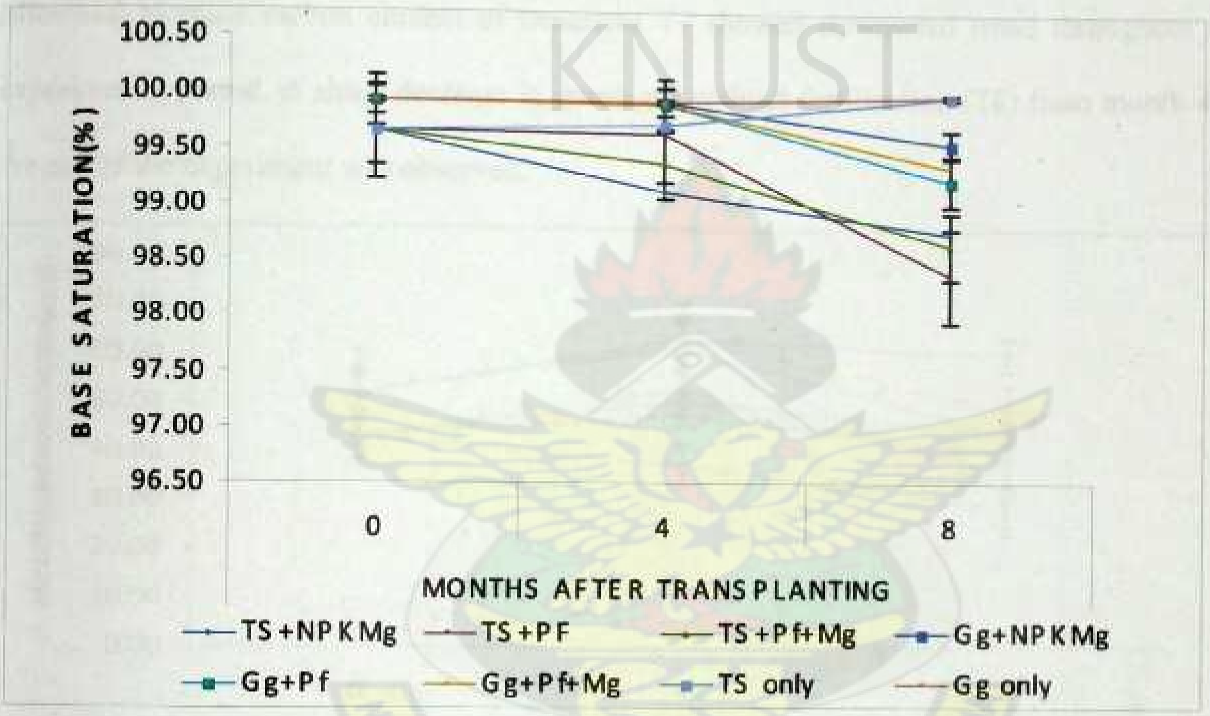

Fig. 4.13 Effects of treatments on percentage base saturation in the media at the beginning, during and after the experiment.

4.2.10 Microbial biomass carbon, nitrogen and phosphorus of the media

4.2.10.1 Microbial biomass carbon

Microbial biomass carbon was significantly high in green-gro medium treatments than in the topsoil treatments at the beginning of the experiment and the fourth month (Fig. 4.14). There was an increase in microbial biomass carbon from the beginning to month 4 and decrease from there to the eighth month in all the media treatments except topsoil without fertilization (T7). Microbial biomass carbon content of treatment T7 showed downward trend throughout the experimental period. A sharp decrease in green-gro without fertilization (T8) from month 4 to the end of the experiment was observed.

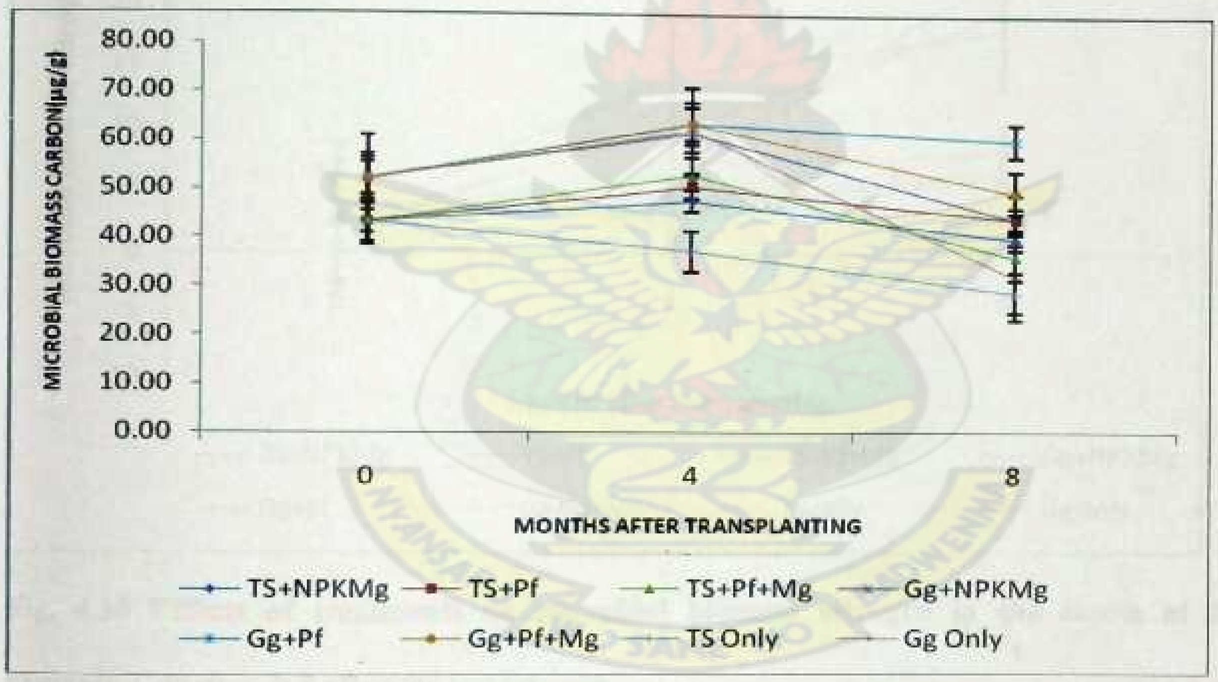

Fig. 4.14 Effects of treatments on microbial biomass carbon in the media at the beginning, during and after the experiment.

4.2.10.2 Microbial biomass nitrogen

Microbial biomass nitrogen showed increasing trend in topsoil treatments from the initial stage to the final stage of the experiment except the topsoil without fertilization (T7) (Fig.4.15). Green-gro medium treatments recorded decreased and increased contents from the initial stage to the end of the study. The differences in topsoil and green-gro treatments were very pronounced at the end of the experiment.

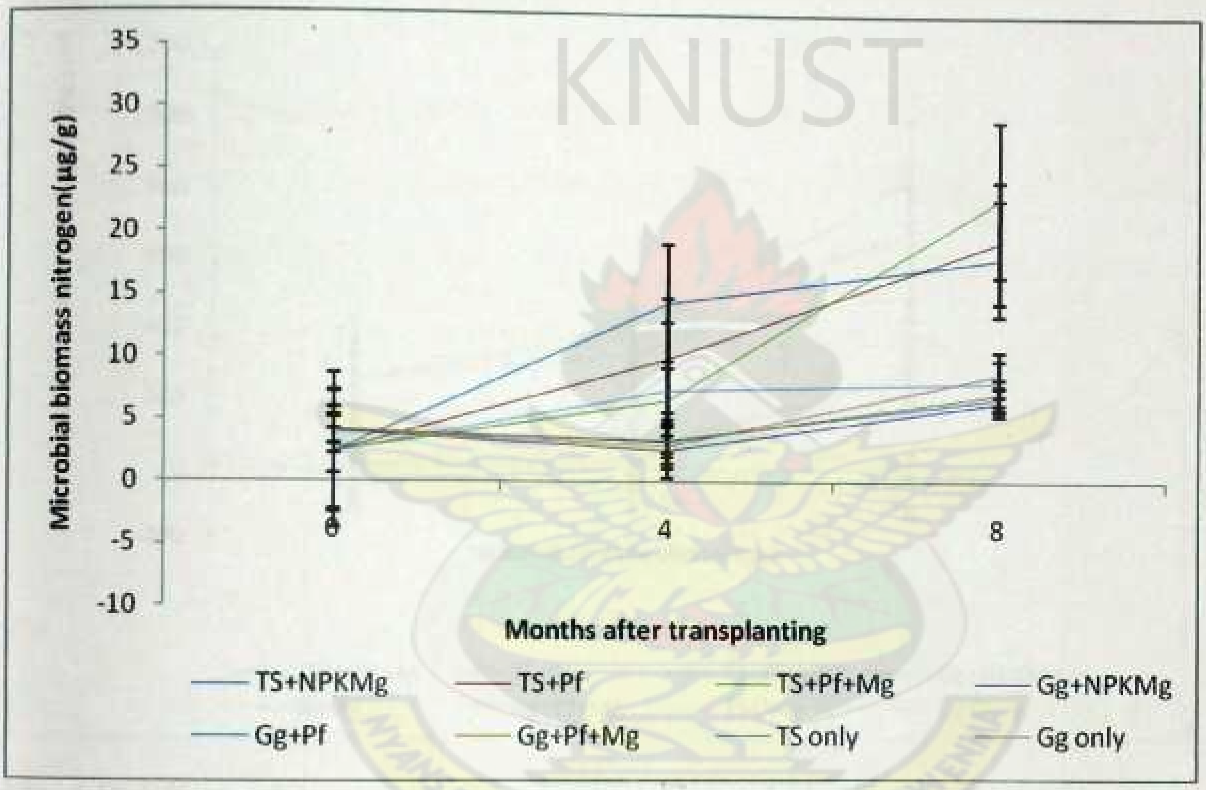

Fig. 4.15 Effects of treatments on microbial biomass nitrogen in the media at the beginning, during and after the experiment.

4.2.10.3 Microbial biomass phosphorus

With the exception of top soil control (T7), all the treatments showed nearly similar pattern of microbial biomass phosphorus accumulation (Fig. 4.16). However in all the stages there were significant differences between green-gro treatments and topsoil treatments. Whereas the lowest green-gro treatment accumulated 503µg/g of microbial phosphorus at the end of the experiment (T8), the highest topsoil microbial phosphorus was 295µg/g (T3).

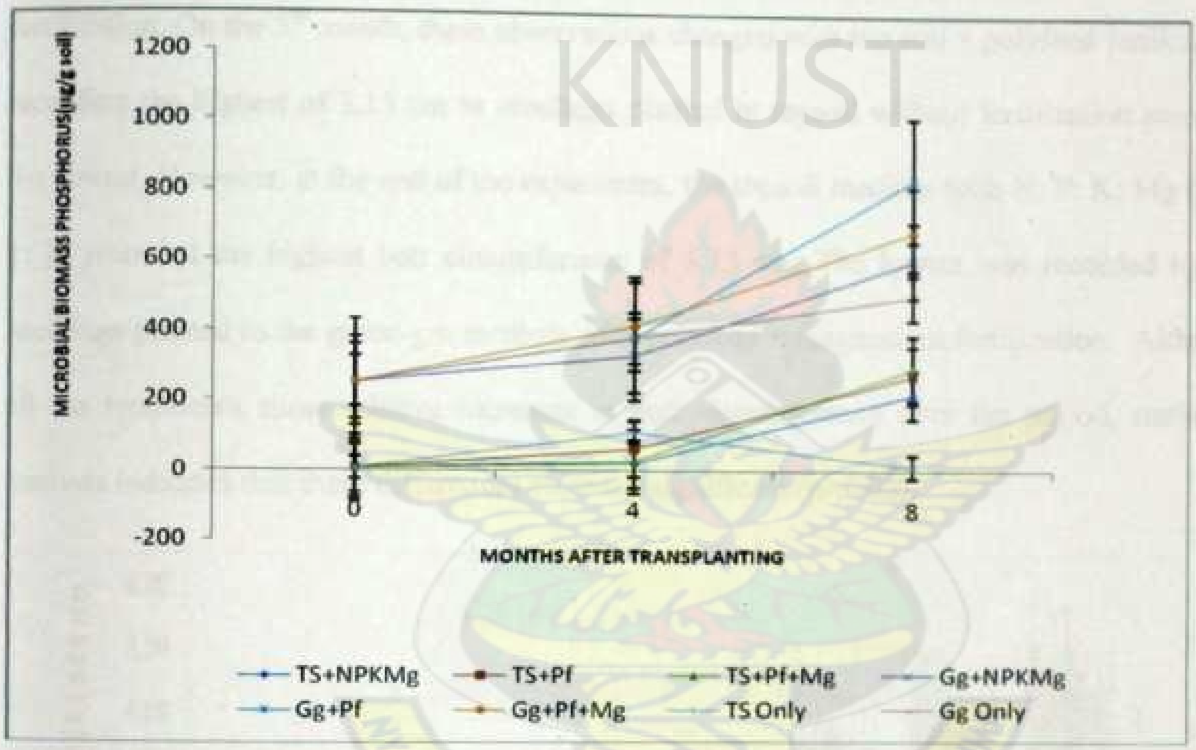

Fig. 4.16 Effects of treatments on microbial biomass phosphorus in the media at the beginning, during and after the experiment.

4.3 Vegetative growth assessment

4.3.1 Effects of treatments on butt circumference

Fig. 4.17 shows the effects of the treatments on butt circumference over the experimental period. One month after the application of treatments, seedlings planted in the green-gro medium without fertilization (T8) recorded the highest butt circumference of 0.98 cm. The lowest was associated with seedlings planted in green-gro medium with polyfeed + magnesium fertilization. On the 5th month, these observations changed with top soil + polyfeed fertilization recording the highest of 3.15 cm as seedlings planted in topsoil without fertilization recorded the lowest. However, at the end of the experiment, the topsoil medium with N: P: K: Mg (1: 1: 1: 2) recorded the highest butt circumference of 5.13 cm. The lowest was recorded by the seedlings planted in the green-gro medium with polyfeed + magnesium fertilization. Although all the treatments show relative increases in butt circumference over the period, statistical analysis indicates that these differences were not significant (p>0.05).

