SESAME (*Sesamum indicum* L.) RESPONSE TO NITROGEN AND PHOSPHORUS FERTILIZERS AS INFLUENCED BY MYCORRHIZAL INFECTION

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DECLARATION

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

Signed---------- Date----------

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This thesis has been submitted for examination with our approval as the University supervisors.

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DEDICATION

To my mother, for her patience and understanding.

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Abstract

Response of sesame to varying rates of nitrogen (0, 100, 200 and 300 kg ha^{-1}), phosphorous (0, 50, 100 and 200 kg ha^{-1}) and farmyard manure (0, 3, 6 and 9 Tonnes ha^{-1}) was studied in a series of experiments conducted at University of Nairobi's Kibwezi dryland field station and at Siaya Farmers Training Centre (F. T. C.) during the short rains of November 1993 to February 1994 and the long rains of April 1994 to July 1994.

In a glasshouse at University of Nairobi's Kabete field station, the influence of soil-borne mycorrhizal infection on sesame response to N and P was examined in pot experiments. Varying levels of N (0, 0.02, 0.04, 0.07 and 0.14 g/l) and P (0, 0.13, 0.25, 0.51 and 1.01 g/l) in Hoagland solution were applied to sesame plants grown in different media namely unsterilised field soil, acid washed sand and steam sterilised field soil. The field soils were obtained from plough layer at Siaya F.T.C.

The white seeded unimproved sesame landrace cultivated in Western Kenya was used in all experiments.

The results showed that N and P fertilizers and similarly farmyard manure applied in the field, did not significantly affect the yield of sesame. Nitrogen and phosphorous application to the potted plants did not significantly affect growth and biomass in the unsterilised field soil but did significantly enhance growth in the sterilised field soil and acid washed sand. Roots of plants grown in the unsterilised field soil were highly infected with mycorrhizal fungi but roots from the sterilised field soil and acid washed sand were barely infected by mycorrhizal fungi, when assessed at eight weeks after emergence.

It was concluded that the local white seeded landrace was not responsive to nitrogen and phosphorous application nor to farmyard manure under field conditions due to mycorrhizal infection.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Sesame botany

Sesame (*Sesamum indicum* L.) belongs to the order Tubiflorae and family Pedaliaceae.

Sesame is an erect branched annual, 0.2 to 3m tall. It has a strong tap root and a dense much branched lateral root system which spreads in the surface soil (Weiss, 1983).

The stem is erect, normally square in section with definite longitudinal furrows. It may be smooth or hairy and the colour ranges from light green to purple though mostly dark green. The type and extent of branching is a varietal characteristic and so is the height at which the first branch occurs (Wiess, 1983).

Leaves vary in shape and size on the same plant and between varieties. Generally the lower leaves are broad and palmate while upper leaves are narrow and lanceolate. Arrangement may be alternate or opposite and may even be mixed on the same plant. Leaves are commonly dark green but can be lighter with an occasional yellowish tint. They grow on petioles of up to 5cm without stipules.

Flowers arise in the leaf axils on the upper parts of the stems or branches with the number per axil varying between one and three (and occasionally up to six). They may vary in colour from white to purple with red or purplish spots on the inner surface. The flowers are self pollinated although outcrossing of up to 5% may occur (Pustovoit, 1973).

The fruit is an erect capsule with a short angular beak. The shape which varies from narrow to broad and from oblong to square and its length is a varietal characteristic as is the above ground height of the first capsule.

Young capsules are green to purplish in colour with mature capsules being straw, brown or purple depending on the variety. Capsules are dehiscent at maturity. Their number per plant varies according to variety and environment. Ripening is from the stem base upwards with the topmost capsules ripening last (Weiss, 1983).

Sesame seeds are small, ovate and slightly flattened. They are pointed at one end and the testa may be smooth or ribbed. The colour may vary between black, brown, grey, straw or white. They have an average weight of 2 to 4g per thousand seeds (Weiss, 1983).

1.2 Economic importance

Sesame has a production advantage over other oilcrops grown in Kenya in that it can successfully yield under low purchased input use and low management farming systems. It would thus lend itself easily to small scale farmers with limited liquidity. Sesame can produce modest yields under drought stressed conditions typical of the semi-arid marginal areas e.g. it can be grown with as little 300 mm of rainfall and still produce high quality yields (Weiss, 1983). Sesame can also set seed and yield under fairly high temperatures and is a good crop in rotation or grown as a companion crop under low inputs (Weiss, 1971).

The sesame grown in Kenya is used for domestic consumption or sold. Farmers and their households usually consume most of what is produced as roasted seed or the seed may be roasted and pounded into a paste then used to garnish cakes and bread or simply mixed with vegetable to make a stew. The seed may also be used to make confectionery which is then sold. Some of the seed find its way into undocumented export markets through unregistered middlemen while some end up in the domestic oil industry mainly through small crushing /extraction mills (W'Opindi, 1981).

Bulk storage of sesame is more economical than other bulky oil seeds since the seed is small and relatively heavy (as long as it is dry and clean)(Weiss, 1983). The seed has high oil and protein content which can be put to various uses. Oil content varies between 47% and 55% depending on environment and variety, while protein content lies between 17% to 25% of dry weight (Ashri, 1989; Cobley 1976) The oil is of high quality, stable and has a long shelf life owing to it's content of an antioxidant sesamol which is derived from sesamolin. This prevents rancidity and foods fried is sesame oil keeps longer than if fried in other oils(Ashri, 1989). The major fatty acids of sesame oil are oleic, linoleic, palmitic and stearic acids which gives the oil it's desirable semi drying qualities. (Weiss, 1983; Smith *et al.*, 1981). The seed's lower fibre content makes it easy to extract it's oil as it needs no decortication. Commercial extraction varies between 30% -50% depending on the method used (Ashri, 1989; Godin and Spensely, 1971). The high grade oil can be used for the manufacture of compound cooking fats, margarines and salad oils. While the low grade oil is used in industry e.g. soap making, as a fixture cosmetics and medicines e.g. penicillin (Ashri 1989; Godin and Spensely 1971). The sesamin and sesamolin in the oil can act as a synergist with pyrethrin to effectively control insects. The cake or meat contains 34-50% protein and can be used to incorporate into animal feeds or mixed with other ingredients (e.g. sorghum flour , maize flour or even chickpeas) to produce very nutritious human foods(Ashri 1989; Anon 1972). The leaves may also be used as a vegetable. Sesame is, therefore, a raw material source for use in various industries.

1.3 Ecology

Sesame (*Sesamum indicum*) most probably originated in Africa since, not only does greatest diversity of the genus *sesamum* and its family *Pedaliaceae*

occur in Africa (Tribe, 1967; Greenway, 1945) but all the wild species, with the exception of *Sesamum prostratum* which is found in Eastern India, are found in Africa (Hill, 1977;Purseglove 1968; Greenway, 1945). It probably spread at a very early date to India where a second centre of diversity developed (Purseglove, 1968; Greenway, 1945) and where many cultivars presently exist.

Sesame is a crop of the tropics and warm temperate regions (Auckland, 1970). The diversity of local ecotypes well adapted to their particular locality is an indication of the plants' potential of extension into the much cooler regions of the more temperate zones (Weiss 1983). However, it is generally sensitive to low temperature which limit its altitudinal range in the tropics to areas below 1500 m above sea level (ASL) (Auckland 1970). It has been collected in Nepal up to 2000 m ASL and has been grown experimentally in Kenya up to 1800 m ASL (Weiss 1983). It's main distribution is between 25° S and 25°N but can be found growing up to 40°N in China, Russia and the U.S.A.; 30°S in Australia and 35°S in South America (Weiss 1983). A temperature of 25°C - 27°C has been found to encourage rapid germination, initial growth and flower initiation. Temperatures below 20°C for any length of time will delay germination and seedling growth (Weiss 1983). Below 10°C germination and growth is inhibited (Salehuzzaman and Pasha 1979). Temperature of less than 18°C after emergence will retard growth. Sesame is basically a short day plant but many varieties have become adapted to various photoperiods (Weiss 1983). Sesame grows well on a variety of soils, but thrives best on light well drained and moderately fertile soils (Langhan, 1985; Weiss, 1983). Neutral pH is preferred although it has been grown in soils with pH ranging between 4 and 9 (Beech, 1985). Sesame is extremely susceptible to salinity (Yousif *et al.*, 1972).

Sesame is extremely susceptible to flooding but is reported to be relatively tolerant to drought and heat, producing a crop even with little rainfall in the range of 300 - 750 mm (Auckland, 1971, Weiss 1983). This indicates that once established, sesame is capable of withstanding a higher degree of drought stress than many other cultivated plants. The seedling stage however is extremely susceptible to moisture deficit and good moisture supply is necessary for higher yields (Weiss 1983).

1.4 Production

Sesame is said to have been first produced in Kenya in the 1800's (Kingi unpublished, 1987) although it may have been first introduced to farmers as late as 1903 to 1913 (W'Opindi 1980). However it's production has dwindled over the years and only in recent years has there been renewed interest in the crop. This has been largely due to interest shown by local entrepreneurs e.g. the small oil extracting mills existing mainly in the coast province who buy the harvested seed and the middlemen who buy the seed for export.

Currently most of the sesame cultivated in Kenya is mainly by small scale farmers in the Coast, and Western province. Production as at 1991 stood at 3200 metric tons planted on 8000 ha with an average yield of 0.2 mt ha^{-1} yr^{-1} (Ayiecho and Nyabundi, 1995). This is distributed as shown in table 1. These figures contrast sharply with FAO figures (FAO, 1993) which estimates production at 8000 metrics tons planted on 21000 ha with an average of 0.4 mt ha^{-1} yr^{-1}.

Table 1: The distribution of sesame production in Kenya.

District/Province	Area (ha)
Lamu	2000
Kilifi	3000
Kwale	2000
Western	1000
Total	8000

(Source: Ayiecho and Nyabundi, 1995.)

This contrast indicates the paucity of information regarding sesame and the Kenyan oilcrops industry as a whole.

Sesame in Kenya has been reported to yield an average of between 220 - 230 kg ha^{-1} (W'Opindi 1981). However other reports indicate that intercropped sesame can yield up to 500 kg ha^{-1} while a pure stand crop can realise 1000 kg ha^{-1}. (Anon, 1987) with experimental plots giving up to 2230 kg ha^{-1} (W'Opindi 1980). Little research has been done to establish the appropriate agronomic package for sesame production. On commercial scale, cultivation required for wheat or similar small grains are also suitable for sesame (Weiss, 1971). Lee (1985) reported that under Korean conditions a number of ploughings followed by harrowing are necessary in preparing a seedbed for sesame to ensure good germination. However, according to Ayiecho and Nyabundi (1995) a rough tilth is ideal for sesame under Kenyan conditions. In most African and Asian countries however, sesame is grown as an intercrop with other crops and the seedbed preparation must also consider the associated crops. Moreover in most sesame growing countries sesame is considered a secondary crop and is only grown on land already prepared for the main crop (FAO, 1985, 1981).

There are no standardised methods of seeding sesame nor are the seed rates well established. Sesame can be drilled using mechanised planters but much of the world's sesame is manually planted by broadcasting or hill planting. Conventional seed rates may vary from region to region and planting density can be as low as 100,000 plants ha^{-1} and as high as 600,000 plants

ha^{-1}. The branching types can effectively compensate for the low plant populations (Khidir, 1981) through the development of more robust branches. For the coastal regions of Kenya W'Opindi (1981) recommended a spacing of 60 x 15 cm with 5 seeds per hill to be thinned to one plant per hill at 15 cm height.

Sesame seedlings grow slowly in initial stages making them poor competitors against the more vigorous weeds. Furthermore, cultivation among the young and delicate seedlings is difficult. It is, therefore, necessary to control weeds prior to sowing. Weiss, (1971) observed that inter-row cultivation can check plant growth by excising shallow roots. Pre-planting and pre-emergence herbicides have been used with some success (FAO, 1985; 1981) but the practicability of their use by Kenyan small scale farmers is questionable.

The wide range of soil types on which sesame can grow is due more to diversity of types well adapted to local conditions than to basic adaptability of any one variety. The crop is grown by small holders generally under low standards of husbandry and little or no fertilizer application and this has led to the general misconception that it is adapted to poor soils and responds poorly to fertilizer application. However, as Weiss (1971) pointed out, while landraces developed under low management low input conditions may not respond significantly to applied fertilizers, improved varieties capable of high yields will need additional plant nutrients to optimize returns. Sesame has, however, been noted to perform better in fertile than infertile soils (Weiss, 1983; Anon, 1972). For American conditions Langhan (1985) noted that sesame grows best on fertile soil, heavy applications of commercial fertilizers being required where soil fertility is not adequate. It should, however, be emphasised that fertilizer can only be given serious attention when crop response is economical and only for use by those farmers with high

management standards. Plant inoculation with *Azospirillum* has shown positive results. If the inoculum can be produced cheaply then inoculation can provide small scale farmers with a suitable first stage in improvement of sesame nutrition. *Azobacter* cultures have also shown positive results (Vadar *et al.*, 1982).