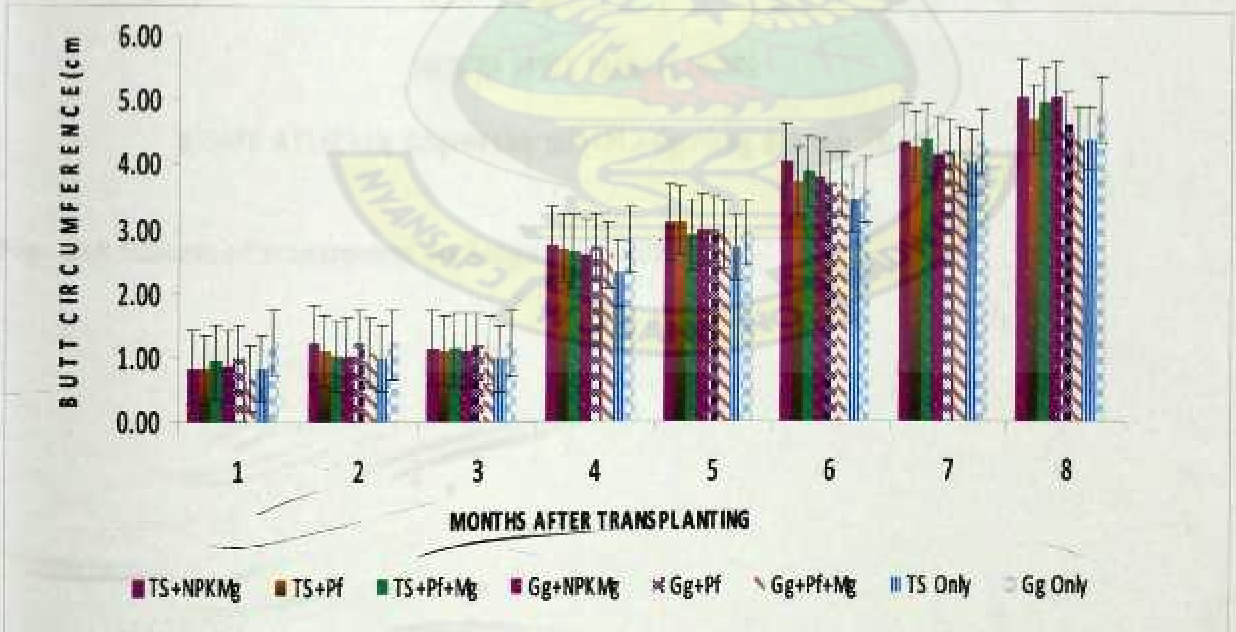

Fig. 4.17 Effects of treatments on butt circumference of the seedlings.

4.3.2 Effects of treatments on plant height

The effects of treatments on plant height are shown in Fig. 4.18. There was near linear growth among the seedlings in all the treatments. Seedlings planted in the green-gro medium were higher than their counterparts planted in the topsoil for the first four months. The pattern changed with the topsoil producing the highest seedlings than their counterparts in green-gro medium. However, there were no significant differences among seedlings in height over the experimental period.

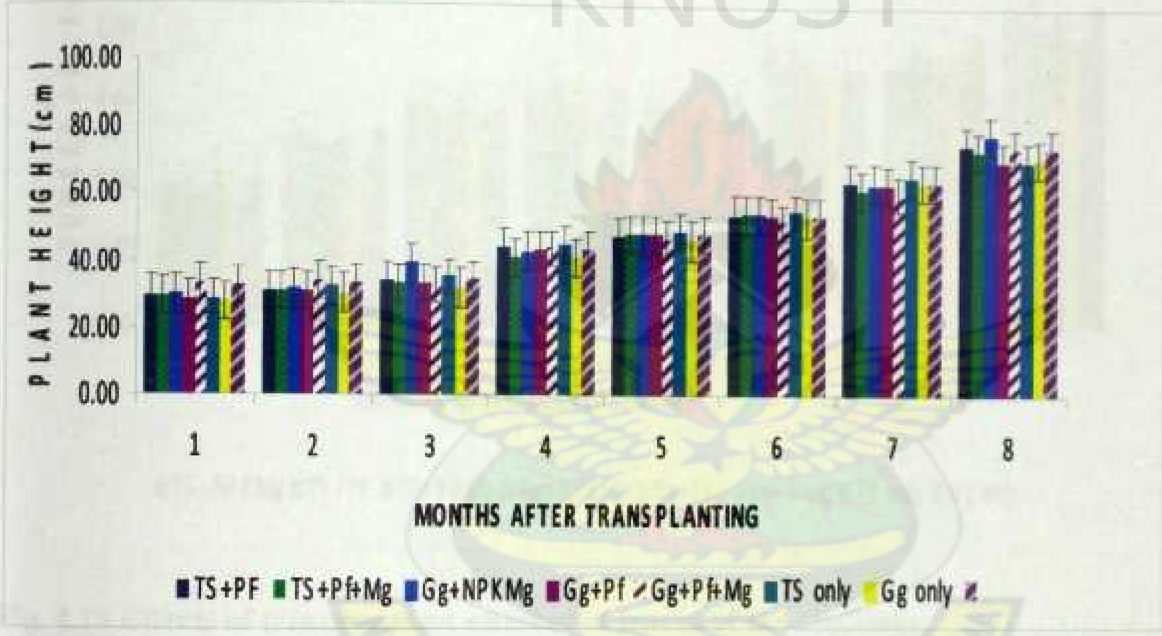

Fig. 4.18 Effects of treatments on height of seedlings.

4.3.3 Effects of treatments on number of leaves

The effects of treatments on number of leaves are presented in Fig. 4.19. Leaf number peaked 9.1 at 8 months after transplanting and was observed in T3. There was general increase in seedling leaf number from month 1 to month 4 in all the treatments. Seedlings leaf number of all the treatments decreased in month 5 and started increasing again from months 6 to 8.

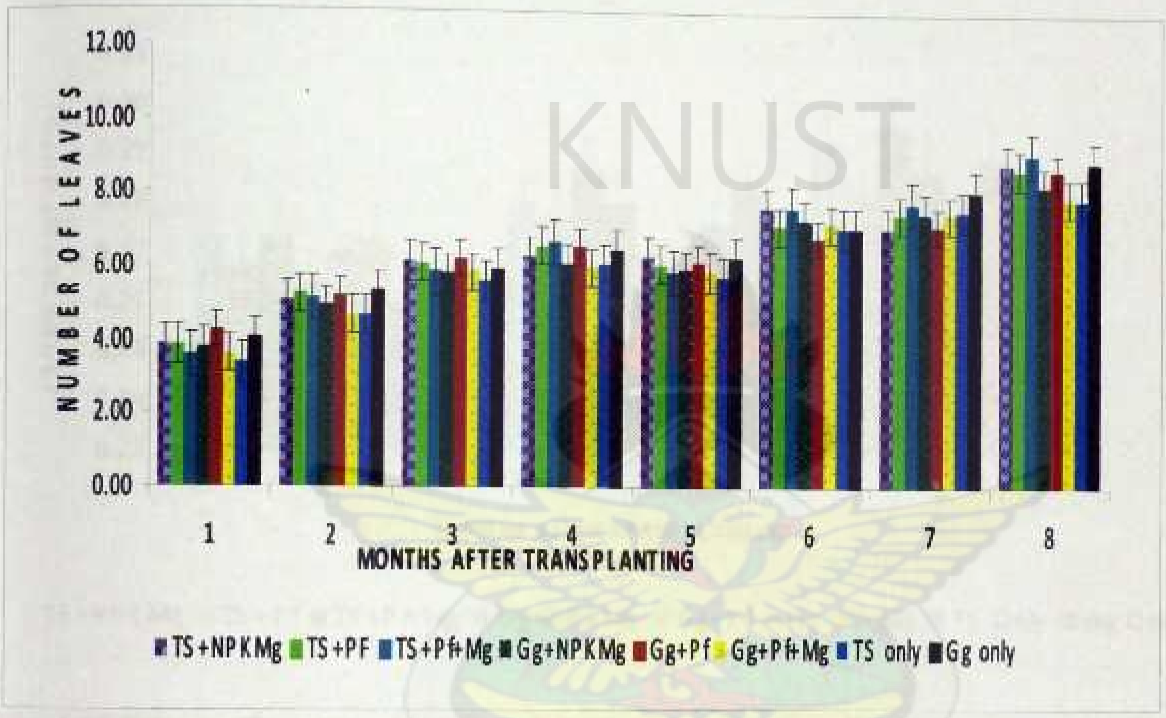

Fig. 4.19 Effects of treatments on number of leaves of the seedlings.

4.3.4 Effects of treatments on frond dry weight

The effects of treatments on frond dry weight are presented in Fig. 4.20. Topsoil with N: P: K: Mg (1:1:1:2) and Polyfeed + magnesium treatments showed the highest frond dry weight throughout the period. The lowest frond dry weight was associated with topsoil without fertilization treatment.

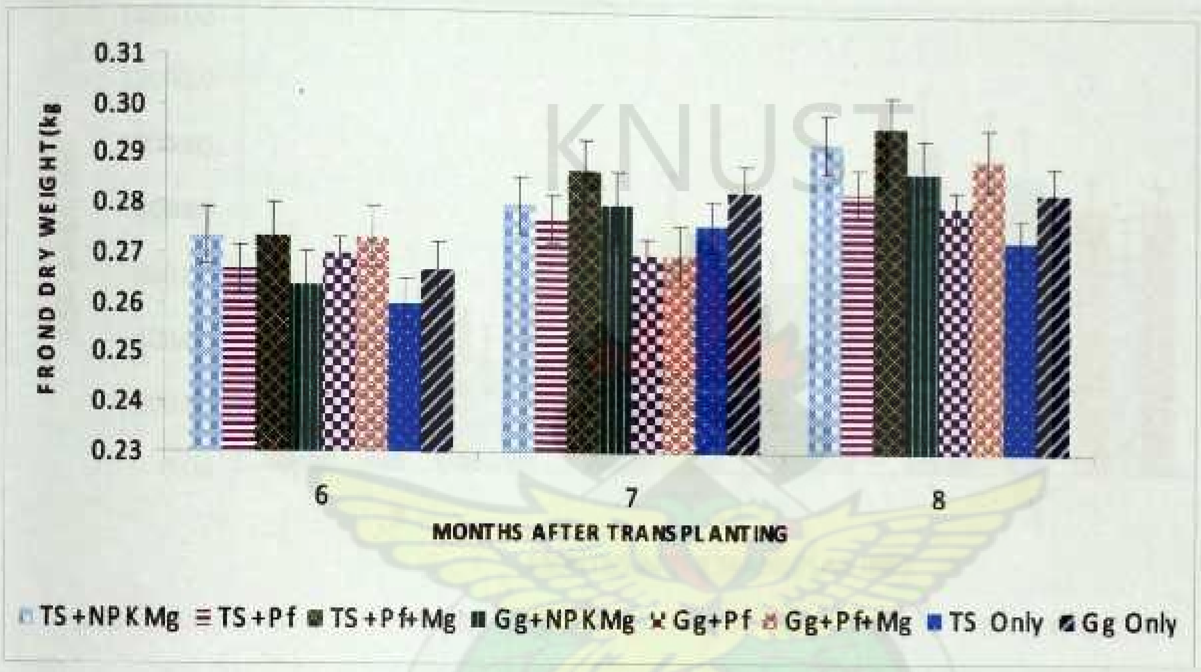

Fig. 4.20 Effects of treatments on frond dry weight of the seedlings.

4.3.5 Effects of treatments on leaf area

Fig. 4.21 shows the effects of treatments on seedlings leaf area. Leaf area peaked at the eighth month and the highest leaf area was observed in topsoil with Polyfeed + magnesium fertilization in the seventh month and topsoil with N P K Mg (1:1:1:2) fertilization in the eighth month.

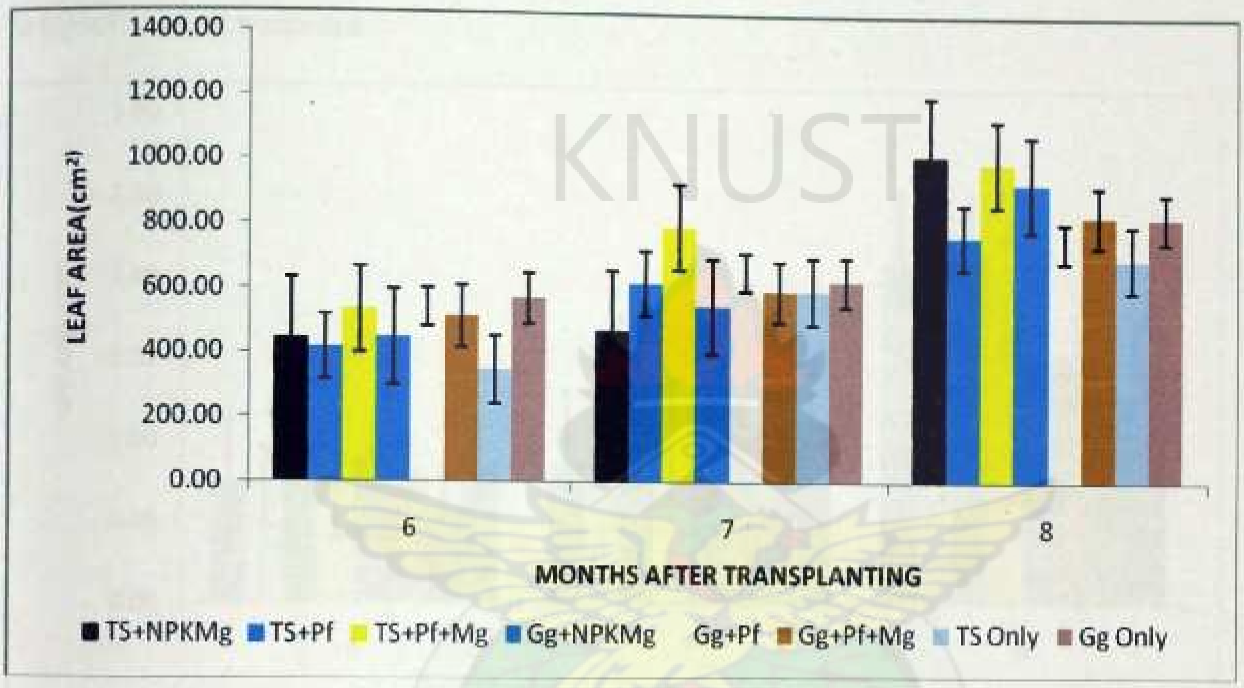

Fig. 4.21 Effects of treatments on leaf area of the seedlings.

4.3.6 Effects of treatments on leaf area index

Effects of treatments on leaf area index (LAI) are presented in Fig. 4.22. The highest leaf area and leaf area index were observed among seedlings planted in topsoil and treated with polyfeed + magnesium (T3) for months 7 and 8. Leaf area and leaf area index showed increasing trend in all the treatments from 6th to 8th month. Lowest leaf area and leaf area index were observed in topsoil control treatment.

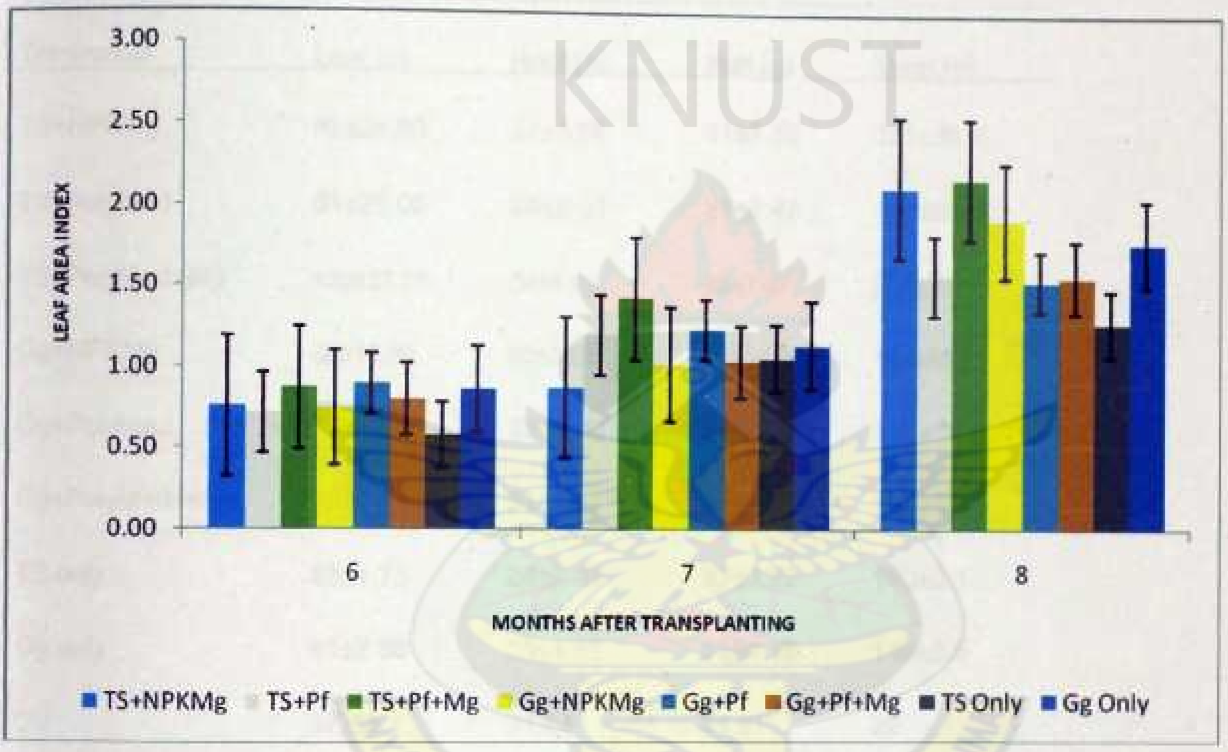

Fig. 4.22 Effects of treatments on leaf area index of the seedlings.

4.4 Destructive measurement

Total dry matter production was high in T3 followed by T2 (Table 4.2). The least dry matter production was by T5 and T6. All the seedlings produced more leaf dry matter than stem and roots except T 5 and T6 which had root weight higher than the stem and showed highest root: shoot ratio.

Table 4.2 Effects of treatments on dry matter production

Treatments	Leaf (g)	Root (g)	Butt (g)	Total (g)
TS+NPKMg	92±24.90	27±4.78	41±7.78	161±35.9
TS+Polyfeed	81±21.00	24±2.24	31±2.42	137±25.5
TS+Polyfeed+Mg	123±37.70	34±5.99	45±7.97	204±47.1
Gg+NPKMg	86±19.00	29±3.63	32±3.90	149±25.7
Gg+Polyfeed	73±9.55	32±1.00	24±1.30	132±10.4
Gg+Polyfeed+Mg	75±4.95	31±10.77	25±1.69	132±11.4
TS only	83±1.75	24±2.02	32±3.22	140±3.1
Gg only	91±2.68	25±4.51	31±4.19	149±3.5
CV	37.62	31.64	24.67	29
Df	7,16	7,16	7,16	7,16
P	0.7	0.78	0.8	0.53
	NS*	NS*	NS*	NS*

Means are not significantly different (P>0.05).

NS* = Not significant (P>0.05).

4.5 Percentage Seedlings Mortality

Mortality rate was higher among seedlings planted in the topsoil than those planted in the green-gro medium (Table 4.3). It was also high in seedlings fertilised with polyfeed than the other fertilizer formulations. Mortalities of the seedlings planted in the green-gro medium were observed in the early stages of the experiment, whereas those of the topsoil were observed in the later part when drought was severe and media nutrients accumulation was also high.

Table 4.3 Effects of treatments on percentage mortality

	Months after transplanting								
Treatments	1	2	3	4	5	6	7	8	Total
					%				
TS+NPKMg	0	0	0.00±00b	0.00±00b	0.00±00	3.33±1.92	3.33±3.33a	6.70±3.85a	13.3±0.08a
TS+Polyfeed	0	0	0.00±00b	0.00±00b	0.00±00	0.00	6.70±3.85a	6.70±3.85a	13.3±0.07a
TS+Pf+Mg	0	0	0.00±00b	0.00±00b	0.00±00	3.33±1.92	0.00±00b	3.33±1.93b	6.67±0.01b
Gg+NPKMg	0	0	3.33±1.93a	3.33±1.24a	0.00±00	0.00±00	0.00±00b	0.00±00c	6.67±0.02b
Gg+Pf	0	0	6.70±2.35a	6.70±1.92a	0.00±00	3.33±3.22	0.00±00b	0.00±00c	16.65±0.02a
Gg+Pf+Mg	0	0	3.33±1.89a	3.33±2.67a	0.00±00	0.00	0.00±00b	0.00±00c	6.67±0.00b
TS only	0	0	0.00±00b	0.00±00b	0.00±0	0.00	0.00±00b	0.00±00c	0.00±0.00c
Gg only	0	0	3.33±2.18a	0.00±00b	0.00±00	0.00	0.00±00b	0.00±00c	3.33±1.12c
CV	0	0	133.44	282.84	282.48	208.97	223.57	200.45	5.57
Df	0	0	7,16	7,16	7,16	7,16	7,16	7,16	7,16
P	0	0	0.25	0.033	0.033	0.308	0.282	0.0566	0.001
			S*	S*	NS*	NS*	S*	S*	S*

Means with the same letters are not significantly different (P>0.05).

NS* = Not significant (P>0.05).

S* = significant at P<0.05.

4.6 Effects of treatments on plant nutrients

4.6.1 Total plant nitrogen

There was a sharp increase of total plant nitrogen in all the seedlings from the 1st to the 3rd month after transplanting (Fig. 4.23). Total plant nitrogen was higher in seedlings planted in topsoil with fertilization than seedlings planted in green-gro medium from the first to the sixth month. Seedlings planted in topsoil with Polyfeed + magnesium recorded the highest total plant nitrogen of 4.37% in the eighth month. However, the highest total plant nitrogen of 4.56% was observed in that same treatment on the sixth month.

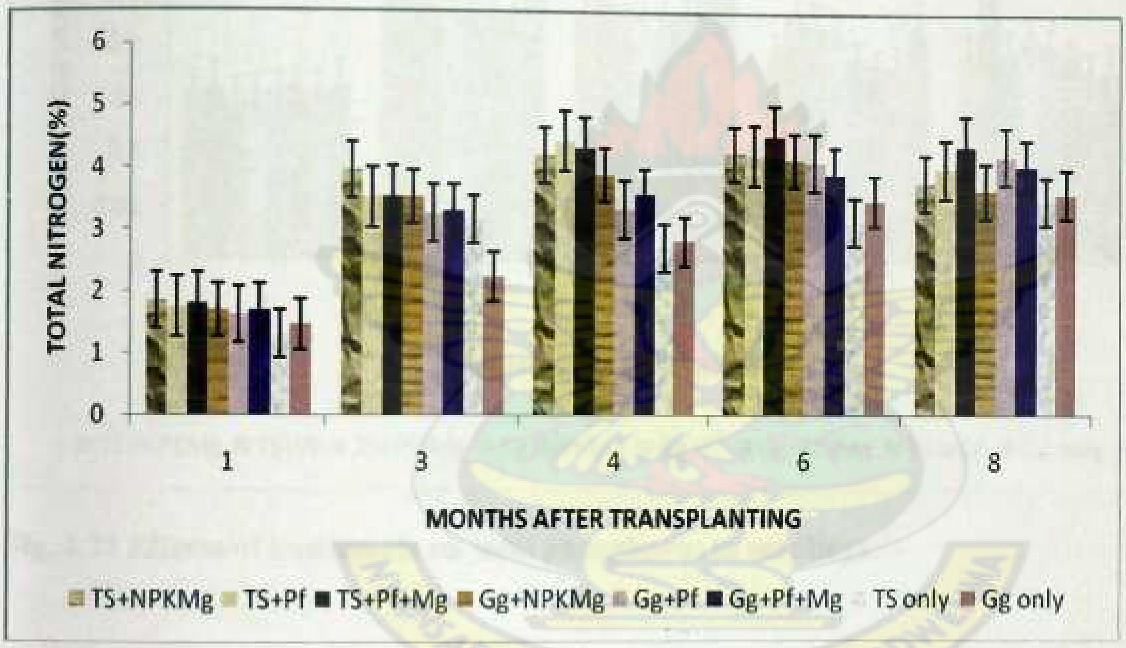

Fig. 4.23 Effects of treatments on total nitrogen in seedlings.

4.6.2 Total plant phosphorus

Phosphorus content of all the seedlings increased from month 1 to month 3 and peaked at month 4 (Fig. 4.24). The highest total plant phosphorus was recorded by seedlings planted in topsoil with polyfeed fertilization (T2) from month 4 to month 8. Seedlings planted in topsoil and green-gro medium without fertilization (T7 and T8) recorded the lowest total plant phophorus accumulation in month 8.

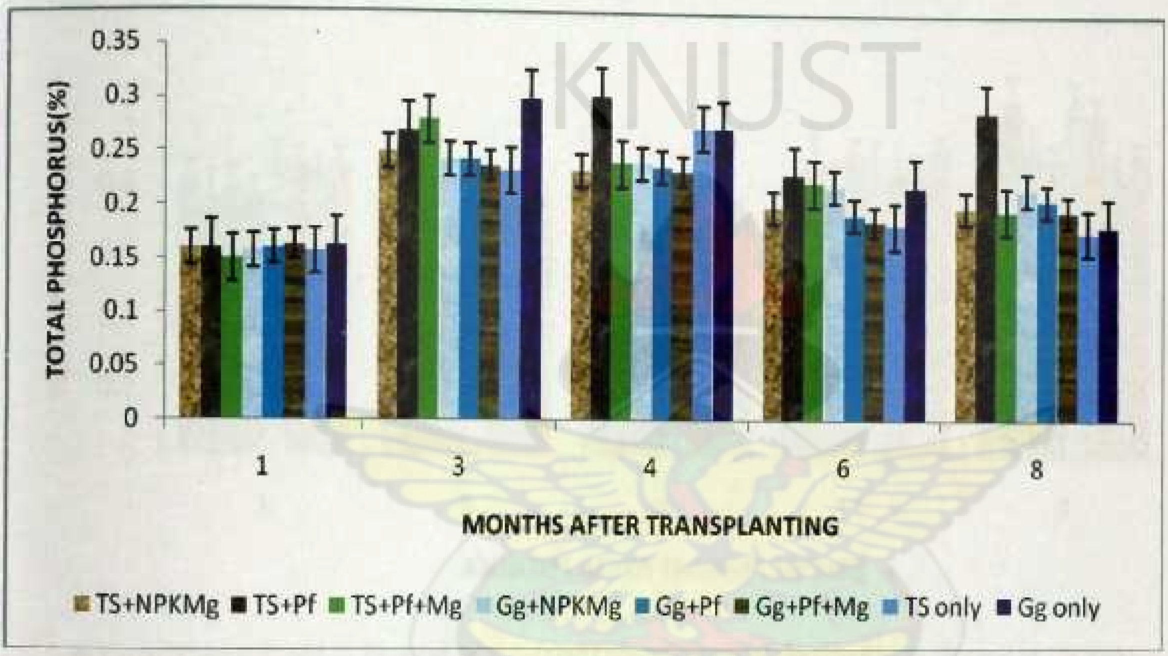

Fig. 4.24 Effects of treatments on total phosphorus in seedlings.

4.6.3 Total plant potassium

Total plant potassium in all the seedlings decreased from month one to month four and increased from there to the end of the study (Fig. 4.25). The highest total plant potassium was associated with seedlings planted in topsoil with polyfeed fertilization and lowest with seedlings planted in topsoil without fertilizatoin (T7) at the eighth month. However, total plant potassium did not show any significant difference throughout the experimental period.