Capsule shattering is one of the biggest problems in sesame production. Capsules ripen irregularly from the base upwards and the topmost are often only half mature at harvest. The time for harvest is usually a compromise between good quality seed and maximum yield. It is usually recommended that sesame be harvested when the first capsules dehisce but most are still green. The crop then has to be stooked until all the capsules are dry before threshing (Weiss, 1983).

The biggest constraint to sesame production in Kenya is it's neglect by farmers who consider it a secondary crop and this results in poor yields. This has mainly been attributed to poor pricing and marketing infrastructure accompanied by poor extension services for the crop.

1.4 JUSTIFICATION

Yields of sesame are higher in other regions e.g. Central and Southern America and in United States of America than in Africa. This has been attributed more to the production practices for sesame in these areas than to any natural adaptation of the crop to their ecological condition. In the United States of America yields of up to 2000 kg ha^{-1} have been reported (Anon, 1972) while in Kenya an average yields lie between 220 and 230 kg ha^{-1} (Ayiecho and Nyabundi, 1995; W'Opindi, 1981).

Little research has been done on the agronomic requirements of sesame in Kenya. Few experiments have been reported and these have been concentrated in the coastal region. These experiments have produced

conflicting results and are at best inconclusive and as such cannot be used as a guideline for fertilizer application on the crop in Kenyan conditions. The variability in yields on farmers fields (10-1000 kg ha^{-1}) and experimental plots (770-2230 kg ha^{-1}) (M.O.A, 1976) suggest potential for improvement by developing appropriate production practices. Although preliminary experiments in fertiliser show poor responses, the exhaustive nature of the crop suggest that it might need additional nutrients, therefore more detailed work on it's nutritional requirements will be essential.

To date no known studies on rhizospheric microorganism associations with sesame roots have been carried out in Kenya. These could shed light on the varying results that have been obtained in the fertilizer trials already done in Kenya. Initial observations have shown that roots of sesame grown in Siaya are heavily colonized by mycorrhiza (Ayiecho and Nyabundi, 1995).

1.5 OBJECTIVES

(1) To determine the response of sesame yield to varying levels of nitrogen, phosphorous and organic manure.

(2) To determine whether mycorrhizal associations have any effect on sesame response to nitrogen and phosphorus fertilization.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Role of N and P in plants

Though beneficial effects of adding mineral elements (e.g. plant ash or lime) to soils to improve plant growth has been known in agriculture for more than 2000 years. It was mainly to the credit of Justus von Liebig (1803 - 1873) that scattered information concerning the importance of mineral elements for plant growth was compiled and summarised and that the mineral nutrition for plants was established as a scientific discipline. These achievements led to a rapid increase in the use of mineral fertilizers in agriculture and horticulture to improve growth.

2.1.1 Nitrogen

N is a constituent of amino acids, the subunits of proteins. All enzymes that have been isolated are protein in nature. Nitrogen is also a constituent of chlorophyll. As such it is involved in all processes associated with enzymatic reactions protoplasm and photosynthesis as first shown by Hewitt *et al.* (1950).

Adequate supply of nitrogen is associated with vigorous aerial vegetative growth and a dark green colour. Nitrogen is also essential for fruit and seed formation. Grain formation also depend on certain threshold levels of protein, hence grain formation has ben found to be significantly related to nitrogen supply especially in cereals (Tisdale *et al.*,1990; Boswell *et al.*, 1985). An imbalance of nitrogen or its excess in relation to other nutrients such as phosphorous, potassium and sulphur can prolong the growing period, delaying crop maturity (Boswell *et al.*, 1985; Black, 1968)

The supply of nitrogen is related to carbohydrate utilization. When nitrogen supply is insufficient, carbohydrates, will be deposited in vegetative cells causing them to thicken. When nitrogen supply is adequate, and conditions favour growth, proteins are formed from the manufactured carbohydrates thus less carbohydrate is deposited in the vegetative portion, more protoplasm (which is highly hydrated) is formed resulting in a more succulent plant (Tisdale and Nelson, 1966).

Excessive succulence resulting from excess nitrogen may cause a weakening of fibre in fibre crops ,lodging in grain crops and reduction of sugar content in sugar beets. This occurs especially when phosphorous supply is also inadequate or when varieties not adapted to high nitrogen fertilization are used. It can also make plants more susceptible to insect and disease attack (Tisdale and Nelson, 1966).

Nitrogen deficiency causes decrease in cell division, expansion and elongation, resulting in reduction of morphological parts of the plant (Bartholomew and Clark, 1966; Frank, 1965). Leaves turn pale yellow and small; stems are thin and upright; lateral shoots are few. The plant growth has a sparse appearance and is generally stunted (Tisdale *et al.*, 1990; Black, 1968).

Due to its central role in plant functions and its abundance in plant material, nitrogen is found to be the most common limiting factor in crop production (Boswell *et al.*,1985; Harre and White, 1985; Wrigley, 1982; Black, 1968)

2.1.2 Phosphorous

Together with nitrogen and potassium, phosphorous is classified as a major nutrient element though it is required in less quantities than either nitrogen or potassium (Tisdale *et al.*, 1990; Sauchelli, 1965). As a constituent of nucleoproteins, P is involved in the proportion of protoplasm concerned

with cell division and the transfer of hereditary characteristics by the chromosomes. It is also a constituent of nucleotide H^+ ion carriers e.g. nicotinamide adenine dinucleotide (NAD), nicotinamide adenine dinucleotide phosphate (NADPH), diphosphatepyrine (DPN), triphosphate pyridine (TPN) that occur as steps in the metabolic processes; Krebb's cycle, glycolysis and the pentose cycle. Phosphorous is also a constituent of the unique high energy compounds adenosine tri- and di- phosphates (ATP and ADP, respectively). A considerable amount of energy liberated by respiration is stored within cells as high-energy phosphate bonds (ADP and ATP) and as reduced co-enzymes NADP and NADPH. High energy bonds provide the energy for the synthesis of compounds such as starch and proteins on which plant growth and reproductive processes depend. Phosphorous is also involved in photosynthesis in the conversion of light to useful chemical energy NADPH and ATP. It participates more directly in the photochemical events of photosynthesis than does CO_2. Carbon dioxide assimilation is dependent on a preceding phosphate assimilation resulting in ATP formation at the expense of light energy (Arnon 1959). The single most important of the many essential functions of P in plant life is its role in energy storage and transfer. ATP is the energy source powering virtually every energy requiring biological process in plants. Phosphorylation is the transfer of energy-rich phosphate molecules (Pi) from ATP to energy requiring substances in the plant. It results in lowering of activation energy barriers and overcomes otherwise unfavourable thermodynamic conditions within the plants' system. This results in a greatly increased number of chemical reactions possible within the plants' system.

Phosphorous is also an important structural component of many biochemicals including nucleic acids, coenzymes, neucleotides, phosphoproteins, phospholipids, and sugar phosphates (Marshner, 1986).

An adequate supply of phosphorous early in the life of a plant is important in laying down the primordia for its reproductive parts. Phosphorous is considered essential for seed formation, root growth and early crop maturity (Tisdale and Nelson, 1966). Sufficient phosphorus supply has also been shown to increase resistance to disease, improve the quality of certain fruits, forages and vegetables and increase cereal straw strength (Young *et al.*, 1985).

Phosphorous deficiency leads to generalised growth retardation which leads to delayed maturity and reduction in yields (Tisdale *et al.*, 1990; Russel, 1973). However excess phosphate over and above the crop requirement may also depress yields especially in light soils in dry years. This has been attributed to hastening of the maturation process and consequent reduction of vegetative growth (Russel, 1973)

2.2 Nitrogen and Phosphorus availability, uptake and utilisation.

The most direct way to determine nutrient availability in soils is to measure the growth responses of plants by means of field plot fertilizer trials. This procedure however is time consuming and the results are not easily extrapolated from one location to another. Chemical soil analysis - soil testing is a comparatively rapid and inexpensive procedure. However it is not satisfactory for various reasons; it indicates only the potential capacity of the soil to supply nutrients to plants, it does not sufficiently characterise the mobility of nutrients in the soil; it does not supply information on the plant factors such as root growth and root induced changes in the rhizosphere that are of decisive importance for nutrient uptake under field conditions (Marschner 1986).

decomposing organic matter. Studies have shown that the dividing line between immobilisation and release of nitrogen is a C:N ratio of approximately 20:1 (Tisdale *et al.*, 1990; Lewis, 1986; Barber, 1984).

In well drained neutral to slightly acid soils the oxidation of NO_2^- to NO_3^- is higher than that of NH_4^+ to NO_2^-. The rate of NO_2^- formation is equal to or greater than the rate of NH_4^+ formation consequently NO_3^- is the form that tends to accumulate in soils. Factors influencing activities of nitrifying bacteria will affect the amount of nitrate produced. These factors include; soil aeration, soil temperature, soil moisture, soil pH, population of nitrifying organisms and supply of NH_4^+ ion (Tisdale *et al.*, 1990; Wild, 1988a; Barber, 1984).

Nitrogen is absorbed by plants mainly in the form of nitrate (NO_3^-) and ammonium (NH_4^+) ions and as urea (Tisdale *et al.*, 1990; Wild, 1988a; Barber, 1984). NO_3^- is the dominant source of nitrogen since it generally occurs in higher concentrations than NH_4^+ and is free to move to the roots by mass flow and diffusion. The amounts of these ions (NO_3^- and NH_4^+) in most soils at any one time is small compared to the ongoing requirements of the plant cover (Epstein 1972). Furthermore nitrate is readily leached beyond the reach of the roots by rain or irrigation water. Therefore soil nitrogen in a form available for plant absorption must be constantly replenished by nature (from atmospheric gaseous nitrogen), by man (in form of fertilizers or inoculations of roots by nitrogen fixing bacteria) or released from organically bound soil nitrogen through mineralisation of soil nitrogen by soil micro-organisms.

Since NO_3^- does not form precipitates with soil constituents there is great fluctuation in its concentration in the soil solution, the rate of nutrient replenishment and the anions of readily soluble nutrients in the soil profile within the root hair zone (Wild, 1988a; Barber, 1984). The rate of replenishment from the labile pool has to be extremely high for nitrate. The rate of

replenishment of NO_3^- is dependent on nitrification of NH_4^+ formerly adsorbed to the solid phase or supplied by mineralisation of organically bound nitrogen. As these rates are often very low, in order to meet the demand of fast growing plants the supply must be maintained either by exploration of the subsoil, by the roots or by split application of nitrogen fertilizer (Tisdale *et al.*, 1990; Wild, 1988a; Barber, 1984).

Nitrate and ammonium are the major sources of inorganic nitrogen taken up by roots of higher plants. Preference for either NO_3^- or NH_4^+ form is determined by age, type of plant and environment among other factors (Wild, 1988a; Barber,1984; Frank, 1965). Some plants (e.g. kale tomatoes and tobacco) grow best when provided with some NO_3^-. Others like blue berries and some rice cultivars cannot tolerate NO_3^- (Tisdale *et al.*, 1990). In general calcifuges (plants adapted to acid soils e.g. wetland rice) have a preference for NH_4^+ (Ismunadji and Dijkshoorn, 1971). In contrast calcicoles (plants with preference to calcarous, high pH soils) utilise NO_3^- preferentially (Kirkby, 1967). For any plant species uptake and utilization of NH_4^+ is greater than that of NO_3^- at low temperatures though at low temperatures uptake of both ions is low. Their uptake rises with increase in temperature until uptake of NO_3^- exceeds that of NH_4^+ at about 30°C (Wild, 1984; Clarkson and Warner, 1979; Lycklama,1963). In some cases highest growth rates are obtained with a combination of both NH_4^+ and NO_3^- (Gashaw and Mugwira, 1981; Cox and Reisenauer, 1973) or with NH_4^+ only (Sommer and Six, 1982). Uptake of NO_3^- is usually high and occurs by active absorption. It is favoured by low pH conditions and its absorption can be completely inhibited or depressed by NH_4^+ (Tisdale *et al.*, 1990; Jungk, 1970; Fried *et al.*, 1950; Van der Honert and Hooymans, 1955). Ideally NH_4^+ is the nitrogen source since energy is saved when it is used instead of NO_3^- for protein synthesis. NO_3^- must be reduced before it is incorporated into protein. The reduction is an energy requiring process (Tisdale *et al.*, 1990). NH_4^+

uptake proceeds best at neutral pH and is depressed by increasing acidity. Absorption of NH_4^+ reduces the concentration of inorganic cations such as Ca^{2+}, Mg^{2+} and K^+ in plant tissues while raising the levels of inorganic anions including phosphorus, sulphur and Cl^-. When plants are fed NH_4^+ a decline in rhizospheric pH occurs. This can have an effect on the availability of nutrients and other biological activity in the rhizosphere (Cox and Reisenauer, 1973). According to Reisenauer (1978) wheat seedlings were larger when both NH_4^+ and NO_3^- were present than when only NO_3^- was present. Presence of some NH_4^+ yielded larger corn plants than when only NO_3^- was present (Warncke and Barber 1973).