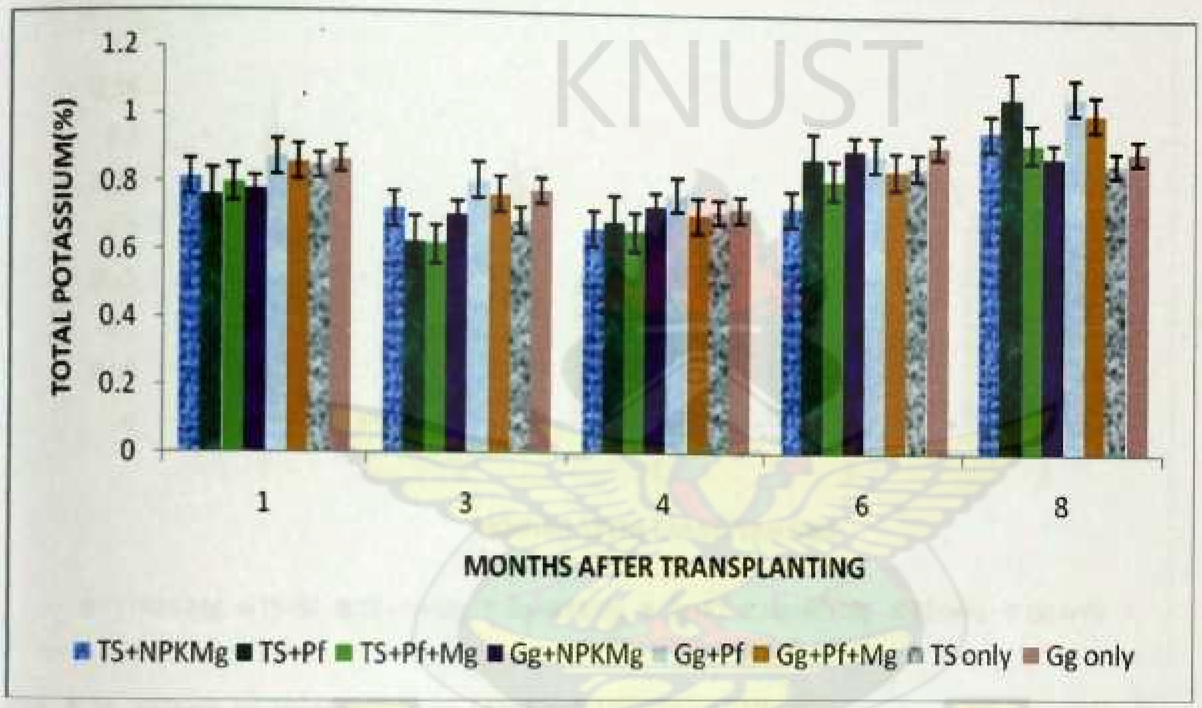

Fig. 4.25 Effects of treatments on total potassium in seedlings.

4.6.4 Total plant calcium

Total plant calcium in all the seedlings generally declined from month 1 to month 6 and increased from month 6 to month 8 (Fig. 4.26). It was highest in seedlings planted in green-gro medium with polyfeed fertilization (T5) at month 1. The trend changed with seedlings planted in topsoil with polyfeed fertilization (T2) recording the highest total plant calcium content at months 6 and 8.

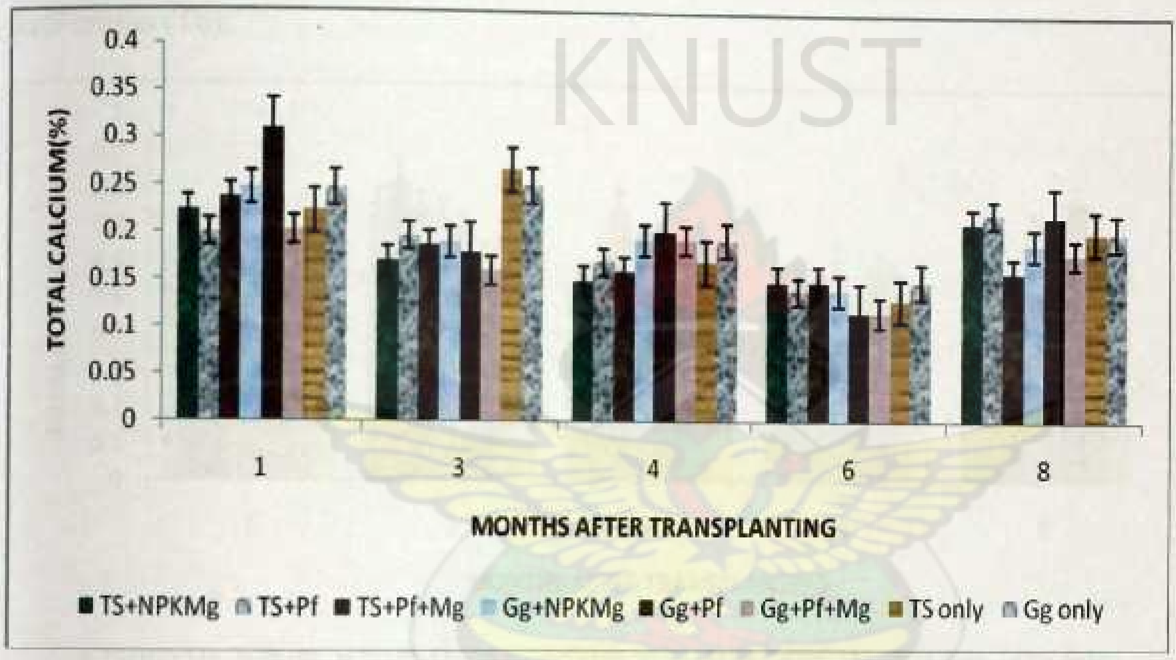

Fig. 4.26 Effects of treatments on total calcium in seedlings.

4.6.5 Total plant magnesium

Total plant magnesium in all the seedlings increased from month 1 to month 3 and declined from month 4 to month 6 (Fig. 4.27). There was a general increase again at month 8. Total plant magnesium peaked at month 3 and the highest was observed in seedlings planted in topsoil with polyfeed fertilization (T2). However, the highest total plant magnesium at month 8 was observed in seedlings planted in green-gro medium with polyfeed + magnesium fertilization (T6).

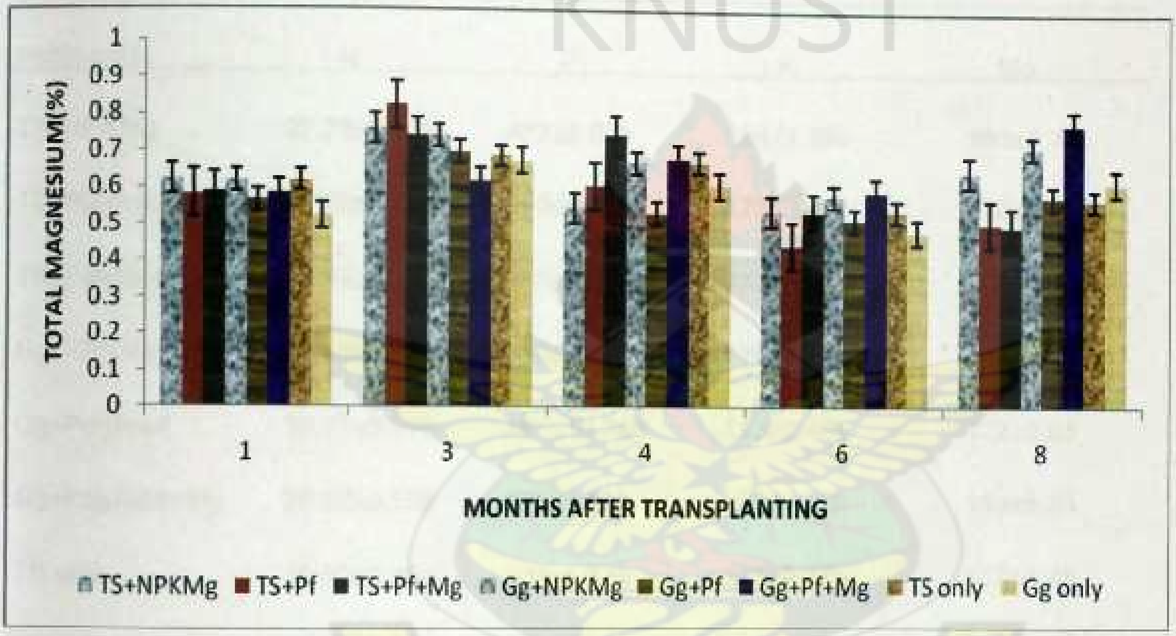

Fig. 4.27 Effects of treatments on total magnesium in seedlings.

4.7 Nutrient Use Efficiency (NUE)

4.7.1 Nutrient Efficiency Ratio (NER)

Table 4.4 shows the Nutrient Efficiency Ratio (NER) as influenced by treatments. The NER was high in topsoil and green-gro treatments without fertilization (T7 and T8) in almost all the nutrients with the exception of potassium. The topsoil treatments recorded the lowest NER of nitrogen whereas Green-gro treatments recorded the lowest NER of potassium.

Table 4.4 Effects of treatments on Nutrient Efficiency Ratio

treatments	N	P	K	Mg
TS+NPKMg	27.75±0.79b	472±8.00b	124±1.16b	163±1.74
TS+Polyfeed	27.86±1.10b	400±6.29d	123±0.62b	170±2.42
TS+Polyfeed+Mg	26.93±0.53b	455±5.03b	132±0.55a	161±1.26
Gg+NPKMg	29.55±1.55b	469±9.80b	125±1.35b	149±5.15
Gg+Polyfeed	30.21±0.52b	481±10.74b	113±2.44c	172±2.63
Gg+Polyfeed+Mg	30.22±0.55b	503±4.53b	120±1.22b	153±5.23
TS only	35.62±1.18a	503±5.32a	125±2.74b	163±1.45
Gg only	36.62±0.87a	435±6.38c	120±1.04b	172±1.78
CV	5.39	2.75	2.22	4.77
Df	7,16	7,16	7,16	7,16
P	0.0001	0.0001	0.0001	0.47
	S*	S*	S*	NS*

Means with the same letters are not significantly different (P>0.05).

NS* =Not significant (P>0.05).

S* =Significant at P<0.05.

4.7.2 Apparent Nutrient Recovery efficiency (ANR)

Table 4.5 shows the Apparent Nutrient Recovery efficiency (ANR) as influenced by treatments. The highest Apparent Nutrient Recovery efficiency for almost all the nutrients was observed in topsoil treatments. The green-gro treatments recorded negative values for all the nutrients except nitrogen.

Table 4.5 Effects of treatments on Apparent Nutrient Recovery efficiency

Treatments	N	P	K	Mg
	………………………………	…%…	………………	………………
TS+NPKMg	21.55±0.52a	0.32±0.01b	0.73±0.03b	0.56±0.02b
TS+Polyfeed	2.47±0.13d	0.18±0.00c	0.02±0.00c	0.02±0.00c
TS+Polyfeed+Mg	17.83±0.90b	0.84±0.01a	1.86±0.33a	1.51±0.01a
Gg+NPKMg	10.72±0.43c	-0.08±0.01d	-0.23±0.01d	-0.62±0.02b
Gg+Polyfeed	0.57±0.04e	-0.17±0.01e	-0.26±0.22d	-5.17±0.22d
Gg+Polyfeed+Mg	1.33±0.08e	-0.39±0.01f	-0.71±0.01d	-0.02±0.00c
TS only	--	--	--	--
Gg only	--	--	--	--
CV	8.83	16.9	10.5	3.72
Df	5,12	5,12	5,12	5,12
P	0.0001	0.0001	0.0001	0.0001
	S*	S*	S*	S*

Means with the same letters are not significantly different (P>0.05).

S* =significant at P<0.05.

4.7.3 Nutrient Recovery Rate (NRR)

Table 4.6 shows the Nutrient Recovery Rate (NRR) as influenced by treatments. The highest NRR for nitrogen was recorded in T1, phosphorus and potassium was in T3 and magnesium in T2.

Table 4.6 Effects of treatments on Nutrient Recovery Rate

Treatments	N	P	K	Mg
		%		
TS+NPKMg	64.94±1.90a	1.76±0.11b	5.08±0.14b	4.53±0.31b
TS+Polyfeed	12.31±0.60e	0.87±0.04d	2.77±0.10d	37.94±1.16a
TS+Polyfeed+Mg	35.48±1.55c	2.24±0.05a	7.55±0.28a	4.81±0.26b
Gg+NPKMg	57.25±2.68b	1.73±0.11b	4.51±0.28c	4.74±0.02b
Gg+Polyfeed	10.31±0.92e	0.65±0.06d	2.93±0.03d	36.04±1.93a
Gg+Polyfeed+Mg	21.75±1.07d	1.31±0.03c	5.52±0.11b	3.11±0.13b
TS only	--	--	--	--
Gg only	--	--	--	--
CV	8.54	9.03	6.73	10.69
Df	5,12	5,12	5,12	5,12
P	0.0001 S*	0.0001 S*	0.0001 S*	0.0001 S*

Means with the same letters are not significantly different (P>0.05).

S* =Significant at P<0.05.

4.8 Economic evaluation of raising an oil palm seedling

Table 4.7 presents the economic evaluation of raising an oil palm seedling. The cost of topsoil per bag was GH¢ 0.10 and GH¢ 0.48 for the green-gro (Appendix 17). The lowest cost of fertilizer (GH¢ 0.08) used was observed in T1 and T4 (Appendices 17 and 21) and the highest (GH¢ 0.19) recorded in T2 and T5 (Appendices 18 and 22). The highest net profits were recorded by seedlings planted in topsoils. Seedlings planted in the green-gro medium and fertilized with Polyfeed recorded the lowest net profit. Cost: Benefit ratio was low among seedlings planted in green-gro medium than seedlings planted in topsoil and lower expenditure equivalent ratio was recorded by the seedlings planted in topsoil.