Most of the NH_4^+ has to be incorporated into organic compounds in the roots whereas NO_3^- is mobile in the xylem and can be stored in vacuoles of roots, shoots and storage organs. Ammonium and ammonia, however, are toxic at low levels and the formation of amino acids and amides and related compounds is the main pathway for detoxification of NH_4^+ taken up by roots or ammonia derived from NO_3^- reduction or nitrogen fixation . It appears that nearly all of the assimilated ammonia is translocated to the shoots as amino acids, amides and related compounds (Raven and Smith, 1976; Martin, 1970). Depending on plant species, developmental stage and age, the nitrogen content required for optimal growth varies between 2% and 5% of the plant dry weight (Marschner, 1986). When this supply is sub-optimal growth is retarded; nitrogen is mobilised in mature leaves and retranslocated to areas of new growth. An increased supply stimulates growth, delays senescence and changes plant morphology in a typical manner (Marschner, 1986) particularly if the nitrogen availability is high in the rooting medium during early growth.

2.2.2 Phosphorous

The phosphorous content of soils is relatively l ow with most soils containing between 0.02% and 0.10% total phosphorus. Total phosphorous concentration is usually highest in the surface soil and d ecreases with depth down the soil horizon (Barber, 1984; Tisdale and Nelson, 1966).

The reaction of phosphate with sesquoxides and oxihydrates of clay minerals lead to the formation of generally insoluble clay p hosphate complexes. This occurs under low soil pH conditions. In alkaline soil, phosphorous forms soluble phosphates and relatively insoluble calcium ph sphates. Maximum phosphorous availability occurs between pH 6 to pH 6.5. (Tisdale *et al.*, 1990; Young et al., 1985; Sauchelli, 1965). The inorganic phospho rus content of soils is frequently higher than that of organic phosphorous except where the phosphorous is contained in predominantly organic soils. Or ganic phosphorous content of mineral soil is higher in the surface horizon t han in the subsoil due to the accumulation of organic matter in the upper par t of the soil profile (Tisdale *et al.*, 1990; Wild, 1988b; Barber, 1984).

The concentration of the orthophosphate ions in the soil solution and the maintenance of suitable concentrations of them are of g reatest importance to plant growth. The required concentration of phosphorus in the soil solution depends largely on the crop species being grown and the l evel of production desired. (Tisdale *et al.*, 1990).

Apart from soil pH., physical characteristics of the soil l such as aeration, compaction, moisture content and temperature also determi ne the availability of phosphorous.

Soil aeration influences the oxidative state of phosphorous, the decomposition of organic matter and release of phosphorus; fo r example, under the anaerobic conditions in paddy rice ferric iron is reduce d to ferrous form

which reacts with phosphorous to form the more soluble hence more available ferrous phosphates (Young *et al.*, 1985).

Soil compaction affects soil aeration whereby increased compaction results in anaerobic conditions and also physically impedes root penetration resulting in positional unavailability of phosphorous since it is relatively immobile in soil (Young *et al.*, 1985).

Temperature affects the activity of micro-organisms involved in organic matter decomposition . Low temperatures have been shown to decrease phosphorous availability and response to phosphorous fertilizer application have been observed to increase under such conditions (Young *et al.*, 1985).

A major portion of the phosphate ions have been shown to move to the roots by diffusion through the water films around the soil particles. Hence soil moisture affects phosphorous availability to plants (Olsen *et al.*, 1961).

Description of soil phosphorous can be reduced to the following:

Soil solution <=> labile soil P <=> non labile P.

Labile soil P is the readily available portion of the solid phase phosphorous that acts as a reserve to the soil solution P (referred to as the capacity or quantity factor) and has a high dissociation rate permitting rapid replenishment of soil solution P. Depletion of labile soil P usually causes non labile P to become labile again but at a very slow rate.

The equilibrium shown above can be temporarily disrupted by the addition of soluble phosphate fertilisers, by immobilisation of soluble phosphorous by microorganisms and by rapid mineralization of soil organic mater resulting from planting or cultivation (Tisdale *et al.*, 1990).

Phosphorus is absorbed largely as the primary and the secondary orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-} respectively) which are present in the soil solution. The amount of each present depends largely on the soil solution pH. $H_2PO_4^-$ is predominant at pH less than 7.2 and is the form predominant in

most agricultural soils. Above pH 7.2 HPO_4^{2-} is predominant while at pH 7.2 both occur in equal amounts. Other forms of P which may be components of commercial fertilizers are suitable and available for crops since they hydrolyse in aqueous solution to orthophosphate ions after which absorption occurs (Young *et al.*, 1985; Tisdale and Nelson, 1966). The concentration of mineral nutrients in the soil solution varies over a wide range, depending on such factors as soil moisture, pH, CEC, redox potential, quality and quantity of soil organic matter and microbial activity and fertilizer application. It is an indication of the mobility of nutrients both towards the plant roots in the vertical direction hence availability and leaching potential. Compared with other nutrients concentration of P is extremely low, leaching or transport to root surfaces being of minor importance in most soils. In contrast to other anions (e.g NO_3^- and SO_4^-) phosphate strongly reacts with surface active sesquoxides and oxihydrates of clay minerals; between 20% and 70% of the phosphate in soil solution may be present in organically bound form (Welp *et al.*, 1983).

Phosphorus is present in plant tissues and soil in quantities much less than nitrogen. The generally small quantities of P in the soils and its tendency to react with soil components forming relatively insoluble compounds many of which are limited in availability to plants make it a topic of major importance in soil fertility management. Very high P concentrations that exist temporarily in and near fertilizer bands are expected to encourage further P uptake by mass flow and diffusion. Mass flow in soils low in P provides a small quantity of the P requirement of plants. Diffusion is the most important mechanism involved in the movement of P to absorbing roots (Tisdale *et al.*, 1990). The principal factors affecting phosphorous diffusion are; percentage by volume of the soil occupied by soil water, the tortuosity of the diffusion path, the phosphate buffering capacity of the soil and the soil temperature

(Wild, 1988b; Marschner, 1986). Maintenance of a suitable concentration of phosphorous going into the soil (phosphorous intensity) depends on the solid phase phosphorous going into solution to replace that withdrawn by plant uptake. The rate of organic matter decomposition also influences the phosphorous intensity or soil solution concentration. Phosphate is not reduced in plants because it remains in its highest oxidized form as inorganic phosphate (P_i) or it is esterified as a simple phosphate ester (eg sugar phosphate) or attached to another phosphate by the energy rich pyrophosphate bond. P_i taken up by the roots is incorporated within a few minutes into organic P but thereafter reduced again as P_i in the xylem (Marschner 1986). P requirement for optimal growth is in the range of 0.3% - 0.5% of the plant dry weight during vegetative stages of growth (Marschner 1986). Because of the function of P in growth and metabolism of plants, deficiency leads to a general reduction of most metabolic processes. The level of P available to lettuce and radish plants during the first few days of growth was found to be critical for proper growth up to maturity. Change induced by P deficiency inhibit growth even if the P is supplied later on, in which case P is taken up and accumulated yet not utilized by the plant (Avnimelech and Scherzer, 1971).

Species differ markedly in their responses to phosphorous concentrations. Increased P results in increased growth by some species over a wide range of P concentrations while others show little increase in growth. Some may even show a decrease at high P concentrations. Rorison (1969) observed this in an experiment conducted with four different species of plants. Isolated roots of different species may take up similar amounts of P. According to an experiment by Nassery and Harley (1969), P was utilised in shoot growth in *Urtica* but remained as inorganic P in the shoots of *Deschampsia*. Consequently *Urtica* growth was restricted when plants were

deprived of P but that of *Deschampsia* continued at a steady rate. This, therefore, means that some species or possibly ecotypes are adapted to growth under conditions of low P but also take advantage of periods of enhanced P supply. Similar results were obtained by Clarkson (1967) using *Agrotis stolonifera* and *A. camina*. The ability of plants to make use of or store transient supplies of P is of advantage to plants which colonise P deficient soils.

2.3 Effects of varying levels of N and P on growth and yield of sesame

Generally, as the supply of plant growth factors increases, the growth rate and yield increases although with diminishing returns. This is true for all growth factors such as CO_2 , water, light and mineral nutrients.

Experiments in India have shown that seed yields of sesame increased with increasing levels of N and P (Itnal, 1993; Darwati,1990; Deshmukh *et al.*, 1987; Prakasha and Thimegodwa 1987; Puste and Maiti 1987). Other work in India (Sarma, 1994; Kumar and Prasad, 1993) showed response to N but not P. Similar results were reported in Venezuela (Pineda and Velasquez, 1986). Samui *et al.* (1986), in India reported increase in dry matter (DM) production in 3 sesame cultivars when N application was increased. It has also been shown that for most crops including sesame yield components such as plant height, number of capsules and number of branches increased with increasing N and P application (Samui *et al.*, 1986). Sinharoy *et al* (1990),Majumdar *et al.*, (1987) in India, observed an increase in number of primary branches, plant height and seeds per capsules of sesame with increasing N and P.

In Kenya work on sesame response to N and P has not produced conclusive results. Trials in 1968 indicated increase in yield with N and P application but the yields were low at both high and low levels of N and P

with 187.5 kg ha^{-1} Sulphate of ammonia (21% N) and 250 kg ha^{-1} double super phosphate (42% P_2O_5) giving the highest yields (Gichuki and Gethi, 1988). Other trials in Lamu showed a depressing effect on yield by N and P application (Anon, 1972). Further work by Gethi (1989) showed that sesame benefited from residual fertilizer N and P applied on preceding relay cropped maize. However at Siaya, sesame showed no significant response to levels between 0 and 150 kg Nha^{-1} and P between 0 and 90 kg P per hectare fertilizer application (Odeny, 1993). Mondal (1992) however, reported an increase in sesame yield with application of farmyard manure in India.

It is interesting to note that most major sesame producing countries in Africa have reported no response by sesame to fertilizer application. This was observed by Omran *et al.* (1985) in Ethiopia and Osman (1985) in Sudan.

2.4 Soil microorganisms and plant growth

2.4.1 Root-microorganism associations

Roots in non-sterile media support a large population of micro-organisms on their external surface (rhizosphere) and in the rhizospheric soil. The number of bacteria (but not necessarily fungi) is much larger at the rhizoplane and in the rhizosphere than in the bulk soil. Usually the number of microorganisms per unit surface area of roots increase basipetally and on average cover less than 10% of the rhizoplane (Rovira *et al.*, 1983). For higher plants preferential invasion by certain species is advantageous (e.g. in associative nitrogen fixation, whereas for others it is a disadvantage (e.g. invasion by pathogens). Micro-organisms may be free living or may form symbiotic relationships with the roots.

2.4.2 Root-fungus associations (Mycorrhizae)

The role of soil micro-organisms in nutrient cycling is well documented and widely known. Rhizosphere microorganisms however play a direct significant role in soil nutrient plant relationships. Mycorrhiza literally means "fungus root" and are the norm for most vascular plants. Many plants depend on their mycorrhizal structures for adequate uptake of nutrients and survival in natural ecosystem (Mason *et al.*, 1991). Almost all plant species of economic importance in the tropics are able to be infected by mycorrhizal fungi with most forming vesicular-arbascular mycorrhizae though some trees form ectomycorrhizae (Gerdemann, 1975; Harley, 1969a).In the tropics endomycorrhizae are most common (Mason *et al.*,1991) The more ubiquitous endomycorrhizae are symbiotic associations between certain fungi and plant roots, in which the fungal partner grows mainly inside the root cortex and penetrates cells of the host's roots. In contrast ectomycorrhizae are associations in which the fungus forms a sheath around each root but does not penetrate the root cells or move beyond the cortex. Endomycorrhizae aid uptake of nutrients and water in the same way as ectomycorrhizae through their hyphae which they send out of the plant cells into the soil. These "sheathless" mycorrhizae may absorb significant amounts of nutrients through the surface of host cells in addition to absorbing them through the fungal hyphae.

There is also substantial evidence that plant water relations may be enhanced by mycorrhizal colonisation. Most benefits include increased drought tolerance, decreased drought recovery lag and improved soil water extraction (Mason *et al.*, 1991). VA mycorrhizae thus show the potential to enhance crop production in arid and semi arid regions. The most common mechanism proposed to explain the role of VA mycorrhizae in plant water relations is improved host phosphorus nutrition (Mason *et al.*, 1991). Similarly, mycorrhizal

plants appear to be more tolerant of some plant diseases than non-mycorrhizal plants because of differences in nutrient status (Mason *et al.*, 1991).

2.4.2.1 Influence of mycorrhizae on plant growth and mineral uptake

It has been recorded by many researchers that mycorrhizae improve plant growth by increasing the uptake of nutrients particularly phosphorus (Dubey, 1993;Mason *et al.*, 1991; Marschner, 1986; Yost and Fox, 1979; Sanders and Tinker, 1973; Voggo, 1971; Harley, 1969). This however should only hold true for plants grown in soils low in P (Mason *et al.*, 1991; Marschner, 1986; Yost and Fox, 1979). Mycorrhizae have also been shown to enhance uptake of other nutrients including calcium, zinc, copper and sulphur (Harley, 1969). These nutrients, like phosphate are translocated through the hyphal network which extends from the mycorrhizal surface into the surrounding soil far beyond the zone accessible to the non-mycorrhizal roots.

In 1937, Hatch put forward a theory. "Mineral salt theory of mycorrhiza". It states that all nutrients are absorbed through the fungus, and mycorrhizal infection tends to improve the absorption of whatever major nutrient is most deficient. His analysis indicated that ectomycorrhizal seedlings of *Pinus* were larger in size and also contained greater quantities of the major elements N,P,K per unit weight than their non-mycorrhizal controls. This led him to forward the view that importance of mycorrhizae lay in their increasing the efficiency of uptake of any nutrient in short supply. An experiment by Mosse (1957) clearly demonstrated increased amounts of K, Fe and Ca per unit weight of tissues in mycorrhizal plants as compared to uninoculated controls. His results were soon confirmed by many others as mentioned below. Certain experiments however showed phosphate absorption to be more stimulated by mycorrhizal infection than that of other nutrients (Stone, 1950; Mcomb and Griffith, 1946; Mcomb, 1938;). Such findings together

(Stone, 1950; Mcomb and Griffith, 1946; Mcomb, 1938;). Such findings together with the fact that P deficiency is common in most soils and also the suitability of isotope ^{32}P for experimental purposes at that time led workers to concentrate their study on P uptake by mycorrhizal roots ignoring the other nutrients. The result has been a misconception held by some people up to now that mycorrhizae only improved P uptake (Harley and Smith, 1983).

The increased growth of plants in mycorrhizal associations is commonly accompanied by higher total amounts and frequently higher concentrations of some mineral nutrients in the tissues. Such has been established with phosphorous (Pairunan *et al.,* 1980; Stribley *et al.,* 1980; Baylis, 1967; Daft and Nicholson, 1964 and Gerdemann, 1964).

Despite the reductions in root : shoot ratio, increased total root length in mycorrhizal plants would certainly contribute to increased phosphorous tissue concentrations. If growth kept pace with phosphate uptake as it would if P were the limiting factor, tissue concentrations would be constant as they are dependent on relative rates of uptake and growth. If tissue concentrations increased, then some other factor other than P must be limiting growth except in extreme starvation conditions. It has been shown that mycorrhizal plants have considerably higher P concentrations than non-mycorrhizal plants of the same dry weight (Harley and Smith, 1983). Stribley *et al.* (1980) suggest that the increased carbohydrate utilization in mycorrhizal plants together with increased phosphate uptake means that they are carbon limited hence higher tissue concentrations.

2.4.2.2 N and P nutrition as affected by mycorrhizal infection

Phosphorous

Increased inflow of phosphate into both onion and clover roots infected by different mycorrhizal fungi has been demonstrated (Smith, 1982; Smith *et al.*, 1979; Sanders *et al.*, 1977 and Sanders and Tinker, 1973, 1971). Results of Harley and Smith (1975) showed that inflow into mycorrhizal roots (of which up to 50% of the root length was infected) was on average 3-4 times greater than into uninfected onion roots. This increased efficiency could be attributed to excellence and continued growth of extramatrical mycelium into soil. This hyphal system can be envisaged as extending beyond the phosphate depletion zone around the roots and exploiting a greater and less depleted volume of soil than the root hairs would be able to do. It is reasonable to accept that much of the increased phosphate uptake is due to improved exploitation of a given volume of soil, coupled with more rapid translocation of phosphate through hyphae to roots than diffusion through the soil to the root surface. However, two other mechanisms would also result in the increased efficiency of uptake by infected roots, namely;.

i) The possibility that at low soil phosphate concentrations, the mycorrhizal roots can absorb phosphate effectively than the associated roots.

ii) Infected plants can exploit sources of soil phosphate unavailable to uninfected ones e.g rock phosphate fertilizer or fixed inorganic soil phosphate.

Mosse *et al.* (1973) suggested that mycorrhizal infection might alter the threshold concentration from which plants were able to absorb phosphate. This has also been investigated by Cress *et al.* (1979) using tomato, Jintakanon *et al.* (1967) and Howeler *et al.* (1979) using cassava. The results indicate that the affinity of the uptake sites for phosphates was much higher in the mycorrhizal roots. The work with cassava illustrates two points; this species appears to have a very high phosphate requirement, coupled with a very inefficient phosphate uptake system in the absence of mycorrhizal infection. Despite this (like sesame) it is well known for its growth on low fertility soils

and clearly its efficiency of uptake is markedly increased when roots are infected by mycorrhizal fungi (Harley and Smith, 1983). Thus the importance of mycorrhizal infection to a particular species or variety of host plant may depend on the phosphate concentration in the soil, the relative affinities of root and fungal systems for phosphate and also upon the phosphate requirement of the host.

The suggestion that mycorrhizal roots can exploit soil phosphate sources that are normally unavailable to plants is based on results such as those of Murdoch *et al.* (1967) where growth of mycorrhizal maize responded to rock phosphate or bicalcium phosphate application whereas these fertilizers had no effect on the growth of non-mycorrhizal plants at application rates used in the experiment. In contrast, both mycorrhizal and non-mycorrhizal plants responded to monocalcium or superphosphate with no significant difference between them. Similar results have also been obtained for insoluble phosphate fertilization of a variety of host plants, usually in soils of low pH (Harley and Smith 1983).

In all investigations, comparisons were made at one or two rates of fertilizer application and most of the results indicated that phosphate from fertilizer was available to mycorrhizal but not to non-mycorrhizal plants (Harley and Smith, 1983). Pairunan *et al.* (1980) have suggested that this conclusion is invalid, and that it is essential to compare growth over a wide range of fertilizer levels so as to encompass complete phosphate response curves. In their experiment using superphosphate and grade C rock phosphate, the amount of rock phosphate which has to be added to the soil to achieve maximum growth of *Trifolium subterraneum* was about 40 times greater than the amount of phosphate from superphosphate that was required for both mycorrhizal and non-mycorrhizal plants. The maximum growth with rock phosphate was less than that of superphosphate irrespective of

mycorrhizal infection. These quantitative differences apart and assuming that the rock phosphate contained no soluble phosphate, nor toxic substances, the results suggest that there is no absolute difference in the availability of rock phosphate to mycorrhizal and non-mycorrhizal plants. Nevertheless, at moderate and realistic levels of application equivalent to the superphosphate range (0 to 0.8 g P per kg soil), mycorrhizal plants were clearly more effective at extracting phosphate from the superphosphate fertilizer. The mechanism behind the increased uptake may depend upon hyphal exploitation of the soil volume or a higher affinity of uptake sites for phosphates of mycorrhizal roots. In addition, both synergistic action between mycorrhizal and phosphate solubilizing bacteria (Azcon *et al.*, 1976) and the possible excretion of H^+ or hydroxyacids by hypha which would increase the availability of rock phosphate have been suggested (Smith, 1980; Johnston and Miller, 1959; Johnston, 1956).

According to Marschner, (1986) mycorrhizae stimulate growth and phosphorus uptake either not at all or to a limited degree in plants species which have extensively highly branched root hairs. In contrast responses are high in species with coarse root systems that are not highly branched. Some plants have the ability to store transient supplies of P (Bannister, 1976). Mycorrhizae have also been thought to provide similar reserves of P (Bannister and Norton, 1974; Harley, 1969a).

Nitrogen

Increased nitrogen concentrations have been reported in vesicular-arbascular mycorrhizal plants (Harley and Smith, 1983). Where they are also symbiotic with nitrogen fixing bacteria or *actinomycetes* this can be attributed to increased rates of nitrogen fixation induced secondarily e.g by increased phosphate uptake rather than to direct uptake of nitrogen compounds from

the soil. There is no evidence that mycorrhizal fungi or any other fungi that matter, can fix atmospheric nitrogen, so that in most mycorrhizal plants when increased concentrations of nitrogen have been recorded they must result from increased uptake from the soil. Smith and Smith (unpublished) found that though roots of mycorrhizal and non-mycorrhizal *Trifolium subterraneum* grown with NH_4^+ as a nitrogen source were considerably shorter than NO_3^- fed plants, mycorrhizal infection certainly stimulated growth of NH_4^+ fed plants more than that of NO_3^- fed plants. This could have been either because infection increased NH_4^+ uptake directly or because the fungal hyphae compensated for shorter root length and maintained the uptake of other nutrients, particularly those of phosphate.

Assimilation of gaseous N_2 in rhizobial root nodules is certainly increased when plants, growing in low phosphate soil are also infected with mycorrhizal fungi. This was probably first observed by Asai (1944, 1943). In most cases in recent experiments, improved nodulation in mycorrhizal plants appears to be the result of relief from phosphate stress, resulting in both a general improvement in growth, and indirect effect upon the N_2 fixing system. The differences between mycorrhizal and non-mycorrhizal plants disappear if the latter are supplied with a readily available phosphate source (Harley and Smith, 1983). It is thus reasonable to assume that increased uptake of nitrogen from the soil by mycorrhizal plants may be due to relief of phosphate stress by the mycorrhizal fungi. In most arable soils the nitrogen source is more likely to be NO_3^- than NH_4^+ due to rapid nitrification of NH_4^+. Plant demands for N exceeds by a factor of about ten the demand for phosphate, depletion zones for NH_4^+ will therefore develop as readily or more readily than those of phosphate though for the more mobile NO_3^- depletion may develop less readily. Since increased nitrogen concentration of mycorrhizal plants have been found

to be higher than non-mycorrhizal plants, the mycorrhizal fungi most probably is responsible for the increased N uptake hence increased growth.

2.4.2.3 Growth depression due to mycorrhizal infection

Growth depression due to the presence of mycorrhizae has also been reported. This was observed particularly in soils high in P (Sparling and Tinker, 1978; Crush, 1976; Johnson, 1976). The growth depression may be temporary immediately following infection and at times have become reversed when plants are kept until the soil becomes very depleted in P (Cooper, 1975; Khan, 1972).

2.4.3 Free living microorganisms and plant growth

Free living micro-organisms also affect plant growth and nutrient uptake. Some like the gram negative rods of *Pseudomonas* and *Xanthomonas* have been found to produce growth promoting hormones (Riviere, 1963). Others like *Azotobacter, Azospirillum* and some *cyanobacteria* are nitrogen fixers. Bothe *et al.* (1983) reported that their contribution to the nitrogen balance is very small being less than 1 kg ha^{-1}. Weiss (1971) reported that beneficial effects have been observed on sesame due to *Azospirillum* presence. Vader *et al.* (1982) also obtained similar results on sesame with *Azotobacter.*

CHAPTER THREE

3.0 MATERIAL AND METHODS

Three experiments were conducted for this study namely:

1)**Experiment one** - Sesame response to N and P fertilizer application under field conditions.

2)**Experiment two** - Sesame response to farmyard manure application under field conditions.

3)**Experiment three** - A glasshouse mycorrhizal N and P response study.

3.1 Experimental Sites

Experiment one and two were carried out over two seasons each at University of Nairobi Kibwezi Dryland Field Station in Makueni District and at the Siaya Farmers Training Centre (F.T.C) in Siaya District. Experiment three was conducted at the University of Nairobi, Kabete Campus Field Station.

Kabete is located on Latitude 1°, 15' South and Longitude 36° 44' East at an altitude of about 1800 m ASL. The area has a mean monthly maximum temperature of 23°C and a minimum of 12°C (Kabete Agrometrological Station, 1993).

Siaya lies on Latitude 0°3'16" North and Longitude 34°17'43" East at an altitude of about 1200m above sea level. The soil consists of a shallow well drained to moderately well drained brown murram cuirass soils and well drained very deep reddish brown to strong brown friable clay (dystic/eutric Nitosols and orthic Ferrasols), developed on acid igneous rocks (Jaetzold and Smith, 1983). The area receives an average rainfall of about 1400 mm per annum with a mean annual maximum temperature of 26.8°C and a minimum of 18°C.

Kibwezi is located on Latitude 2°17' South and Longitude 38°36'36" East at an altitude of 914 metres above sea level. The area receives an average rainfall of about 641 mm with mean annual maximum temperature of 30°C and minimum of 21°C. The soils are deep well drained dusky red to dark reddish brown friable to form sandy clay to clay (chromic luvisols) and well drained very deep light brown to strong brown very friable clay (orthic and xanthic Ferralsols) developed on undifferentiated basement system rocks (Jaetzold and Smith, 1983).