Table 4.7 Agro economic benefit and cost per seedling

treatments	Return/seedling (GH¢)	Cost/ seedling (GH¢)	Net profit (GH¢)	Cost:benefit ratio	Expd eqvt ratio
TS+NPKMg	1.50	0.58	0.92	2.59	1.00
TS+Polyfeed	1.50	0.65	0.85	2.31	1.12
TS+Polyfeed+Mg	1.50	0.59	0.91	2.54	1.02
Gg+NPKMg	1.50	0.94	0.56	1.60	1.62
Gg+Polyfeed	1.50	1.09	0.41	1.38	1.88
Gg+Polyfeed+Mg	1.50	0.95	0.55	1.58	1.64
TS only	1.50	0.48	1.02	3.13	0.83
Gg only	1.50	0.84	0.66	1.79	1.45

CHAPTER 5

5.0 DISCUSSION

5.1 Media characterization

It was observed from the media characterization that the texture of both media were within the range recommended by CIRAD/IRHO (1979), which is a minimum of 15 to 30 % fine elements (fine sand + loam + clay) within 0 to 20cm depth for the growth and development of oil palm. It was also observed that the green-gro medium contained high amount of most plant nutrients compared to the topsoil. This might have resulted from the high quantities of organic materials used for the compost. Finding a compost-fertilizer combination that produces results equal to the fertilizer alone is a topic of many current researches. In a growth chamber study using fescue as the indicator plant, Sikora (1997) found that a compost-fertilizer combination of 33% compost and 67% fertilizer N was equal to 100% NH_4NO_3 fertilizer. The high content of available phosphorus and exchangeable calcium of the green-gro medium were due to poultry manure which contain high calcium di-phosphate fed to the birds. Tisdale *et al.* (1993) stated that manure application improves chemical properties such as cation exchange capacity. Increase in soil concentrations of nitrogen, phosphorus, magnesium and calcium with manure application has been reported by Omaliko (1984). Balingar *et al.* (2001) stated that soil organic matter helps to increase exchangeable calcium and magnesium. It also reduces phosphorus fixation and leaching of nutrients.

5.2 Media analyses after treatment applications

The pH of the topsoil with fertilizer treatments were decreasing while those of green-gro treatment were stable. According to Tisdale *et al.* (1993), manure application improves soil buffering capacity. The content of nitrogen, phosphorus and the exchangeable bases were increasing in all the treatments but the increase was more pronounced in the green-gro medium than in the topsoil. Available potassium content of all the treatments dropped significantly at the final analyses. This observation was in line with findings of Banuelos *et al.* (2007) that application of manure to soil increase total concerntration of most nutrients except potassium. Gilley and Eghball (2002) also reported that manure can serve as important source of plant nutrients including nitrogen and phosphorus. According to Mnkeni and MacKenzie (1985), Sibanda and Young (1986), Iyamuremye *et al.* (1996) and Kwabiah *et al.* (2003), organic materials and their decomposition products can reduce phosphorus fixation in soils and which probably might have resulted in very high concentration of available phosphorus (34.16g/kg at the beginning of the experiment and 108.33g/kg for green-gro + polyfeed at the end of the study) in the green-gro medium.

Available potassium of the green-gro medium treatments decreased rapidly from the fourth month to the eighth month. Investigations by Sinclair (1979), Ghorayshi and Lotse (1986), Mengel *et al.* (1980) and Wulff *et al.* (1998) have shown that several plant species may utilize reserved potassium to a considerable extent (luxury consumption). On the contrary, the exchangeable acidity increased rapidly in all the topsoil treatments than in green-gro medium. This means the higher organic matter content of the green-gro medium has conferred to it stable properties as inferred by Tisdale *et al.* (1993). The microbial biomass carbon and phosphorus were almost always higher in green-gro medium treatments than the topsoil treatments over the experimental period. According to Borken *et al.* (2002), microbial activity and microbial biomass of soils are strongly related to soil chemical parameters such as pH, cation exchange capacity and nutrient availability. This observation supports the high nutrient content of the green-gro medium treatments in the experiment. Also, several findings have confirmed this observation of the experiment that microbial biomass and activity increase with manure application than inorganic fertilizers. Marschner *et al.* (2003) observed that even though organic and inorganic fertilizers are used primarily to increase nutrient availability to plants, they can affect the population, composition, and function of soil microorganisms. Organic fertilizers usually increase soil microbial biomass (Peacock *et al.*, 2001; Parham *et al.*, 2002; Kaur *et al.*, 2005). Work done by Chu *et al.* (2007) showed that organic manure had a significantly greater impact ($P<0.05$) on the microbial biomass C compared to mineral fertilizers.

Several other studies have reported the decreased of microbial biomass by mineral N fertilizer (Ladd *et al.*, 1994; Hopkins and Shiel, 1996; Simek *et al.*, 1999; Sarathchandra *et al.*, 2001; Bittman *et al.*, 2005). The workers have attributed the decreased microbial biomass by mineral N fertilizer application to direct toxicity and reduced pH. In this study topsoil treatments showed decreased pH and reduced microbial biomass carbon and phosphorus. Hopkins and Shiel (1996), Parham *et al.* (2003) and Plaza *et al.* (2004) found that inorganic fertilizers had relatively less effect on soil microbial biomass and microbial activities than organic fertilizers. While Ruppel and Makswitat (1999), Wardle *et al* (1999), Marschner *et al.* (2003) also found that fertilization resulted in microbial community shifts in soils.

5.3 Vegetative growth assessment

There was initial slow establishment and growth rate of the seedlings planted in green-gro medium. This suggested a microbial competition for nutrient resources. Similarity in growth rate of the seedlings irrespective of the treatment differences at the end of the experiment was an indication of capacity of all the media to supply adequate nutrients to the seedlings for optimum growth over the experimental period. This supports the assertion by Abner and Foster (2006) that good quality topsoil high in organic matter can support quality oil palm seedling production. Lewandowski *et al*. (1999) postulated that the quality or health of a soil refers not only to its lack of degradation or contamination, but also to its overall effectiveness for supporting plant growth, managing water and responding to environmental stress. The rate of growth as shown by the results of this study is in line with the assertion above. Most of the measured parameters were high in seedlings planted in topsoil with N P K Mg and Polyfeed + Mg fertilization at the end of the experiment. Tayeb (2005) explained the importance of magnesium in oil palm by reporting that it plays a vital role in the formation of chlorophyll in plants and is also required in the activation of many enzymes concerned with carbohydrate metabolism. He also stated that the application of high rate of nitrogen and potassium tends to depress the uptake of magnesium which probably might have resulted in the vigorous growth of seedlings planted in topsoil with kieserite fertilization.

5.4 Plant nutrients

The total plant nitrogen for all the treatments were below the critical level of 2.50% recommended by IRHO (1960) at one month (1) after transplanting. This might be because of seedling recovery from transplanting shock. However, the level far exceeded the critical level from three months after transplanting to the end of the experiment. Although the nitrogen level of the media was lower than the soil critical level of 1% for oil palm recommended by IRHO (1960). This suggests high nitrogen absorption efficiency of the seedlings in all the media. The lowest plant phosphorus content (0.15%) was recorded by T3 (topsoil + polyfeed + magnesium) at the first analysis and was within the critical level of 0.15% (IRHO, 1960). The phosphorus absorption can also be said to be efficient for all the treatments. Although the phosphorus content in the green-gro medium treatments was all above the critical level over the experimental period, it was below the critical level for the topsoil treatments at the beginning of the experiment (characterization) and in some of the treatments at the second media analyses. Potassium and calcium absorption by the seedlings was inefficient since the seedlings recorded less than 1.0 and 0.31% for K and Ca which were below the critical levels 1.00% and 0.60% respectively (IRHO, 1960). Magnesium absorption was very efficient as the lowest plant content over the experimental period was 0.43% and the critical plant level was 0.24% (IRHO, 1960). However, the magnesium content of the seedling media was lower than the critical level of 0.40 cmol/kg.

5.5 Destructive measurement

Seedlings planted in the topsoil treatments produced higher leaf and butt dry matter compared to their counterparts planted in the green-gro medium. Haynes and Gower (1995) stated that addition of mineral fertilizer (N, P, K, Ca, Mg, S) induced a decrease in soil respiration and fine root production. Borken *et al.* (2002) noted in their study that addition of nutrients by the application of compost did not increase root growth and root respiration. Clemensson-Lindell and Persson (1995) also discovered that application of ammonium sulphate, wood ash and nitrogen-free fertilizer decreased the fine root biomass in a Norway spruce stand in Sweden. This study contradicts the findings of these people since green-gro medium seedlings produced more root than shoots. Higher root to shoot ratio recorded by seedlings planted in green-gro medium and fertilized with Polyfeed and Polyfeed + Magnesium supports the findings of Obigbesan *et al.* (2002). They reported that root growth was inhibited at low P supply as P promotes root proliferation. In this study, the phosphorus content in the medium of these treatments was high. The leaf phosphorus content of seedlings of T7 (topsoil only) was lowest at sixth and eighth months analyses and confirmed the findings of Lucas *et al.* (1979) , Menon and Chien (1990) and Agboola and Obigbesan (1974) that phosphorus fertilizer application increases leaf phosphorus of oil palm seedlings significantly.

5.6 Percentage seedling mortality

Seedling mortality of the green-gro medium treatments was observed in the early stages of the experiment. This suggests that the green-gro medium was not well decomposed at the time of use. Seedling mortality was high in seedlings planted in the topsoil than the green-gro medium at the later stages of the experiment when the drought was pronounced. The organic matter content of the green-gro medium after decomposition improved its quality and confered to it high water holding capacity, cation exchange capacity and buffering capacity which reduced nutrient toxicity and water stress that might cause seedlings mortality.

Several researches have shown the significance of organic matter in soil quality. Islam and Weil (2000) stated that soil organic matter (SOM)-related properties have been shown to serve as a good soil quality indicator. According to Elliot *et al.* (1986), organic matter is predicted to reduce heavy metals availability through the increase of cation exchange capacity and organic matter's ability to adsorb heavy metals into stable form by lingand bond. Soil organic matter is known to have a strong relationship with aggregate formation and stabilization (Tisdall and Oades ,1982; Zhang *et al.*, 1996; Six *et al.*, 2002). The organic fraction of manure can significantly increase soil aggregation, infiltration, microbial activity, structure, and water-holding capacity and can reduce soil compaction and erosion (Gilley and Risse, 2000; Haynes and Naidu, 1998). Seedlings mortality was also high in seedlings with Polyfeed fertilization which might be due to high solubility and high nutrient content of the Polyfeed causing seedling death.

5.7 Nutrient use efficiency (NUE)

The results show that nutrient efficiency ratio (NER) of the treatments without fertilization (T7 and T8) was high for almost all the nutrients, since the nutrient content of the seedlings of these treatments were lower than that of the other treatments. This observation is in line with work done by Adebayo *et al.* (2006) that without phosphorus addition, nutrient content in the leaf of oil palm seedlings was very low. The highest apparent nutrient recovery rate (ANR) recorded by the topsoil + polyfeed + magnesium (T3) for almost all the nutrients was due to the highest dry matter production whereas the negative values obtained by topsoil + polyfeed (T2), green-gro + polyfeed (T5) and green-gro + polyfeed + magnesium (T6) showed that nutrient uptake of seedlings of these treatments was less than that of the topsoil and green-gro without fertilization. The implication is that irrespective of the medium, the nutrient uptake of the seedlings fertilized with Polyfeed was lower than the other fertilizer formulations. Baligar and Bennett (1986a; 1986b), Fageria (1992) and Hauck (1985) had stated that fertilizer use efficiency is affected by several factors such as soil properties, efficiency of crops, climate and the type of the fertilizer used. Fageria *et al.* (1997) also reported that the availability and recovery efficiencies of fertilizers are greatly affected by amendments such organic materials due to their effects in nutrient dynamics.

The results also showed that nutrient recovery rate (NRR) was high in treatments that were given lower doses of nutrients. However, it was higher in topsoil treatments than their green-gro counterparts. Generally, NRR was low in all the treatments for all the nutrients except nitrogen. Zhu (2000) reported that fertilizer nitrogen efficiency in field crops is estimated at 30 to 50 %. According to Baligar and Bennett (1986a; 1986b) the recovery of applied inorganic fertilizers by plants is low in many soils. They reported that estimates of overall efficiency of these applied fertilizers should be about 50% or lower for N, less than 10% for P, and close to 40% for K.

5.8 Agro-economic appraisal

The cost of green-gro medium for a seedling was 450% higher than topsoil for a seedling. This resulted in high input cost of a seedlings planted in green-gro medium. Comparatively, the cost of polyfeed which was GH¢46.00 per 50kg was far higher than the other fertilizers and also resulted in very high input cost of seedlings of T5 (green-gro + polyfeed). Kieserite was only GH¢15.00 per 50kg and the cheapest in cost among all the fertilizers and when mixed with polyfeed in a 1:1 proportion reduced a seedling's fertilizer cost by two thirds (2/3) of the cost of polyfeed only. Moreover, the combination of sulphate of ammonia, muriate of potash, triple super phosphate and kieserite in topsoil gave the lowest seedling input cost among all the fertilised seedlings.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The green-gro medium was brought to market for use by nursery operators to reduce environmental degradation caused by topsoil winning, make efficient use of crop residues and improve seedlings performance at the nursery. The results of this experiment have shown that the performance of oil palm seedlings in the topsoil with fertilization programmes was superior to that of the green-gro medium. The analyses of the green-gro at the beginning, during and after the experiment showed that the green-gro contained high amount of plant nutrients and has good potential for use as nursery potting medium. However, the cost of the green-gro for nursery application is very high (more than 400% compared to the use of topsoil).

The study has shown that polyfeed and kieserite combination gave similar results as N: P: K: Mg (1:1:1:2), the standard OPRI practice. The performance of oil palm seedlings was better on polyfeed + magnesium and N: P: K: Mg fertilizer treatments than Polyfeed only. It was observed from the results of the study that topsoil alone did not improve oil palm seedlings growth at nursery even though that was the cheapest option. The seedlings planted in the green-gro medium with polyfeed and polyfeed + Mg treatments contained more phosphorus and produced more root and lesser shoot than the other treatments at the end of the study.

The study has shown that microbial biomass was higher in the green-gro medium treatments than the topsoil treatments. It was also higher in the green-gro medium treatments with fertilization than green-gro medium treatment without fertilization. The study also showed that input cost for using polyfeed with topsoil for oil palm seedling production was about two times higher than the use of N: P: K: Mg. However, polyfeed + kieserite combination reduced the cost by one third of that of N: P: K: Mg. The study revealed that the cost of using polyfeed and green-gro for oil palm seedling production amounted to one third of the price of an oil palm seedling.

6.2 Recommendations

From the results of the study, it is recommended that

- the quality of the green-gro medium need to be investigated for improvement.
- the preparation of the green-gro should be centered at the nursery operating areas to reduce production cost due to transportation from far away distances.
- Investigations to be made into polyfeed nutrient release and availability to oil palm seedlings. Monthly rate of application of Polyfeed + kieserite on oil palm seedlings should be investigated.
- Nursery fertilizers application is very essential when sole topsoil is used.
- The microbial biomass of the green-gro can be facilitated by the addition of inorganic fertilizers.
- this study should be carried further into the field since conscious efforts are made to apply phosphorus fertilizers to newly transplanted seedlings for early root development.