3.2 Experimental Design treatment and analysis

3.2.1 Experiment one

The experiments were a 4 x 4 factorial, laid out in randomised complete block design and replicated three times. The treatments consisted of; four levels of nitrogen (N_0 = 0 kg N ha^{-1}, N_1 = 100kg N ha^{-1}, N_2 = 200kg N ha^{-1}, N_3 = 300kg N ha^{-1}), four levels of phosphorous (P_0 = 0kg P ha^{-1}, P_1 = 50kg P ha^{-1}, P_2 = 100kg P ha^{-1}, P_3 = 200kg P ha^{-1}). Individual plot size was 4.2m x 3m with 1m between plots and 2m between blocks.

Nitrogen was applied as calcium ammonium nitrate (CAN 26% N) while phosphorus was applied as triple superphosphate (TSP 46% P_2O_5). All the phosphorous was applied at planting and nitrogen was applied in two equal splits; one at planting and the other when the plants were 15 cm tall.

3.2.2 Experiment two

This was a single factor experiment with farmyard manure (FYM) applied at four levels as follows: F0 = 0 T ha^{-1}, F2 = 3 T ha^{-1}, F3 = 6 T ha^{-1}, F4 = 9 T ha^{-1}). The trial was laid out in randomised complete block design replicated three times. The plot size was 4.2m x 3m with one metre between plots and 2

metres between blocks. The farmyard manure was broadcast and incorporated into the soil at planting.

Both experiments 1 and 2 were carried out over two seasons. The first trials were conducted between early November, 1993 to early March, 1994 and the second trials were from mid April to July, 1994.

3.2.3 Experiment three

A glasshouse pot experiment consisting of a 3 x 5 x 5 factorial complete randomised block design replicated three times was laid out at Kabete. The treatments consisted of:

a) Three potting media: M_1 = unsterilised field soil

M_2 = acid washed sand

M_3 = steam sterilised field soil.

b) Five levels of nitrogen in Hoagland solution:

N_0 = 0 Hoagland N (0 g N/l)

N_1 = 1/4 Hoagland N (0.13 g N/l)

N_2 = 1/2 Hoagland N (0.25 g N/l)

N_3 = 1 Hoagland N (0.51 g N/l)

N_4 = 2 hoagland N (1.01 g N/l)

c) Five levels of phosphorus in Hoagland solution:

P_0 = 0 Hoagland P (0 g P/l)

P_1 = 1/4 Hoagland P (0.02 g P/l)

P_2 = 1/2 Hoagland P (0.04 g P/l)

P_3 = 1 Hoagland P (0.07 g P/l)

P_4 = 2 Hoagland P (0.14 g P/l)

The pots were 30 cm in diameter. To obtain the different N and P combinations, KCl and $CaCl_2$ were used to replace KNO_3 and $CaNO_3$, respectively of the Hoagland solution to vary the N levels (while keeping the K and Ca

levels constant) and different quantities of H_3PO_4 were used to vary the P levels.

The field soil (0 - 30 cm) was collected from Siaya F.T.C. In the sterilisation process 50 kg batches of soil in sisal sacks were loaded into a steam autoclave which was topped up to the mark with distilled water. The soil was then steam sterilised at a pressure of 200KPa (134°C) for 10 minutes and allowed to cool before being removed and put into pots which were then covered to avoid contamination.

Sand was washed in batches of 20 litres being the size of the troughs that were used. These were washed thoroughly to remove all silt and clay by stirring and agitating under running water. The water washed sand was then soaked for 48 hours in acid solution consisting of 3 parts concentrated H_2SO_4 (36 N) to 1000 parts water by volume to remove all minerals. The acid was then poured off and the sand rinsed thoroughly several times using distilled water. At the end of every rinse the pH of the run-off was tested using universal indicator paper until a pH of 7 was obtained three times consecutively.

Prior to planting, seeds were sterilised by washing in 5% sodium hypochlorite. Two trials were conducted, the first between May 1995 to June 1995 and the second between January and February 1995.

Results of all three experiments were subjected to analysis of variance as described by Steel and Torrie (1981) and Duncan's multiple range test where the F-test was significant.

3.3 Crop husbandry

In all field trials, the fields were ploughed and harrowed by tractor , then levelled manually using hoes to achieve a medium to rough tilth. The varieties used for the trials were a local white seeded landrace. Each plot

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consisted of eight rows planted 60 cm apart. Seeds were sown by hand to a depth of about 2.0 cm and firmly covered to get maximum contact between the seed and the soil. Fertilizer, CAN and TSP were applied in parallel bands (5 cm away from the planting row and 5 cm deep) covered and similarly tamped down. Thinning was done when the plants were about 15 cm high to achieve an intra-row spacing of 15 cm as recommended by W'Opindi (1981). Immediately after thinning CAN was applied as top dressing in bands 5cm away from the plant row.

Regular weeding was done to ensure a clean seedbed throughout the season. Spraying with thiodan 35% EC to control webworms and Dithane M45 for control of fungal diseases mainly white leaf spot, angular leaf spot and powdery mildew. In Siaya all the experiments were conducted under rainfed conditions. In Kibwezi, supplemental irrigation was given to ensure a good crop stand.

At 4 months after sowing when the foliage had turned yellow and lower capsules started to shatter, the crops were harvested by cutting the plants at the stem base, tying into bundles and stooking to dry. The sesame cultivar used were of the dehiscent type whose capsules open upon drying at which time the bundles were each held upside down over a polythene sheet and tapped with a stick to release the seed from the open capsules. Collected seed was then cleaned by winnowing.

In experiment three, the media were fully watered a day prior to planting. Eight seeds were planted into each pot. These were thinned at 7 days after emergence to 5 plants per pot. The pots were kept free of weeds by pulling out any emerging weeds which occurred mainly in the unsterilized soil media.

The growing media were kept well watered for a period of two weeks after emergence using a full Hoagland solution (N_1P_1) and distilled water

applied alternately. Thereafter, watering was continued using the respective nutrient solution for each treatment instead of the full Hoagland solution. Once again the respective solutions were applied alternately with distilled water. The experiment was terminated at 8 weeks after emergence.

3.4 Measurements

All data in experiments 1 and 2 were collected at maturity. The parameters listed below, apart from the seed yield were recorded from plants falling within a 1 m length randomly selected from the inner 6 rows in each plot. The seed yield was obtained by bulking the seed harvested from all plants in each plot.

In experiment 3 data was taken from growing plants at weekly intervals beginning from 4 weeks after emergence until termination of the experiment.

a) **Plant height (cm/plant).**

This was determined by measuring the height of the plant from the stem base using a metre rule.

b) **Height at the first branch and at the first capsule (cm).**

These were determined by measuring the height from the base of the plant to the first primary branch and lowermost capsule on the main stem, respectively, using a metre rule.

c) Podding Zone (cm).

This was determined as the difference between the plant height and the height at the first capsule.

d) Number of branches/plant.

This was determined by averaging the number of pod bearing primary branches per plant in the sampled area.

e) Number of capsules/plant.

This was determined by averaging the number of capsules per plant in the sampled area.

f) Branch length (cm/plant).

This was determined by measuring the total length of the capsule bearing branches and then calculating the average branch length/plant.

g) Pod size (cm^2).

This was determined by multiplying the measured length and the width of each of 5 pods selected at random from each plant in the sampled area.

h) Seed yield (kg ha^{-1}).

This was determined by weighing the bulked seeds harvested from in each plot after, harvesting and winnowing.

I) Plant Growth (cm).

This was determined by measuring the height of the plants in each pot then averaging. Such measurements were taken weekly beginning from 4 weeks after emergence until the experiment was terminated.

j) Biomass (gm/plant).

This was determined by drying the harvested plants in an oven at 80°C for 5 days then weighing the dry plants.

k) Mycorrhizal infection rate (%cm).

This was determined by removing root samples from the pots, cleaning and staining to reveal the mycorrhizal infection of the roots and measurement of per cent infection as described by Mason *et al.* (1991) outlined in appendix I.

l) Soil analysis.

From each site in each growing season and the excavation sites for the pot experiment soil samples were collected from the top 30 cm in each experimental block and composited. These were then ground to pass through a 2mm sieve then subjected to soil chemical analysis using the procedures described in Methods of soil Analysis Part 2 (Page *et. al.* 1986). Subsamples were taken from the sieved soil samples and analyzed for the following:-

1) Soil pH

The soil pH was measured both in water and 0.01M $CaCl_2$ in a ratio of soil to solution of 1:2.5

2) Total Nitrogen

This was analyzed using the Kjeldahl method (Page *et. al.*, 1986).

3) Available phosphorus

This was determined by the Mehlichs double acid method (Page *et. al.* 1986).

5) Exchangeable bases (CEC)

The total amount of exchangeable base cations in the soil was determined by the Ammonium acetate continuous leaching method using the Buchner funnel filtration technique (Page *et. al.*, 1986).

K and Na were determined using the flame photometric method while Ca and Mg were determined using the atomic absorption method.

CHAPTER FOUR

4.0 RESULTS

Manure application at planting did not significantly affect plant height, yield or the yield components (podding length, number of capsules, number of podding branches and pod size) in both sites in both seasons.

Application of fertilizers N and P did not significantly affect the plant height, yield or yield components measured in seasons one and two at Kibwezi and Siaya, nor were the interactions significant (Tables 2a-7b, Appendix 6a-11b).

TABLE 2a Effect of nitrogen and phosphorous on plant height (cm) of sesame (trial one, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	112	104	95	95	101
N_1	93	99	94	90	94
N_2	107	100	99	102	102
N_3	99	102	112	87	100
P mean	103	101	100	94	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 1.77					

TABLE 2b Effect of nitrogen and phosphorous on plant height (cm) of sesame (trial two, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	113	109	109	121	113
N_1	114	111	109	111	111
N_2	109	109	111	110	110
N_3	113	104	106	102	106
P mean	112	108	109	111	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 1.07					

TABLE 2c Effect of nitrogen and phosphorous on plant height (cm) of sesame (trial one, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	121	143	129	145	134
N_1	152	142	144	130	142
N_2	136	143	125	120	131
N_3	142	138	152	133	141
P mean	137	142	137	133	

	N	P	NP
F TEST	NS	NS	NS

SE = 2.5

TABLE 2d Effect of nitrogen and phosphorous on plant height (cm) of sesame (trial two, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	78	82	90	78	82
N_1	77	72	77	83	77
N_2	74	81	70	72	74
N_3	98	75	85	78	84
P mean	82	78	81	78	

	N	P	NP
F TEST	NS	NS	NS

SE = 1.80

TABLE 3a Effect of nitrogen and phosphorous on podding length (cm) of sesame (trial one, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	54	42	34	40	42
N_1	29	27	25	24	27
N_2	35	40	33	39	35
N_3	39	27	42	22	33
P mean	39	32	34	32	

	N	P	NP
F TEST	NS	NS	NS

SE = 2.08

NS Not significant

TABLE 3b Effect of nitrogen and phosphorous on podding length (cm) of sesame (trial two, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	53	54	51	60	54
N_1	49	52	43	53	49
N_2	51	46	51	44	48
N_3	51	50	49	44	49
P mean	51	50	49	50	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 1.07					

TABLE 3c Effect of nitrogen and phosphorous on podding length (cm) of sesame (trial one, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	34	36	27	40	34
N_1	31	38	46	36	37
N_2	36	40	31	27	33
N_3	47	40	48	34	42
P mean	37	39	38	34	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 1.62					

TABLE 3d Effect of nitrogen and phosphorous on podding length (cm) of sesame (trial two, Kibwezi)

	P_0	P_1	P_2	P_3	Nmean
N_0	33	30	38	33	34
N_1	29	27	34	35	31
N_2	36	38	23	32	32
N_3	50	32	38	34	39
P mean	37	32	33	34	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 1.50					

NS Not significant

TABLE 4a Effect of nitrogen and phosphorous on number of pods (pods/ of sesame (trial one, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	63.7	60.7	62.8	86.0	68.3
N_1	49.6	80.6	61.9	50.7	60.7
N_2	72.0	55.5	64.2	76.1	67.0
N_3	72.0	62.3	75.7	64.7	68.7
P mean	64.3	64.8	66.2	69.4	
	N	P	NP		
F TEST	NS	NS	NS		

SE = 2.56

TABLE 4b Effect of nitrogen and phosphorous on number of pods (pods/ of sesame (trial two, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	81.6	60.7	99.9	81.3	80.9
N_1	76.0	77.7	79.6	70.9	76.0
N_2	76.8	81.2	82.8	70.0	77.7
N_3	52.3	92.3	76.2	68.5	72.3
P mean	71.7	78.0	84.6	72.7	
	N	P	NP		
F TEST	NS	NS	NS		

SE = 2.81

TABLE 4c Effect of nitrogen and phosphorous on number of pods (pods/pl of sesame (trial one, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	33.6	21.6	18.8	30.7	26.2
N_1	13.6	21.6	23.7	15.4	18.6
N_2	21.2	26.0	23.6	19.3	22.5
N_3	21.9	22.1	36.3	21.9	25.5
P mean	22.5	22.8	25.6	21.8	
	N	P	NP		
F TEST	NS	NS	NS		

SE = 1.51

NS Not significant

TABLE 4d Effect of nitrogen and phosphorous on number of pods (pods/plant) of sesame (trial two, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	76.5	47.1	68.0	63.1	63.7
N_1	55.4	70.9	55.2	72.5	63.5
N_2	56.4	51.0	59.9	43.3	55.2
N_3	77.3	67.7	58.4	55.1	64.6
P mean	66.4	59.2	60.4	58.5	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 2.56					

TABLE 5a Effect of nitrogen and phosphorous on number of branches (branches/plant) of sesame (trial one, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	5.3	3.9	5.2	4.6	4.8
N_1	4.1	5.7	3.8	5.1	4.7
N_2	5.1	4.7	4.7	4.1	4.6
N_3	4.6	5.5	5.2	4.9	5.1
P mean	4.8	5.0	4.7	4.7	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 0.14					

TABLE 5b Effect of nitrogen and phosphorous on number of branches (branches/plant) of sesame (trial two, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	6.9	6.3	6.7	7.0	6.7
N_1	6.5	7.7	7.0	7.6	7.2
N_2	5.5	7.7	7.4	7.4	7.0
N_3	6.9	7.6	7.0	6.4	7.0
P mean	6.5	7.3	7.0	7.1	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 0.15					

NS Not significant

TABLE 5c Effect of nitrogen and phosphorous on number of branches (branches/plant) of sesame (trial one, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	2.0	1.3	1.5	1.9	1.7
N_1	1.3	1.5	1.8	0.9	1.4
N_2	1.7	1.9	1.6	2.8	2.0
N_3	1.8	1.5	2.4	1.6	1.8
N mean	1.7	1.6	1.8	1.8	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 0.46					

TABLE 5d Effect of nitrogen and phosphorous on number of branches (branches/plant) of sesame (trial two, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	4.8	4.6	4.8	4.9	4.8
N_1	4.0	5.0	4.1	4.3	4.4
N_2	4.3	4.3	3.2	3.9	3.9
N_3	4.4	4.5	4.1	3.9	4.2
P mean	4.4	4.6	4.1	4.3	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 0.12					

TABLE 6a Effect of nitrogen and phosphorous on yield(kg ha^{-1}) of sesame (trial one, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	201.6	351.2	250.1	337.5	285.1
N_1	238.0	215.3	224.6	237.1	228.7
N_2	294.0	223.7	283.7	282.8	271.1
N_3	232.1	234.6	287.5	220.0	243.5
P mean	241.4	256.2	261.5	269.3	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 11.05					

NS Not significant

TABLE 6b Effect of nitrogen and phosphorous on yield(kg ha^{-1}) of sesame (trial two, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	534.4	514.8	567.6	630.3	564.0
N_1	627.8	422.0	393.5	463.0	476.6
N_2	437.8	514.5	581.5	519.5	514.4
N_3	486.1	555.4	460.2	513.9	503.9
P mean	523.6	502.9	500.7	531.7	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 17.22					

TABLE 6c Effect of nitrogen and phosphorous on yield(kg ha^{-1}) of sesame (trial one, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_0	774.7	614.1	535.7	541.3	616.5
N_1	530.1	606.7	714.4	660.8	628.0
N_2	787.7	630.9	462.9	342.7	556.1
N_3	597.3	1291.9	836.3	444.3	792.5
P mean	672.5	785.9	637.3	479.3	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 54.11					

TABLE 6d Effect of nitrogen and phosphorous on yield(kg ha^{-1}) of sesame (trial two, Kibwezi)

	P_0	P_1	P_2	P_3	P means
N_0	500.0	611.0	509.3	390.7	502.7
N_1	613.0	564.8	532.4	498.2	552.1
N_2	472.2	430.5	500.0	538.1	485.2
N_3	490.7	456.7	509.2	412.0	467.2
N mean	519.0	515.7	512.7	459.7	
	N	P	NP		
F TEST	NS	NS	NS		
SE = 15.70					

NS Not significant

TABLE 7a Effect of nitrogen and phosphorous on pod size (cm²/plant) of sesame (trial two, Siaya)

	P_0	P_1	P_2	P_3	N mean
N_0	1.6	1.6	1.4	1.6	1.6
N_1	1.6	1.7	1.5	1.5	1.6
N_2	1.4	1.5	1.4	1.7	1.5
N_3	2.0	1.6	1.6	1.4	1.6
P Mean	1.7	1.6	1.5	1.6	

	N	P	NP
F TEST	NS	NS	NS

SE = 0.04

TABLE 7b Effect of nitrogen and phosphorous on pod size (cm²/plant) of sesame (trial two, Kibwezi)

	P_0	P_1	P_2	P_3	N mean
N_1	1.6	1.6	1.6	1.6	1.6
N_2	1.7	1.8	1.6	1.8	1.7
N_3	1.6	1.5	1.6	1.7	1.6
N_4	1.9	1.6	1.6	1.8	1.7
P mean	1.7	1.6	1.6	1.7	

	N	P	NP
F TEST	NS	NS	NS

SE = 0.03

NS Not significant

Random samples of roots of sesame plants grown Siaya were heavily infected with mycorrhizal fungi, with over 90%/cm infection rate.

In the greenhouse, results from both trials one and two showed that plants in unsterilised soil (M_1) were significantly taller than those in acid washed sand (M_2) and sterilised soil (M_3) throughout the growing period (Tables 8a-11b). Results from trial one indicate that plants in M_1 were significantly taller than plants in M_3 at 31 Days after emergence (DAE and 37 DAE but statistically similar ($P \leq 0.05$) at 44 DAE and 51 DAE, (Tables 8a, 9a 10a and 11a). However, in trial two plant height (growth) in M_3 remained superior to that in M_1, (Tables 8b, 9b, 10b and 11b).

The interaction between media (M) and nitrogen (N) was significant throughout the growth period of trial one (Tables 8a, 9a, 10a and 11a). Separation of means indicated that N application significantly increased growth of sesame plants in M_2. In M_3 growth was not significanty different at 30 DAE and 37 DAE but was significantly enhanced by N application at 44 DAE and 51 DAE (Tables 8a, 9a, 10a and 11a).

Trial two did not show any significant interaction between N and M until 51 DAE when N application significantly increased growth in both media M_2 and M_3 (Tables 8b, 9b, 10b and 11b). However, results showed growth figures at 37 DAE and 44 DAE to increase numerically with N application in both media M_2 and M_3 but not M_1 (Tables 8b, 9b, 10b and 11b).

Application of N did not significantly affect growth throughout the experimental period in trials one and two except at 37 DAE in trial two where growth was significantly enhanced (Table 9b).

Application of P resulted in a significant increase in growth, in trial one from 37 DAE onwards (Tables 9a, 10a and 11a). Separation of means show that P_4 gave significantly taller plants than P_0 and P_1. The interaction MP was not significant at any time during trial one. In trial two there was no significant effect on growth due to P application (Tables 8b, 9b, 10b and 11b) though at 44 DAE and 51 DAE the interaction between media (M) and phosphorous (P) was significant (Tables 10b and 11b). Separation of these means showed that P application significantly enhanced growth in media M_2 and M_3 but not M_1 at 44 DAE and 51 DAE (Tables 10b and 11b). The interactions NP and MNP were not significant in both trials.

TABLE 8a Effect of planting media and N and P fertilizers on plant height of sesame (cm) at 30 DAE, (trial 1)

		P_0	P_1	P_2	P_3	P_4	Nmean
M_1	N_0	26.0	27.5	28.5	29.5	41.0	30.5t
	N_1	34.0	27.0	30.5	28.5	26.0	29.0tu
	N_2	32.5	27.0	30.0	28.0	15.0	26.5tuv
	N_3	31.5	25.5	29.5	30.5	27.0	29.0tu
	N_4	28.0	28.5	22.0	28.0	36.5	28.5tu
PM_1 mean		30.4	27.0	28.0	29.0	27.0	
M_2	N_0	11.5	5.5	8.0	7.0	6.5	7.7y
	N_1	8.5	7.0	10.5	8.5	12.5	9.5y
	N_2	13.0	14.5	14.5	7.5	20.0	10.0y
	N_3	9.5	9.5	20.0	11.5	9.0	12.0xy
	N_4	17.5	19.5	21.0	31.5	21.5	22.0vw
PM_2 mean		12.0	11.0	15.0	13.0	21.5	
M_3	N_0	18.0	18.0	20.5	15.5	16.5	17.7wx
	N_1	22.5	23.5	29.5	21.0	23.0	24.0tuvw
	N_2	18.0	18.5	18.0	17.5	25.5	19.5w
	N_3	21.5	19.5	26.0	20.0	27.5	19.5uvw
	N_4	21.0	19.5	17.0	21.5	23.5	20.5vw
PM_3 mean		20.0	20.0	22.0	19.0	23.0	
P mean		20.4a	19.3a	22.0a	20.9a	22.9a	

	M	N	P	MN	MP	NP	MNP
F TEST	***	ns	ns	***	ns	ns	ns

SE = 0.98

*** Significant at 0.1% probability level.

ns Not significant.

	M_1	M_2	M_3
M means	29.2a	13.1c	20.9b

Means followed by the same letter(s) (a,b,c;t,u,v,w,x,y) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 8b Effect of planting media and N and P fertilizers on plant height o sesame (cm) at 30 DAE, (trial 2)

		P_0	P_1	P_2	P_3	P_4	Nmean
M_1	N_0	31.3	34.7	42.3	28.5	27.3	33.0
	N_1	56.0	39.2	30.2	24.0	26.3	35.0
	N_2	31.3	40.7	34.8	15.7	29.5	30.5
	N_3	32.8	32.7	22.3	53.5	23.3	33.0
	N_4	45.5	23.3	52.0	7.5	47.3	35.0
PM_1 mean		39.5	44.0	36.5	26.0	31.0	
M_2	N_0	6.8	8.7	8.8	11.3	13.0	10.0
	N_1	6.2	7.7	12.0	12.0	14.2	10.5
	N_2	7.5	10.8	8.3	15.5	16.0	11.5
	N_3	11.2	8.7	12.5	13.7	18.8	13.0
	N_4	11.7	11.7	19.8	18.0	25.7	17.5
PM_2 mean		8.7	19.5	12.3	14.1	17.6	
M_3	N_0	12.7	13.7	15.0	16.0	18.5	15.0
	N_1	15.0	14.3	16.3	18.5	21.2	17.5
	N_2	14.0	14.8	17.8	25.0	25.0	19.5
	N_3	17.5	22.7	25.5	34.7	35.8	24.0
	N_4	20.7	20.0	20.0	28.3	32.8	17.5
PM_3 mean		16.0	17.0	19.0	24.5	26.5	
P mean		21.4a	20.2a	22.6a	21.5a	25.0a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	ns	ns	ns	ns	ns

SE = 1.36
*** Significant at 0.1% probability level.
ns Not significant.

	M_1	M_2	M_3
M means	33.3a	12.4c	20.7b

Means followed by the same letter(s) (a,b,c) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 9a Effect of planting media and N and P fertilizers on plant height of sesame (cm) at 37 DAE. (trial 1)

		P_0	P_1	P_2	P_3	P_4	Nmean
M_1	N_0	39.0	43.5	47.5	40.0	65.0	47.0t
	N_1	41.0	33.0	49.0	44.0	69.5	47.5t
	N_2	46.5	34.5	44.0	47.5	45.5	43.5t
	N_3	48.5	45.5	45.5	43.5	44.5	45.5t
	N_4	38.0	41.5	36.5	43.0	52.5	42.5t
PM_1 mean		42.5	39.5	44.5	43.5	55.5	
M_2	N_0	7.5	10.5	8.5	10.5	8.5	9.0x
	N_1	11.0	8.5	13.5	14.5	20.5	13.5wx
	N_2	18.5	18.0	19.0	14.5	30.5	20.0uvwx
	N_3	10.5	12.5	26.5	19.0	20.0	17.5uvwx
	N_4	22.5	29.0	30.5	36.5	27.5	29.0uv
PM_2 mean		14.0	15.5	19.5	19.0	21.5	
M_3	N_0	25.0	19.5	28.0	16.0	28.5	21.5uvw
	N_1	32.0	30.0	34.9	30.5	28.5	31.0u
	N_2	20.0	19.0	20.5	18.0	24.5	20.5uvw
	N_3	23.0	18.0	33.5	24.5	38.5	27.5uv
	N_4	23.5	20.0	20.5	26.5	34.5	25.0uvw
PM_3 mean		24.5	21.5	27.5	23.0	29.0	
P mean		27.2b	24.8b	30.5b	28.5b	35.4a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	**	*	ns	ns	ns

SE = 1.63

*,**,*** Significant at 5%, 1%, and 0.1% probability level respectively.

ns Not significant.