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APPENDICES

Appendix 1. Means and standard errors for vegetative measurement at month 1

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference Plant height Number of leaves	0.85cm 29.5cm 3.83	0.11 2.91 0.38
Topsoil + polyfeed	Butt circumference Plant height Number of leaves	0.80cm 29.2cm 3.85	0.07 0.29 0.21
Topsoil + polyfeed +Mg	Butt circumference Plant height Number of leaves	0.8cm 29.9cm 3.60	0.08 1.27 0.17
Green-gro + NPKMg	Butt circumference Plant height Number of leaves	0.79cm 28.9cm 3.76	0.07 1.31 0.35
Green-gro + polyfeed	Butt circumference Plant height Number of leaves	0.93cm 33.4cm 4.23	0.08 3.18 0.23
Green-gro + polyfeed + Mg	Butt circumference Plant height Number of leaves	0.74cm 28.9cm 3.60	0.05 0.38 0.15
Topsoil only	Butt circumference Plant height Number of leaves	0.77cm 27.7cm 3.37	0.03 1.53 0.07
Green-gro only	Butt circumference Plant height Number of leaves	0.97cm 32.4cm 4.03	0.13 2.84 0.23

Appendix 2. Means and standard errors for vegetative measurement at month 2

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference Plant height Number of leaves	1.08cm 33.0cm 22.7	0.08 2.96 18.1
Topsoil + polyfeed	Butt circumference Plant height Number of leaves	1.13cm 30.8cm 5.25	0.07 0.20 0.17
Topsoil + polyfeed +Mg	Butt circumference Plant height Number of leaves	4.48cm 31.6cm 5.13	3.24 1.56 0.20
Green-gro + NPKMg	Butt circumference Plant height Number of leaves	1.12cm 30.8cm 4.90	0.07 1.11 0.26
Green-gro + polyfeed	Butt circumference Plant height Number of leaves	1.20cm 34.1cm 5.17	0.04 2.68 0.07
Green-gro + polyfeed + Mg	Butt circumference Plant height Number of leaves	1.13cm 32.3cm 4.67	0.07 20.4 0.12
Topsoil only	Butt circumference Plant height Number of leaves	1.00cm 30.47cm 4.63	0.06 1.34 0.09
Green-gro only	Butt circumference Plant height Number of leaves	1.24cm 33.2cm 5.30	0.17 3.33 0.30

Appendix 3. Means and standard errors for vegetative measurement at month 3

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference Plant height Number of leaves	1.73cm 34.0cm 6.13	0.20 2.79 0.47
Topsoil + polyfeed	Butt circumference Plant height Number of leaves	1.59cm 33.4cm 6.10	0.07 0.29 0.36
Topsoil + polyfeed +Mg	Butt circumference Plant height Number of leaves	1.52cm 39.4cm 5.83	0.04 6.62 0.38
Green-gro + NPKMg	Butt circumference Plant height Number of leaves	1.62cm 33.3cm 5.80	0.09 0.77 0.25
Green-gro + polyfeed	Butt circumference Plant height Number of leaves	1.78cm 32.8cm 6.20	0.10 1.70 0.15
Green-gro + polyfeed + Mg	Butt circumference Plant height Number of leaves	1.57cm 35.3cm 5.83	0.08 1.74 0.16
Topsoil only	Butt circumference Plant height Number of leaves	1.48cm 32.00cm 5.57	0.06 0.35 0.21
Green-gro only	Butt circumference Plant height Number of leaves	1.76cm 34.6cm 5.93	0.21 2.54 00.33

Appendix 4. Means and standard errors for vegetative measurement at month 4

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference Plant height Number of leaves	3.14cm 44.2cm 6.73	0.32 2.57 0.54
Topsoil + polyfeed	Butt circumference Plant height Number of leaves	3.15cm 41.03cm 6.57	0.10 2.43 0.12
Topsoil + polyfeed +Mg	Butt circumference Plant height Number of leaves	2.94cm 43.0cm 6.70	0.25 2.72 0.20
Green-gro + NPKMg	Butt circumference Plant height Number of leaves	3.02cm 43.7cm 6.10	0.23 0.69 0.46
Green-gro + polyfeed	Butt circumference Plant height Number of leaves	3.02cm 44.2cm 6.53	0.08 1.50 0.32
Green-gro + polyfeed + Mg	Butt circumference Plant height Number of leaves	2.96cm 45.3cm 5.97	0.11 0.80 0.23
Topsoil only	Butt circumference Plant height Number of leaves	2.74cm 41.5cm 6.1	0.18 1.11 0.25
Green-gro only	Butt circumference Plant height Number of leaves	2.97cm 43.4cm 6.50	0.10 2.68 0.15

Appendix 5. Means and standard errors for vegetative measurement at month 5

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference Plant height Number of leaves	2.78cm 47.7cm 6.27	0.40 3.38 0.58
Topsoil + polyfeed	Butt circumference Plant height Number of leaves	2.91cm 48.2cm 6.10	0.05 1.99 0.23
Topsoil + polyfeed +Mg	Butt circumference Plant height Number of leaves	2.67cm 48.2cm 5.87	0.16 3.28 0.37
Green-gro + NPKMg	Butt circumference Plant height Number of leaves	2.62cm 48.3cm 5.90	0.18 0.95 0.38
Green-gro + polyfeed	Butt circumference Plant height Number of leaves	2.73cm 47.2cm 6.17	0.25 1.50 0.18
Green-gro + polyfeed + Mg	Butt circumference Plant height Number of leaves	2.61cm 49.6cm 5.87	0.23 0.96 0.13
Topsoil only	Butt circumference Plant height Number of leaves	2.35cm 46.5cm 5.73	0.18 1.76 0.35
Green-gro only	Butt circumference Plant height Number of leaves	2.85cm 48.5cm 6.27	0.37 2.77 0.44

Appendix 6. Means and standard errors for vegetative measurement at month 6

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference	4.10cm	0.40
	Plant height	54.3cm	2.90
	Number of leaves	7.63	0.71
	Frond dry weight	0.27g	0.01
	Leaf area	446cm^2	94.7
	Leaf area index	0.76	0.19
Topsoil + polyfeed	Butt circumference	3.79cm	0.17
	Plant height	54.4cm	2.81
	Number of leaves	7.11	0.37
	Frond dry weight	0.27g	0.01
	Leaf area	418cm^2	84.1
	Leaf area index	0.72	0.11
Topsoil + polyfeed +Mg	Butt circumference	3.93cm	0.28
	Plant height	54.7cm	3.90
	Number of leaves	7.63	0.65
	Frond dry weight	0.27g	0.01
	Leaf area	535cm^2	166
	Leaf area index	0.87	0.34
Green-gro + NPKMg	Butt circumference	3.87cm	0.14
	Plant height	37.cm	16.3
	Number of leaves	7.30	0.35
	Frond dry weight	0.26g	0.01
	Leaf area	448cm^2	92.2
	Leaf area index	0.75	0.20
Green-gro + polyfeed	Butt circumference	3.72cm	0.13
	Plant height	55.2cm	1.47
	Number of leaves	6.80	0.11
	Frond dry weight	543g	0.01
	Leaf area	0.90cm^2	17.0
	Leaf area index	0.75	0.01
Green-gro + polyfeed + Mg	Butt circumference	3.74cm	0.08
	Plant height	55.2cm	0.12
	Number of leaves	7.20	0.30
	Frond dry weight	0.27g	0.01
	Leaf area	364cm^2	191
	Leaf area index	0.81	0.13
Topsoil only	Butt circumference	3.51cm	0.13
	Plant height	53.6cm	2.87
	Number of leaves	7.06	0.55
	Frond dry weight	0.26g	0.01
	Leaf area	349cm^2	49.0
	Leaf area index	0.58	0.08
Green-gro only	Butt circumference	3.64cm	0.10
	Plant height	53.9cm	2.89
	Number of leaves	7.10	0.35
	Frond dry weight	0.27g	0.01
	Leaf area	570cm^2	82.9
	Leaf area index	0.87	0.12

Appendix 7. Means and standard errors for vegetative measurement at month 7

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference	4.42cm	0.47
	Plant height	64.2cm	6.19
	Number of leaves	7.10	0.97
	Frond dry weight	0.28g	0.01
	Leaf area	469cm^2	11.7
	Leaf area index	0.88	0.06
Topsoil + polyfeed	Butt circumference	4.32cm	0.17
	Plant height	61.7cm	2.03
	Number of leaves	7.47	0.73
	Frond dry weight	0.28g	0.01
	Leaf area	620cm^2	234
	Leaf area index	1.21	0.43
Topsoil + polyfeed +Mg	Butt circumference	4.44cm	0.35
	Plant height	63.7cm	5.62
	Number of leaves	7.77	0.48
	Frond dry weight	0.29g	0.01
	Leaf area	795cm^2	97.8
	Leaf area index	1.40	0.26
Green-gro + NPKMg	Butt circumference	4.22cm	0.61
	Plant height	63.2cm	0.99
	Number of leaves	7.50	0.29
	Frond dry weight	0.28g	0.01
	Leaf area	548cm^2	19.7
	Leaf area index	1.02	0.08
Green-gro + polyfeed	Butt circumference	4.26cm	0.14
	Plant height	60.7cm	2.14
	Number of leaves	7.17	0.08
	Frond dry weight	0.27g	0.01
	Leaf area	656cm^2	184
	Leaf area index	1.24	0.35
Green-gro + polyfeed + Mg	Butt circumference	4.14cm	0.08
	Plant height	66.2cm	1.57.
	Number of leaves	7.47	0.24
	Frond dry weight	0.27g	0.01
	Leaf area	596cm^2	92.7
	Leaf area index	1.04	0.12
Topsoil only	Butt circumference	4.08cm	0.28
	Plant height	64.4cm	3.74
	Number of leaves	7.57	0.47
	Frond dry weight	0.28g	0.01
	Leaf area	598cm^2	15.9
	Leaf area index	1.06	0.07
Green-gro only	Butt circumference	4.40cm	0.20
	Plant height	64.1cm	3.24
	Number of leaves	8.07	0.32
	Frond dry weight	0.28g	0.01
	Leaf area	626cm^2	104
	Leaf area index	1.15	0.17

Appendix 8. Means and standard errors for vegetative measurement at month 8

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	Butt circumference	5.13cm	0.25
	Plant height	75.4cm	6.70
	Number of leaves	8.80	0.10
	Frond dry weight	0.29g	0.01
	Leaf area	1019cm^2	135
	Leaf area index	2.12	1.30
Topsoil + polyfeed	Butt circumference	4.77cm	0.16
	Plant height	73.7cm	6.29
	Number of leaves	8.70	0.30
	Frond dry weight	0.28g	0.01
	Leaf area	768cm^2	156
	Leaf area index	1.57	0.31
Topsoil + polyfeed +Mg	Butt circumference	5.04cm	0.30
	Plant height	78.6cm	6.72
	Number of leaves	9.10	0.42
	Frond dry weight	0.29g	0.01
	Leaf area	997cm^2	171
	Leaf area index	2.17	0.45
Green-gro + NPKMg	Butt circumference	5.13cm	0.19
	Plant height	70.9cm	3.91
	Number of leaves	8.23	0.39
	Frond dry weight	0.29g	0.01
	Leaf area	934cm^2	45.7
	Leaf area index	1.92	0.19
Green-gro + polyfeed	Butt circumference	4.67cm	0.28
	Plant height	74.9cm	3.70
	Number of leaves	8.67	0.49
	Frond dry weight	0.28g	0.01
	Leaf area	750cm^2	47.5
	Leaf area index	1.54	0.17
Green-gro + polyfeed + Mg	Butt circumference	4.44cm	0.15
	Plant height	70.8cm	2.21
	Number of leaves	7.90	0.49
	Frond dry weight	0.29g	0.01
	Leaf area	831cm^2	127
	Leaf area index	1.57	0.31
Topsoil only	Butt circumference	4.47cm	0.29
	Plant height	71.2cm	6.50
	Number of leaves	7.87	0.72
	Frond dry weight	0.27g	0.01
	Leaf area	699cm^2	44.3
	Leaf area index	1.28	0.13
Green-gro only	Butt circumference	4.93cm	0.37
	Plant height	74.7cm	4.31
	Number of leaves	8.87	0.30
	Frond dry weight	0.2g	0.01
	Leaf area	827cm^2	184
	Leaf area index	1.77	0.42