	M_1	M_2	M_3
M means	44.8a	17.9c	25.1b

Means followed by the same letter(s) (a,b,c;t,u,v,w,x) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 9b Effect of planting media and N and P fertilizers on plant height of sesame (cm) at 37 DAE, (trial 2)

		P_0	P_1	P_2	P_3	P_4	Nmean
M_1	N_0	46.0	65.0	61.0	39.2	42.7	51.0
	N_1	84.2	58.0	50.8	38.5	48.7	56.0
	N_2	45.7	65.0	59.5	30.3	48.7	50.0
	N_3	59.0	44.8	33.0	76.0	39.3	50.5
	N_4	69.8	40.0	76.8	11.8	76.5	55.5
PM_1 mean		61.0	54.5	56.5	39.0	51.0	
M_2	N_0	8.8	13.3	13.0	14.5	16.8	13.5
	N_1	8.5	9.2	16.3	15.7	19.0	14.0
	N_2	12.3	17.0	13.0	20.7	23.3	16.0
	N_3	19.0	16.2	19.0	21.3	27.8	20.5
	N_4	18.7	18.2	31.3	29.8	40.3	27.5
PM_2 mean		13.5	15.0	19.5	19.0	25.0	
M_3	N_0	14.3	19.5	25.0	26.3	29.2	23.0
	N_1	16.3	21.5	19.8	21.7	31.8	22.5
	N_2	16.8	20.3	26.0	31.5	37.3	27.0
	N_3	24.0	31.7	32.2	39.5	43.2	34.0
	N_4	30.7	33.2	44.5	52.7	58.7	70.4
PM_3 mean		20.5	25.5	29.5	34.0	40.0	
P mean		31.6a	31.5a	34.8a	31.3a	31.9a	

F Test	M	N	P	MN	MP	NP	MNP
	***	*	ns	ns	ns	ns	ns

SE = 2.16

*,*** Significant at 5% and 0.1% probability level respectively.

ns Not significant.

	M_1	M_2	M_3		
M means	52.4a	18.5c	29.9b		
	N_0	N_1	N_2	N_3	N_4
N means	29.0b	30.7b	31.2b	35.1ab	42.2a

Means followed by the same letter(s) (a,b,c) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 10a Effect of planting media and N and P fertilizers on plant height of sesame (cm) at 44 DAE, (trial 1)

		P_0	P_1	P_2	P_3	P_4	Nmean
M_1	N_0	60.5	71.5	74.5	61.5	105.5	74.5t
	N_1	62.0	57.5	74.5	65.0	50.0	62.0t
	N_2	74.5	65.5	71.5	74.5	73.0	72.0t
	N_3	71.0	53.5	78.0	59.0	65.5	65.5t
	N_4	55.0	62.0	53.5	66.0	77.0	62.5t
PM_1mean		64.5	62.0	70.5	65.0	74.5	
M_2	N_0	15.5	15.0	15.0	15.5	16.0	15.5w
	N_1	18.0	18.0	23.5	27.0	35.5	24.5vw
	N_2	24.5	30.5	37.5	29.5	52.5	35.0uv
	N_3	26.0	21.0	43.5	40.5	36.5	36.5uv
	N_4	33.0	47.5	54.5	57.5	45.5	47.5u
PM_2mean		23.5	26.5	34.5	34.0	37.0	
M_3	N_0	23.0	24.5	42.5	20.0	30.0	28.0vw
	N_1	60.0	35.5	44.5	53.0	35.5	45.5u
	N_2	19.0	23.0	27.5	19.0	36.0	25.0vw
	N_3	30.0	28.0	45.5	37.5	45.5	37.5uv
	N_4	32.5	26.0	40.0	42.0	48.0	37.5vw
PM_3mean		33.0	27.5	40.0	34.5	39.0	
P mean		39.6bc	39.8bc	42.3ab	44.7abc	50.1a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	*	***	ns	ns	ns

SE = 2.18

*, *** Significant at 5% and 0.1% probability level respectively.

ns Not significant.

	M_1	M_2	M_3
M means	66.7a	30.8b	34.6b

Means followed by the same letter(s) (a,b,c;t,u,v,w) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 10b Effect of planting media and N and P fertilizers on plant height of sesame (cm) at 44 DAE, (trial 2)

		P_0	P_1	P_2	P_3	P_4	Nmean
M_1	N_0	68.3	77.8	84.8	66.8	74.2	74.5
	N_1	123.8	100.2	83.2	64.5	76.3	89.5
	N_2	79.0	121.3	93.8	50.7	71.0	83.0
	N_3	88.3	78.8	47.8	112.2	63.3	78.0
	N_4	99.8	65.3	112.0	24.7	98.2	80.0
PM_1 mean		92.0t	89.0t	84.5tu	64.0uvw	76.5tuv	
M_2	N_0	14.8	16.8	16.7	18.8	23.8	18.0
	N_1	15.5	19.3	26.3	27.3	23.5	26.0
	N_2	17.3	31.3	28.8	32.0	44.0	30.0
	N_3	24.0	28.2	45.3	36.3	45.7	36.0
	N_4	33.2	35.2	48.2	53.3	62.0	47.0
PM_2 mean		21.0y	27.0y	33.0xy	33.0xy	43.0wxy	
M_3	N_0	34.3	59.5	70.0	71.7	63.3	60.0
	N_1	36.5	47.0	40.0	56.2	72.0	53.0
	N_2	41.8	51.3	57.0	62.7	81.7	59.0
	N_3	47.3	62.3	67.8	74.5	82.8	67.0
	N_4	50.5	54.5	73.8	91.3	104.5	75.0
PM_3 mean		42.0wxy	55.0vwx	62.0uvw	71.0tuv	84.0t	
P mean		51.6b	56.5ab	59.7ab	56.2ab	66.8a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	ns	ns	**	ns	ns

SE = 3.15

** *** Significant at 1% and 0.1% probability level respectively.

ns Not significant.

	M_1	M_2	M_3
M means	81.1a	31.3c	62.2b

Means followed by the same letter(s) (a,b,c;t,u,v,w,x,y) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 11a Effect of planting media and N and P fertilizers on plant height o sesame (cm) at 51 DAE, (trial 1)

		P_0	P_1	P_2	P_3	P_4	Nmean
	N_0	63.0	104.5	105.5	89.5	143.5	107.5t
	N_1	105.5	81.5	105.0	90.5	92.5	94.0t
M_1	N_2	113.0	91.5	102.0	111.5	105.5	104.5t
	N_3	105.0	76.5	102.0	93.5	97.5	97.5t
	N_4	74.5	105.0	82.0	87.0	104.0	90.5t
PM_1 mean		97.0	92.0	99.5	94.5	108.5	
	N_0	14.0	18.0	13.5	21.0	14.5	16.0w
	N_1	15.0	28.5	35.0	42.5	51.5	34.5vw
M_2	N_2	38.0	46.0	55.5	47.0	80.5	54.0uv
	N_3	16.5	30.0	68.0	62.5	59.0	47.0uv
	N_4	32.5	54.5	81.0	74.0	63.0	61.0u
PM_2 mean		23.5	35.5	50.5	50.0	53.5	
	N_0	21.5	53.0	35.0	22.5	50.5	36.0w
	N_1	46.0	58.5	53.0	64.5	66.0	57.5vw
M_3	N_2	22.5	39.5	28.5	20.5	53.5	34.5uv
	N_3	25.5	32.5	44.5	59.5	59.5	44.5u
	N_4	39.0	52.5	60.0	55.0	68.5	55.0uv
PM_3 mean		31.0	47.0	44.0	46.0	59.5	
P mean		50.2b	58.7bc	65.2ab	64.4ab	73.5a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	**	***	ns	ns	ns

SE = 3.70

, * Significant at 1% and 0.1% probability level respectively.

ns Not significant.

	M_1	M_2	M_3
M means	98.2a	43.2b	45.2b

Means followed by the same letter(s) (a,b,c;t,u,v,w) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 11b Effect of planting media and N and P fertilizers on plant height of sesame (cm) at 51 DAE, (trial 2)

		P_0	P_1	P_2	P_3	P_4	Nmean
	N_0	93.7	120.2	118.3	99.2	109.2	108.0tuv
	N_1	170.5	135.7	123.8	101.2	117.0	179.5t
M_1	N_2	88.5	146.5	134.3	67.0	122.3	111.5tu
	N_3	121.8	115.0	70.0	133.5	95.0	107.0tuv
	N_4	125.3	94.8	86.5	35.5	140.5	96.5uvw
M_1mean		120.0tu	122.5t	106.5tuv	87.0vu	117.0tu	
	N_0	21.2	23.8	23.3	28.2	30.0	25.5z
	N_1	24.3	26.7	36.8	34.8	43.2	33.0z
M_2	N_2	24.8	36.0	35.0	42.8	56.3	39.0yz
	N_3	34.8	40.8	65.0	51.07	70.0	52.5xyz
	N_4	44.5	48.7	65.3	74.3	83.2	63.5xy
PM_2mean		30.0z	35.0z	45.0yz	46.5yz	65.5wxy	
	N_0	42.5	68.3	80.5	88.3	90.2	74.0wx
	N_1	44.0	57.7	56.5	71.8	88.8	63.5xy
M_3	N_2	51.6	62.0	67.2	77.7	99.5	71.5wx
	N_3	57.0	72.8	83.3	90.0	102.5	81.0vwx
	N_4	68.5	72.5	102.3	136.0	155.0	107.0tuv
PM_3mean		53.0xyz	67.0wxy	78.0wx	93.0uvw	107.0tuv	
P mean		67.5b	74.8b	76.6b	75.5b	93.5a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	*	**	**	ns	ns

SE = 4.3

*, **, ***, Significant at 5%, 1% and 0.1% probability level respectively.
ns Not significant.

	M_1	M_2	M_3
M means	110.6a	42.6c	79.5b

Means followed by the same letter(s) (a,b,c;t,u,v,w,x,y) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

Analysis on biomass taken at 51 DAE in trial one showed that M_4 was significantly superior to M_2 and M_3 which were not significantly different (Table 12a). In trial two biomass results indicated M_3 to be significantly greater than M_4 which was also significantly greater than M_2 (Tables 12a and 12b). Nitrogen application did not significantly affect biomass in trial one but P application resulted in a significant biomass increase with P_0, P_1, P_2 and P_3 being statistically similar ($P \leq 0.05$) but significantly less than P_4 (Table 12a). In trial two however, biomass analysis results indicated that N and P application promoted growth significantly. Mean separation tests performed showed that biomass at N_4 was significantly greater than at N_0 (Table 12b) and P_4 was significantly greater than P_3, which was superior to P_2, P_1 and P_0 which were statistically similar ($P \leq 0.05$).

The interactions MN, MP, NP and MNP were not significant in trial one (Table 12a). However, in trial two NM, MP and NP interactions were significant (Table 12b). Separation of means showed that N application did not have any significant effect on biomass in M_1 but did so in M_2 and M_3 in which N_4 was superior to N_3 which was also superior to N_2, N_1 and N_0 which were statistically similar ($P \leq 0.05$). In the same trial P_4 was significantly superior to P_3 which was likewise superior to P_2, P_1 and P_0, in M_2 and M_3 but not in M_1.

Separation of biomass means for the interaction NP (Table 12c) also showed that at the P level P_4, N_4 was significantly greater than N_3 which was also superior to N_2, N_1 and N_0. However, at P_0, P_1 and P_2 N application did not significantly affect biomass. Biomass was significantly greater at P_4 than at all the other P levels at all levels of nitrogen.

The low DM values (in trial one) of plants grown in sterilized field soil media of trial one, which were even lower than those of sesame grown in acid washed sand (Table 12a) could most probably be attributed to the infection of damping off disease that occurred amongst most of the pots (over 50% of the

pots) containing sterilized soil. Though growth (plant height) in those s pots showed contrary results at 51 DAE (Table 11a), many of the plants w of normal height but spindly in appearance indicating a lower level nutrition which could have resulted in low biomass. Some however, w obviously stunted in appearance.

TABLE 12a Effect of planting media and N and P fertilizers on biomass (g/plant) at 51 DAE, (trial 1)

		P_0	P_1	P_2	P_3	P_4	N mea
M_1	N_0	18.5	23.4	17.4	17.4	36.6	22.6
	N_1	13.6	10.5	29.4	18.2	16.5	17.6
	N_2	21.2	23.1	26.5	25.5	24.6	24.2
	N_3	24.2	15.3	22.5	14.9	23.6	20.2
	N_4	18.1	23.1	12.7	13.9	16.2	16.8
PM_1 mean		19.2	19.1	21.7	18.0	23.4	
M_2	N_0	0.4	1.1	2.3	4.2	7.9	3.2
	N_1	0.6	2.0	3.5	5.4	10.1	4.3
	N_2	1.1	1.7	3.8	5.4	12.9	5.0
	N_3	1.4	2.3	3.5	5.8	16.0	5.8
	N_4	1.7	2.7	5.9	9.2	35.2	10.9
PM_2 mean		1.0	2.0	3.8	6.0	16.4	
M_3	N_0	0.8	1.6	2.7	3.4	9.3	3.6
	N_1	1.1	1.7	3.1	3.5	9.5	3.8
	N_2	1.4	2.0	3.9	4.8	9.6	4.3
	N_3	2.5	2.0	4.3	6.8	11.8	5.5
	N_4	1.5	2.6	4.5	8.8	13.7	6.2
PM_3 mean		1.5	2.0	3.7	5.7	10.8	
P mean		7.2b	7.7b	9.4b	9.8b	16.9a	

F Test	M	N	P	MN	MP	NP	MNP
	***	ns	***	ns	ns	ns	ns

SE = 1.05

*** Significant at 0.1% probability level.

ns Not significant.