Appendix 9. Means and standard errorse for soil analysis during the experiment

Treatment	Variable	Means	Standard error
Topsoil + NPKMg	pH	5.10(1:1 H_2O)	0.11
	Total nitrogen	0.14%	000
	Available phosphorus	2.9mg/kg	3.92
	Available potassium	139.9mg/kg	114
	Organic carbon	1.93%	0.07
	Organic matter	3.40%	0.15
	Exchangeable calcium	7.93cmol/kg	1.60
	Exchangeable magnesium	3.23cmol/kg	0.60
	Exchangeable potassium	0.7cmol/kg	2.90
	Exchangeable sodium	2.77cmol/kg	0.29
	Total exchangeable bases	14.30cmol/kg	4.89
	Exchangeable acidity	0.45cmol/kg	0.22
	ECEC	14.75cmol/kg	4.79
	Base saturation	99.1%	0.46
	Microbial carbon	47.8µ/g	6.70
	Microbial nitrogen	14.9 µ/g	9.53
	Microbial phosphorus	18.6 µ/g	2.03
Topsoil + polyfeed	pH	5.90(1:1 H_2O)	0.42
	Total nitrogen	0.18%	0.04
	Available phosphorus	5.2mg/kg	24.5
	Available potassium	127.3mg/kg	88.9
	Organic carbon	2.30%	0.32
	Organic matter	3.97%	0.59
	Exchangeable calcium	9.03cmol/kg	1.47
	Exchangeable magnesium	2.40cmol/kg	0.45
	Exchangeable potassium	0.35cmol/kg	1.23
	Exchangeable sodium	2.47cmol/kg	0.14
	Total exchangeable bases	14.27cmol/kg	0.67
	Exchangeable acidity	0.18cmol/kg	0.04
	ECEC	14.4350.3cmol/kg	0.63
	Base saturation	99.6%	0.09
	Microbial carbon	50.8 µ/g	2.97
	Microbial nitrogen	9.93 µ/g	4.30
	Microbial phosphorus	62.0 µ/g	10.8
Topsoil + polyfeed +Mg	pH	5.67(1:1 H_2O)	0.55
	Total nitrogen	0.14%	0.01
	Available phosphorus	3.3mg/kg	6.39
	Available potassium	27.3mg/kg	30.6
	Organic carbon	2.07%	0.13
	Organic matter	3.53%	0.22
	Exchangeable calcium	8.30cmol/kg	1.50
	Exchangeable magnesium	4.63cmol/kg	0.91
	Exchangeable potassium	0.38cmol/kg	0.23
	Exchangeable sodium	3.57cmol/kg	0.12
	Total exchangeable bases	16.88cmol/kg	2.36
	Exchangeable acidity	0.35cmol/kg	0.15
	ECEC	17.23mol/kg	2.21
	Base saturation	99.4%	0.30
	Microbial carbon	53.0 µ/g	1.97
	Microbial nitrogen	6.6 µ/g	3.73
	Microbial phosphorus	25.8 µ/g	4.64
Green-gro + NPKMg	pH	7.07(1:1 H_2O)	0.03
	Total nitrogen	0.23%	0.03
	Available phosphorus	38.5mg/kg	31.1
	Available potassium	175.1mg/kg	68.8
	Organic carbon	2.60%	0.20
	Organic matter	4.47%	0.37
	Exchangeable calcium	19.7cmol/kg	0.27
	Exchangeable magnesium	8.4cmol/kg	1.33
	Exchangeable potassium	0.68cmol/kg	9.21
	Exchangeable sodium	5.00cmol/kg	0.69
	Total exchangeable bases	33.84cmol/kg	11.3
	Exchangeable acidity	0.08cmol/kgcmol/kg	0.02
	ECEC	33.92cmol/kg	11.0
	Base saturation	9909%	6.42
	Microbial carbon	61.8 µ/g	0.86
	Microbial nitrogen	2.59330 µ/g	25.8
	Microbial phosphorus	22.5 µ/g	4.52

Green-gro + polyfeed	pH	6.97(1:1H_2O)	0.22
	Total nitrogen	0.24%	0.03
	Available phosphorus	41.4mg/kg	48.1
	Available potassium	261.1mg/kg	128
	Organic carbon	2.83%	0.38
	Organic matter	4.87%	0.67
	Exchangeable calcium	18.9cmol/kg	0.33
	Exchangeable magnesium	8.27cmol/kg	0.84
	Exchangeable potassium	83.7cmol/kg	7.66
	Exchangeable sodium	5.33cmol/kg	0.78
	Total exchangeable bases	27.26cmol/Kg	8.92
	Exchangeable acidity	0.12cmol/kg	0.02
	ECEC	27.38cmol/kg	8.92
	Base saturation	99.9%	0.02
	Microbial carbon	63.7 µ/g	6.48
	Microbial nitrogen	3.44 µ/g	0.84
	Microbial phosphorus	213 µ/g	10.8
Green-gro + polyfeed + Mg	pH	7.10(1:1 H_2O)	0.10
	Total nitrogen	0.29%	0.03
	Available phosphorus	30.5mg/kg	39.5
	Available potassium	228.2mg/kg	176
	Organic carbon	3.27%	0.32
	Organic matter	5.63%	0.54
	Exchangeable calcium	19.3cmol/kg	1.55
	Exchangeable magnesium	10.6cmol/kg	0.50
	Exchangeable potassium	0.67cmol/kg	104
	Exchangeable sodium	6.20cmol/kg	0.91
	Total exchangeable bases	36.8cmol/kg	12.9
	Exchangeable acidity	0.09cmol/kg	0.01
	ECEC	36.89cmol/kg	12.9
	Base saturation	99.9%	0.01
	Microbial carbon	63.4 µ/g	5.97
	Microbial nitrogen	3.17 µ/g	0.69
	Microbial phosphorus	413 µ/g	41.6
Topsoil only	pH	6.93(1:1H_2O)	0.20
	Total nitrogen	0.17%	0.01
	Available phosphorus	1.0mg/kg	1.53
	Available potassium	47.6mg/kg	45.0
	Organic carbon	2.20%	0.06
	Organic matter	3.67%	0.15
	Exchangeable calcium	9.83cmol/kg	0.89
	Exchangeable magnesium	4.40cmol/kg	0.21
	Exchangeable potassium	0.12cmol/kg	5.28
	Exchangeable sodium	2.20cmol/kg	0.11
	Total exchangeable bases	16.55cmol/kg	6.24
	Exchangeable acidity	0.09cmol/kg	0.01
	ECEC	16.64cmol/kg	6.24
	Base saturation	99.7%	0.07
	Microbial carbon	37.9 µ/g	4.66
	Microbial nitrogen	7.4 µ/g	6.02
	Microbial phosphorus	109 µ/g	63.9
Green-gro only	pH	7.43(1:1H_2O)	0.03
	Total nitrogen	0.30%	0.02
	Available phosphorus	30.0mg/kg	26.0
	Available potassium	198.0mg/kg	53.4
	Organic carbon	3.36%	0.20
	Organic matter	5.87%	0.29
	Exchangeable calcium	16.5cmol/kg	1.65
	Exchangeable magnesium	9.73cmol/kg	0.75
	Exchangeable potassium	0.51cmol/kg	10.8
	Exchangeable sodium	7.97cmol/kg	1.80
	Total exchangeable bases	34.74cmol/kg	13.8
	Exchangeable acidity	0.06cmol/kg	0.01
	ECEC	34.80cmol/kg	13.8
	Base saturation	99.9%	0.01
	Microbial carbon	62.2 µ/g	1.71
	Microbial nitrogen	2.85 µ/g	1.60
	Microbial phosphorus	379 µ/g	445.0

Appendix 10. Means and standard reeors for soil analysis after the experiment

Teatment	Variable	Mean[	Standard error
Topsoil + NPKMg	pH	5.46(1:1H_2O)	0.09
	Total nitrogen	0.29%	0.01
	Available phosphorus	31.9mg/kg	14.0
	Available potassium	135.4mg/kg	9.77
	Organic carbon	1.93%	0.25
	Organic matter	3.21%	0.51
	Exchangeable calcium	6.23cmol/kg	0.61
	Exchangeable magnesium	5.57cmol/kg	0.53
	Exchangeable potassium	0.64cmol/kg	0.88
	Exchangeable sodium	2.16cmol/kg	1.95
	Total exchangeable bases	14.60cmol/kg	0.95
	Exchangeable acidity	1.11cmpl/kg	0.06
	ECEC	15.72cmol/kg	0.90
	Base saturation	98.7%	0.07
	Microbial carbon	40.0 μ/g	3.89
	Microbial nitrogen	18.1 μ/	6.56
	Microbial phosphorus	219 μ/g	34.6
Topsoil + polyfeed	pH	6.13(1:1H_2O)	0.73
	Total nitrogen	0.30%	0.02
	Available phosphorus	60.2mg/kg	23.2
	Available potassium	137.1mg/kg	18.0
	Organic carbon	1.84%	0.05
	Organic matter	3.17%	0.08
	Exchangeable calcium	4.17cmol/kg	0.47
	Exchangeable magnesium	1.67cmol/kg	0.63
	Exchangeable potassium	0.63cmol/kg	4.06
	Exchangeable sodium	9.030.78cmol/kg	5.43
	Total exchangeable bases	7.25cmol/kg	9.66
	Exchangeable acidity	1.30cmol/kg	000
	ECEC	8.55cmol/kg	9.66
	Base saturation	98.4%	0.17
	Microbial carbon	44.1 μ/g	7.75
	Microbial nitrogen	19.4 μ/g	2.66
	Microbial phosphorus	274 μ/g	115
Topsoil + polyfeed +Mg	pH	5.93(1:1H_2O)	0.68
	Total nitrogen	0.25%	0.06
	Available phosphorus	53.9mg/kg	7.69
	Available potassium	133.7mg/kg	52.3
	Organic carbon	1.93%	0.15
	Organic matter	3.33%	0.26
	Exchangeable calcium	0.25cmol/kg	0.31
	Exchangeable magnesium	3.00cmol/kg	1.57
	Exchangeable potassium	0.60cmol/kg	5.51
	Exchangeable sodium	0.96cmol/kg	2.03
	Total exchangeable bases	7.67cmol/kg	8.56
	Exchangeable acidity	1.13cmol/kg	0.29
	ECEC	14.06cmol/kg	8.64
	Base saturation	98.6%	0.33
	Microbial carbon	36. μ/g	1.34
	Microbial nitrogen	22.9 μ/g	6.10
	Microbial phosphorus	295 μ/g	20.1
Green-gro + NPKMg	pH	7.13(1:1H_2O)	0.24
	Total nitrogen	0.41%	0.04
	Available phosphorus	89.6mg/kg	76.0
	Available potassium	154.7mg/kg	9.52
	Organic carbon	2.31%	0.40
	Organic matter	4.55%	0.48
	Exchangeable calcium	0.41cmol/kg	0.04
	Exchangeable magnesium	22.0cmol/kg	2.98
	Exchangeable potassium	0.89cmol/kg	0.64
	Exchangeable sodium	2.12cmol/kg	4.73
	Total exchangeable bases	36.98cmol/kg	0.20
	Exchangeable acidity	0.63cmol/kg	5.99
	ECEC	38.61cmol/kg	0.17
	Base saturation	99.5%	6.15
	Microbial carbon	44.1 μ/g	0.10
	Microbial nitrogen	6.50 μ/g	3.64
	Microbial phosphorus	605 μ/g	0.74
			37.69

Green-gro + polyfeed	pH	6.77(1:1H$_2$O)	0.42
	Total nitrogen	0.39%	0.01
	Available phosphorus	108.3mg/kg	76.7
	Available potassium	172.2mg/kg	80.9
	Organic carbon	2.81%	0.13
	Organic matter	4.85%	0.23
	Exchangeable calcium	22.2cmol/kg	2.75
	Exchangeable magnesium	8.93cmol/kg	3.09
	Exchangeable potassium	0.97cmol/kg	12.1
	Exchangeable sodium	1.58cmol/kg	1.21
	Total exchangeable bases	33.65mol/kg	15.8
	Exchangeable acidity	1.00cmol/kg	0.46
	ECEC	34.65cmol/kg	15.5
	Base saturation	99.2%	0.42
	Microbial carbon	60.4 µ/g	4.86
	Microbial nitrogen	6.77 µ/g	0.73
	Microbial phosphorus	937 µ/g	39.7
Green-gro + polyfeed + Mg	pH	6.70(1:1H$_2$O)	0.05
	Total nitrogen	0.42%	0.05
	Available phosphorus	9721mg/kg	101
	Available potassium	150.9mg/kg	27.9
	Organic carbon	2.81%	0.24
	Organic matter	4.84%	0.41
	Exchangeable calcium	16.8cmol/kg	5.06
	Exchangeable magnesium	18.9cmol/kg	1.50
	Exchangeable potassium	0.92cmol/kg	3.33
	Exchangeable sodium	2.16cmol/kg	0.35
	Total exchangeable bases	38.84cmol/kg	5.21
	Exchangeable acidity	0.92cmol/kg	0.17
	ECEC	39.76cmol/kg	5.05
	Base saturation	99.3%	0.14
	Microbial carbon	49.6 µ/g	1.60
	Microbial nitrogen	7.17 µ/g	0.84
	Microbial phosphorus	687 µ/g	57.5
Topsoil only	pH	6.00(1:1H$_2$O)	0.25
	Total nitrogen	0.20%	0.06
	Available phosphorus	7.6mg/kg	60.0
	Available potassium	32.8mg/kg	29.3
	Organic carbon	1.91%	0.01
	Organic matter	3.30%	0.02
	Exchangeable calcium	8.77cmol/kg	0.94
	Exchangeable magnesium	3.03cmol/kg	0.89
	Exchangeable potassium	0.21cmol/kg	2.33
	Exchangeable sodium	1.48cmol/kg	1.25
	Total exchangeable bases	13.49cmol/kg	3.96
	Exchangeable acidity	0.41cmol/kg	0.20
	ECEC	13.91cmol/kg	3.28
	Base saturation	99.9%	1.67
	Microbial carbon	28.9 µ/g	2.94
	Microbial nitrogen	8.13 µ/g	1.37
	Microbial phosphorus	11 µ/g	3.38
Green-gro only	pH	6.57(1:1H$_2$O)	0.62
	Total nitrogen	0.37%	0.05
	Available phosphorus	50.6mg/kg	58.4
	Available potassium	92.7mg/kg	57.3
	Organic carbon	2.43%	0.36
	Organic matter	4.19%	0.62
	Exchangeable calcium	23.8cmol/kg	1.98
	Exchangeable magnesium	10.3cmol/kg	1.61
	Exchangeable potassium	0.62cmol/kg	8.82
	Exchangeable sodium	1058cmol/kg	0.97
	Total exchangeable bases	36.33cmol/kg	13.7
	Exchangeable acidity	0.25cmol/kg	0.03
	ECEC	36.35cmol/kg	15.2
	Base saturation	99.9%	2.03
	Microbial carbon	32.2 µ/g	3.89
	Microbial nitrogen	8.80 µ/g	0.90
	Microbial phosphorus	503 µ/g	106

Appendix 11. Means and standard errors for seedlings leaf analysis 1

Treatment	Variable	Means (%)	Standard error
Topsoil + NPKMg	Total N	1.84	0.05
	Total P	0.16	0.01
	Total K	0.81	0.11
	Total Ca	0.22	0.02
	Total Mg	0.62	0.01
Topsoil + polyfeed	Total N	1.75	0.04
	Total P	0.16	0.00
	Total K	0.76	0.06
	Total Ca	0.20	0.01
	Total Mg	0.58	0.07
Topsoil + polyfeed +Mg	Total N	1.81	0.12
	Total P	0.15	0.02
	Total K	0.80	0.03
	Total Ca	0.24	0.02
	Total Mg	0.59	0.03
Green-gro + NPKMg	Total N	1.70	0.15
	Total P	0.16	0.01
	Total K	0.78	0.06
	Total Ca	0.25	0.01
	Total Mg	0.62	0.02
Green-gro + polyfeed	Total N	1.62	0.17
	Total P	0.16	0.01
	Total K	0.87	0.09
	Total Ca	0.31	0.02
	Total Mg	0.56	0.06
Green-gro + polyfeed + Mg	Total N	1.70	0.10
	Total P	0.16	0.01
	Total K	0.86	0.06
	Total Ca	0.20	0.03
	Total Mg	0.59	0.03
Topsoil only	Total N	1.32	0.29
	Total P	0.16	0.01
	Total K	0.85	0.01
	Total Ca	0.22	0.02
	Total Mg	0.62	0.02
Green-gro only	Total N	1.47	0.07
	Total P	0.16	0.01
	Total K	0.87	0.05
	Total Ca	0.25	1.01
	Total Mg	0.52	10.1

Appendix 12. Mean and standard errors for seedlings leaf analysis 2

Treatment	Variable	Means (%)	Standard error
Topsoil + NPKMg	Total N	4.00	0.28
	Total P	0.25	0.01
	Total K	0.72	0.05
	Total Ca	0.17	0.01
	Total Mg	0.76	0.07
Topsoil + polyfeed	Total N	3.53	0.06
	Total P	0.27	0.01
	Total K	0.62	0.07
	Total Ca	0.19	0.01
	Total Mg	0.83	0.09
Topsoil + polyfeed +Mg	Total N	3.53	0.23
	Total P	0.28	0.04
	Total K	0.62	0.06
	Total Ca	0.19	0.00
	Total Mg	0.74	0.07
Green-gro + NPKMg	Total N	3.53	0.20
	Total P	0.24	0.01
	Total K	0.71	0.10
	Total Ca	0.19	0.02
	Total Mg	0.74	0.07
Green-gro + polyfeed	Total N	3.27	0.32
	Total P	0.24	0.01
	Total K	0.80	0.05
	Total Ca	0.18	0.02
	Total Mg	0.70	0.02
Green-gro + polyfeed + Mg	Total N	3.31	0.20
	Total P	0.24	0.01
	Total K	0.77	0.05
	Total Ca	0.16	0.01
	Total Mg	0.62	0.05
Topsoil only	Total N	3.18	0.30
	Total P	0.23	0.01
	Total K	0.69	0.06
	Total Ca	0.27	0.06
	Total Mg	0.69	0.03
Green-gro only	Total N	2.35	0.09
	Total P	0.30	0.05
	Total K	0.78	0.09
	Total Ca	0.25	0.04
	Total Mg	0.68	0.02

Appendix 13. Mean and standard errors for seedlings leaf analysis 3

Treatment	Variable	Means (%)	Standard error
Topsoil + NPKMg	Total N	4.22	0.31
	Total P	0.23	0.01
	Total K	0.67	0.10
	Total Ca	0.15	0.02
	Total Mg	0.55	0.06
Topsoil + polyfeed	Total N	4.45	0.43
	Total P	0.30	0.02
	Total K	0.69	0.06
	Total Ca	0.17	0.03
	Total Mg	0.60	0.03
Topsoil + polyfeed +Mg	Total N	4.33	0.45
	Total P	0.24	0.01
	Total K	0.66	0.05
	Total Ca	0.16	0.01
	Total Mg	0.75	0.01
Green-gro + NPKMg	Total N	3.89	0.43
	Total P	0.24	0.01
	Total K	0.73	0.01
	Total Ca	0.19	0.06
	Total Mg	0.67	0.09
Green-gro + polyfeed	Total N	3.34	.043
	Total P	0.24	0.01
	Total K	0.77	0.08
	Total Ca	0.20	0.04
	Total Mg	0.53	0.01
Green-gro + polyfeed + Mg	Total N	3.57	0.31
	Total P	0.23	0.01
	Total K	0.71	0.01
	Total Ca	0.19	0.03
	Total Mg	0.68	0.05
Topsoil only	Total N	2.29	0.43
	Total P	0.27	0.03
	Total K	0.72	0.04
	Total Ca	0.17	0.01
	Total Mg	0.67	0.02
Green-gro only	Total N	2.82	0.36
	Total P	0.27	0.03
	Total K	0.73	0.03
	Total Ca	0.19	0.03
	Total Mg	0.61	0.02

Appendix 14. Mean and standard errors for seedling leaf analysis 4

Treatment	Variable	Means (%)	Standard error
Topsoil + NPKMg	Total N	4.56	0.31
	Total P	0.20	0.01
	Total K	0.73	0.10
	Total Ca	0.15	0.01
	Total Mg	0.54	0.07
Topsoil + polyfeed	Total N	4.22	0.16
	Total P	0.23	0.03
	Total K	0.88	0.08
	Total Ca	0.14	0.01
	Total Mg	0.44	0.04
Top soil + polyfeed +Mg	Total N	4.52	0.19
	Total P	0.22	0.02
	Total K	0.81	0.07
	Total Ca	0.15	0.03
	Total Mg	0.53	0.03
Green-gro + NPKMg	Total N	4.15	0.09
	Total P	0.22	0.03
	Total K	0.91	0.04
	Total Ca	0.14	0.01
	Total Mg	0.58	0.01
Green-gro + polyfeed	Total N	4.11	0.07
	Total P	0.19	0.01
	Total K	0.89	0.07
	Total Ca	0.12	0.03
	Total Mg	0.52	0.02
Green-gro + polyfeed + Mg	Total N	3.92	0.31
	Total P	0.19	0.01
	Total K	0.85	0.06
	Total Ca	0.12	0.04
	Total Mg	0.59	0.04
Topsoil only	Total N	3.15	0.04
	Total P	0.18	0.01
	Total K	0.86	0.04
	Total Ca	0.13	0.01
	Total Mg	0.54	0.03
Green-gro only	Total N	3.49	0.26
	Total P	0.22	0.02
	Total K	0.92	0.03
	Total Ca	0.15	0.03
	Total Mg	0.48	0.02

Appendix 15. Mean and standard errors for seedling leaf analysis 5

Treatment	Variable	Means (%)	Standard error
Topsoil + NPKMg	Total N	3.79	0.05
	Total P	0.20	0.01
	Total K	0.96	0.07
	Total Ca	0.21	0.03
	Total Mg	0.65	0.05
Topsoil + polyfeed	Total N	4.01	0.18
	Total P	0.29	0.04
	Total K	1.06	0.08
	Total Ca	0.22	0.05
	Total Mg	0.50	0.05
Topsoil + polyfeed +Mg	Total N	4.37	0.31
	Total P	0.20	.0.1
	Total K	0.93	0.03
	Total Ca	0.16	0.02
	Total Mg	0.50	0.14
Green-gro + NPKMg	Total N	3.66	0.05
	Total P	0.21	0.03
	Total K	0.89	0.06
	Total Ca	0.19	0.02
	Total Mg	0.71	0.04
Green-gro + polyfeed	Total N	4.22	0.05
	Total P	0.21	0.03
	Total K	1.07	0.09
	Total Ca	0.22	0.00
	Total Mg	0.58	0.03
Green-gro + polyfeed + Mg	Total N	4.06	0.19
	Total P	0.20	0.02
	Total K	1.02	0.03
	Total Ca	0.18	0.02
	Total Mg	0.78	0.03
Topsoil only	Total N	3.49	0.04
	Total P	0.18	0.02
	Total K	0.87	0.07
	Total Ca	0.20	0.03
	Total Mg	0.57	0.06
Green-gro only	Total N	3.61	0.14
	Total P	0.18	0.03
	Total K	0.19	0.05
	Total Ca	0.20	0.03
	Total Mg	0.62	0.01

Appendix 16. Mean and standard errors for dry matter and percentage mortality

Treatment	Variable	Means (g)	Standard error
Topsoil + NPKMg	Dry butt	41.0	7.78
	Dry leaf	92.8	24.9
	Dry root	27.6	4.78
	Total dry matter	161	35.9
	Percentage mortality	13.3	0.08
Topsoil + polyfeed	Dry butt	31.2	2.42
	Dry leaf	81.8	21.0
	Dry root	24.2	2.24
	Total dry matter	137	25.5
	Percentage mortality	20.0	0.00
Topsoil + polyfeed +Mg	Dry butt	45.7	7.97
	Dry leaf	124	37.7
	Dry root	34.3	5.99
	Total dry matter	204	47.1
	Percentage mortality	6.67	0.01
Green-gro + NPKMg	Dry butt	32.7	3.90
	Dry leaf	86.5	19.0
	Dry root	29.7	3.63
	Total dry matter	149	25.7
	Percentage mortality	3.33	0.02
Green-gro + polyfeed	Dry butt	24.8	1.30
	Dry leaf	73.3	9.54
	Dry root	32.5	1.00
	Total dry matter	132	10.4
	Percentage mortality	10.0	0.02
Green-gro + polyfeed + Mg	Dry butt	25.3	1.69
	Dry leaf	75.8	4.95
	Dry root	31.0	10.8
	Total dry matter	132	11.4
	Percentage mortality	1.00	0.00
Topsoil only	Dry butt	32.3	3.22
	Dry leaf	83.5	1.76
	Dry root	24.0	2.02
	Total dry matter	140	3.11
	Percentage mortality	1.00	0.00
Green-gro only	Dry butt	31.7	4.19
	Dry leaf	91.8	2.68
	Dry root	25.5	4.51
	Total dry matter	149	3.5
	Percentage mortality	10.0	0.00

Appendix 17. Cost components for agro economic analysis

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month (GH¢)
Soil	2 trucks	50	100	0.10
Green-gro	2 trucks	240	480	0.48
Polybag	1000	0.05	50	0.05
Germinated seednut	1000	0.22	220	0.22
Sulphate of ammonia	50 kg	20		
Triple super phosphate	50 kg	25		
Murate of potash	50 kg	18		
Kieserite	50 kg	15		
Polyfeed	50 kg	46		
Watering (80 times)	5 man days	3	200	0.20
Fertilization (6 times)	2 man days	3	36	0.036
Mulching (1 time)	2 man days	3	6	0.006
Mulching material	1 truck	50	50	0.05
Roundup (4 times)	1 liter	60	24	0.024
Spraying (4 times)	2 man days	5	20	0.020
Insecticide (2 times)	0.5 liter (karate)	7.5	15	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5	10	0.01
Spraying (2 times)	2 man days	5	10	0.01
Hand picking (4times)	2 man days	3	6	0.006

Appendix 18. Cost components for Top soil + N P K Mg

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling /8month/(GH¢)
Top Soil	2 trucks	50.00	100.00	0.10
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Sulphate of ammonia (6 times)	6 kg	4.00	14.40	0.014
Triple super phosphate (6 times)	6 kg	5.00	18.00	0.018
Murate of potash (6 times)	6 kg	3.60	13.00	0.013
Kieserite (6 times)	12 kg	3.00	21.60	0.022
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.50	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.010
Spraying (2 times)	2 man days	5.00	10.00	0.010
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			580.42	0.58

Appendix 19. Cost components for Top soil + polyfeed

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month/(GH¢)
Top Soil	2 trucks	50.00	100.00	0.10
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Polyfeed (6 times)	30 kg	0.92	165.60	0.092
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.5.0	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.01
Spraying (2 times)	2 man days	5.00	10.00	0.01
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			649.02	0.65

Appendix 20. Cost components for Top soil + polyfeed + Mg

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month/(GH¢)
Top Soil	2 trucks	50.00	100.00	0.10
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Kieserite	15kg	0.30	27.00	0.027
Polyfeed (6 times)	15 kg	0.92	165.60	0.092
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.5.0	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.01
Spraying (2 times)	2 man days	5.00	10.00	0.01
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			593.22	0.59

Appendix 21.Cost components for Green-gro +N P K Mg

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month/(GH¢)
Green-gro	2 trucks	240.00	480.00	0.48
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Sulphate of ammonia (6 times)	6 kg	4.00	14.40	0.014
Triple super phosphate (6 times)	6 kg	5.00	18.00	0.018
Murate of potash (6 times)	6 kg	3.60	13.00	0.013
Kieserite (6 times)	12 kg	3.00	21.60	0.022
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.50	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.010
Spraying (2 times)	2 man days	5.00	10.00	0.010
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			940.42	0.94

Appendix 22. Cost components for Green-gro + polyfeed

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month (GH¢)
Green-gro	2 trucks	240.00	480.00	0.48
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Polyfeed (6 times)	30 kg	0.92	165.60	0.092
watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.5.0	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.01
Spraying (2 times)	2 man days	5.00	10.00	0.01
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			100.90	1.01

Appendix 23. Cost components for Green-gro + polyfeed + kieserite

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month/(GH¢)
Green-gro	2 trucks	240.00	480.00	0.48
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Kieserite (6 times)	15 kg	0.30	82.80	0.083
Polyfeed (6 times)	15kg	0.92	27.00	0.027
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.50	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.01
Spraying (2 times)	2 man days	5.00	10.00	0.01
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			953.22	0.95

Appendix 24. Cost components for Top soil only

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month (GH¢)
Top Soil	2 trucks	50.00	100.00	0.10
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.50	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.010
Spraying (2 times)	2 man days	5.00	10.00	0.010
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			483.42	0.48

Appendix 25. Cost components for Green-gro only

Activity/input	Qty/1000 seedlings	Unit cost (GH¢)	Cost/1000/ 8mths (GH¢)	Cost/seedling/ 8month/(GH¢)
Green-grop	2 trucks	240.00	480.00	0.48
Polybag	1000	0.05	50.00	0.05
Germinated seednut	1000	0.22	220.00	0.22
Watering (80 times)	5 man days	3.00	200.00	0.20
Fertilization (6 times)	2 man days	3.00	36.00	0.036
Mulching (1 time)	2 man days	3.00	6.00	0.006
Mulching material	1 truck	50.00	50.00	0.05
Roundup (4 times)	1 liter	6.00	24.00	0.024
Spraying (4 times)	2 man days	5.00	20.00	0.020
Insecticide (2 times)	0.5 liter (karate)	7.50	15.00	0.015
Fungicide (2 times)	0.5 Kg (dithane)	5.00	10.00	0.010
Spraying (2 times)	2 man days	5.00	10.00	0.010
Hand picking (4times)	2 man days	3.00	6.00	0.006
Total			843.42	0.84