	M_1	M_2	M_3
M means	20.3a	5.8b	4.8b

Means followed by the same letter (a,b,c) are not significantly differe probability level according to Duncan's Multiple Range Test.

TABLE 12b Effect of planting media and N and P fertilizers on biomass of sesame (g/plant) at 51 DAE, (trial 2)

		P_0	P_1	P_2	P_3	P_4	N mean
M_1	N_0	18.5	23.4	17.4	36.3	22.6	23.6uvwx
	N_1	13.0	10.5	29.4	16.5	16.5	17.2wxyz
	N_2	21.2	23.1	26.5	24.6	24.0	23.9uvw
	N_3	24.7	15.3	22.5	23.6	23.6	21.9vwxy
	N_4	18.1	23.1	17.7	16.2	16.2	18.2wxyz
PM_1 mean		19.2vw	19.1vw	22.7vw	23.4vwx	20.6vw	
M_2	N_0	0.3 1.7	5.6	8.0	11.2	5.4z	
	N_1	0.3 2.6	6.0	9.5	17.5	7.2z	
	N_2	0.2 3.3	6.6	9.6	22.6	8.5yz	
	N_3	1.0 3.5	7.2	13.9	26.9	10.5xyz	
	N_4	1.2 5.1	7.9	15.3	53.4	17.0wxyz	
PM_2 mean		0.6z	3.2z	6.7xyz	11.3wxyz	26.7v	
M_3	N_0	0.1 2.3	11.1	24.6	65.0	20.5vwxy	
	N_1	0.1 3.2	14.3	32.6	77.2	25.5uvw	
	N_2	0.3 5.6	16.1	37.7	94.5	31.8uv	
	N_3	0.5 6.9	18.1	44.8	96.3	33.3u	
	N_4	2.0 8.4	23.5	52.6	139.4	45.1t	
PM_3 mean		0.6z	5.3yz	16.6vwxy	38.4u	94.4t	
P mean		5.6c	12.1c	14.2c	23.7b	47.4a	

F Test	M	N	P	MN	MP	NP	MNP
	***	*	***	*	***	*	ns

SE = 2.8

*, ***, Significant at 5% and 0.1% probability level respectively .

ns Not significant.

	M_1	M_2	M_3
M means	22.8b	9.6c	31.2a

	N_0	N_1	N_2	N_3	N_4
N means	16.5b	20.0ab	22.1ab	20.7ab	26.7a

Means followed by the same letter(s) (a,b,c;t,u,v,w,x,y,z) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

TABLE 12c Effect of N and P fertilizers on biomass of sesame (g/plant) at 51 DAE, (trial 2)

	P_0	P_1	P_2	P_3	P_4	N mean
N_0	6.3ij	9.1hij	11.4fghij	22.8defghi	32.9cde	16.5y
N_1	4.5j	5.4j	16.6fghij	19.3efghij	37.1bcd	20.0xy
N_2	7.2hij	10.7ghij	16.4fghij	23.6defgh	46.9bc	22.1xy
N_3	8.7hij	8.6hij	15.9fghij	27.4defg	48.9b	20.7xy
N_4	7.1hij	12.2fghij	16.3fghij	28.0def	70.2a	26.7x
Pmean	8.6z	12.1z	14.2z	23.7y	47.4x	

SE = 3.22

$LSD_{.05}P$ = 6.3 $LSD_{.05}N$ = 6.3 $LSD_{.05}NP$ = 5.0

Means followed by the same letter(s) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

Mycorrhizal analysis in both trials one and two showed roots in M_1 to be highly infected (93.7%/cm and 95.7%/cm respectively) as opposed to M_2 and M_3 in which roots were barely infected at 0.14%/cm and 0.10%/cm respectively in trial one and 0.12%/cm and 0.16%/cm respectively in trial two (Tables 13a and 13b).

TABLE 13a Effect of planting media and N and P fertilizers on mycorrhizal infe rate (% infection/cm) of sesame at 51 DAE, (trial 1).

		P_0	P_1	P_2	P_3	P_4	N mean
M_1	N_0	95.4	100.0	99.4	84.9	98.2	95.8
	N_1	93.5	89.2	98.4	95.1	93.9	93.4
	N_2	95.3	95.7	93.2	92.1	93.6	94.0
	N_3	90.0	99.7	98.0	92.0	87.2	93.4
	N_4	86.3	80.9	95.4	99.2	98.5	92.1
PM_1 mean		92.1	93.1	96.9	92.2	94.3	
M_2	N_0	1.4	0.0	0.0	0.5	0.0	0.4
	N_1	0.0	0.0	0.0	0.0	0.0	0.0
	N_2	0.0	0.1	0.0	0.0	0.0	0.1
	N_3	0.0	0.0	0.0	0.1	0.0	0.2
	N_4	0.0	0.0	0.0	0.0	0.0	0.0
PM_2 mean		0.3	0.1	0.0	0.3	0.0	
M_3	N_0	1.4	0.0	0.0	0.0	0.0	0.0
	N_1	0.0	0.0	0.0	0.0	0.0	0.0
	N_2	0.0	0.0	0.0	0.0	0.0	0.0
	N_3	0.0	0.0	0.0	0.4	0.0	0.1
	N_4	0.0	0.0	0.0	1.4	0.0	0.3
PM_3 mean		0.3	0.0	0.0	0.4	0.0	
P mean		30.8a	31.1a	32.3a	30.9a	31.9a	

F Test	M	N	P	MN	MP	NP	MNP
	**	ns	ns	ns	ns	ns	ns

SE = 5.14

** Significant at 1% probability level.

ns Not significant.

	M_1	M_2	M_3
M means	93.7a	0.1b	0.1b

Means followed by the same letter(s) (a,b,c) are not significantly different at probability level according to Duncan's Multiple Range Test.

TABLE 13b Effect of planting media and N and P fertilizers on mycorrhizal infection rate (% infection/cm) of sesame at 51 DAE, (trial 2)

		P_0	P_1	P_2	P_3	P_4	N mean
M_1	N_0	95.1	98.4	99.0	92.3	97.0	96.4
	N_1	97.9	97.7	95.8	98.3	100.0	97.9
	N_2	95.8	98.6	98.2	97.4	99.0	97.8
	N_3	96.6	97.0	93.2	90.7	97.2	94.9
	N_4	80.0	98.3	98.6	99.1	83.0	91.7
PM_1 mean		93.1	98.0	97.0	95.6	95.3	
M_2	N_0	0.0	0.0	0.0	0.0	0.0	0.0
	N_1	0.0	0.0	0.0	0.0	0.0	0.0
	N_2	0.0	0.5	0.0	2.3	0.0	0.6
	N_3	0.0	0.0	0.0	0.0	0.0	0.0
	N_4	0.0	0.0	0.0	0.0	0.0	0.0
PM_2 mean		0.0	0.1	0.0	0.5	0.0	
M_3	N_0	0.0	0.0	1.5	0.0	0.0	0.3
	N_1	0.0	0.0	0.0	0.0	0.0	0.0
	N_2	0.0	0.0	0.0	0.0	0.0	0.0
	N_3	0.0	0.0	0.0	0.0	0.0	0.0
	N_4	0.0	0.0	0.0	0.0	0.0	0.0
PM_3 mean		0.0	0.0	0.3	0.0	0.0	
P mean		31.0a	32.7a	32.4a	32.0a	31.8a	

F Test	M	N	P	MN	MP	NP	MNP
	**	ns	ns	ns	ns	ns	ns

SE = 5.3

** Significant at 1% probability level.

ns Not significant.

	M_1	M_2	M_3
M means	95.8a	0.1b	.01b

Means followed by the same letter (a,b,c) are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

CHAPTER FIVE

5.0.DISCUSSION

The lack of response of sesame to FYM applied at planting and N and P application in field trials at Kibwezi and Siaya over two seasons could be due either to low yield potential of local landraces or due to improved nutrient uptake through mycorrhizal infection of the sesame roots or both factors combined.

These results are consistent with others recently reported from Siaya (Ayiecho and Nyabundi, 1995; Odeny *et al.*, 1994). Omran *et al.* (1985) and Osman (1985) observed that most major sesame producing countries in Africa have reported no response by sesame to fertilizer application. Similarly Ashri (1989), FAO (1985, 1981) and Acland (1973) noted that in many trials in many countries, yield responses of accepted sesame varieties to improved growing conditions and higher inputs were disappointing. Osman (1985) in Sudan and Bosnu (1977) in Ghana reported that local cultivars of sesame did not respond significantly to nitrogen application. Phosphorous has also been ineffective in increasing sesame yields (Pineda and Velasquez, 1986; Daulay and Singh, 1982). In contrast, significant response in yields to increasing levels of nitrogen and phosphorous has been reported by many investigators in countries outside Africa (Sarma, 1994; Itnal *et al.*, 1993; Darwati *et al.*, 1990; Deshmukh *et al.*, 1987; Prakasha and Thimmegodwa, 1987; and Puste and Maiti, 1986). Pineda and Velasquez (1986) observed an increase in yield by sesame in response to nitrogen but not phosphorous. Similarly an increase in dry matter of sesame was observed with increasing nitrogen (Samui *et al.*, 1986). Sinharoy *et al.*, 1990 and Majumdar *et al.*, 1987 observed positive response of sesame yield components; plant height, number of capsules and number of primary branches to nitrogen and phosphorous. Most of the results were obtained from

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The lack of response of sesame to FYM applied at planting and N and P application in field trials at Kibwezi and Siaya over two seasons could be due either to low yield potential of local landraces or due to improved nutrient uptake through mycorrhizal infection of the sesame roots or both factors combined.

These results are consistent with others recently reported from Siaya (Ayiecho and Nyabundi, 1995; Odeny *et al.*, 1994). Omran *et al.* (1985) and Osman (1985) observed that most major sesame producing countries in Africa have reported no response by sesame to fertilizer application. Similarly Ashri (1989), FAO (1985, 1981) and Acland (1973) noted that in many trials in many countries, yield responses of accepted sesame varieties to improved growing conditions and higher inputs were disappointing. Osman (1985) in Sudan and Bosnu (1977) in Ghana reported that local cultivars of sesame did not respond significantly to nitrogen application. Phosphorous has also been ineffective in increasing sesame yields (Pineda and Velasquez, 1986; Daulay and Singh, 1982). In contrast, significant response in yields to increasing levels of nitrogen and phosphorous has been reported by many investigators in countries outside Africa (Sarma, 1994; Itnal *et al.*, 1993; Darwati *et al.*, 1990; Deshmukh *et al.*, 1987; Prakasha and Thimmegodwa, 1987; and Puste and Maiti, 1986). Pineda and Velasquez (1986) observed an increase in yield by sesame in response to nitrogen but not phosphorous. Similarly an increase in dry matter of sesame was observed with increasing nitrogen (Samui *et al.*, 1986). Sinharoy *et al.*, 1990 and Majumdar *et al.*, 1987 observed positive response of sesame yield components; plant height, number of capsules and number of primary branches to nitrogen and phosphorous. Most of the results were obtained from

experiments conducted with different sesame cultivars that had probably been previously selected from local strains or landraces.

Soil analysis from the sites showed that N levels were low whereas P levels were moderate (Appendix 5) but the lack of response to nitrogen and phosphorous application would suggest that these levels were adequate for the sesame variety or that sesame has other means of obtaining these nutrients.

The cultivar used in this experiment was by no means a pure line as shown by the variety of phenotypic characteristics observed in the field, namely; stem and capsule colour, locule number, seed colour and number of capsules per axil. Weiss (1971) suggested that landraces developed under low management, low input conditions may not respond to fertilizer but improved varieties capable of high yields will need additional nutrients to optimise returns. He further stated that a local sesame strain is often well adapted to specific local conditions which if altered, necessitates the need to select another strain which is more capable of taking advantage of the new situation. This is supported by the suggestion of several authors (e.g. Ashri, 1989, 1985 and Rajan, 1981) that the genetic variability for yield improvement in sesame has been exhausted through selection under low inputs and therefore increases in yield will be achieved through controlled crosses designed to create new and increased variability.

Analysis on sesame roots collected from fields in Siaya showed high levels of VAM fungal infection (more than 90%/cm of root). Sesame root infection by VAM fungi has also been demonstrated by other workers (Sulochana and Manoharachary, 1990; Sulochana *et al.*, 1989; Vijayalaskshmi and Rao, 1988; and Girijia and Nair, 1985). The phenomenon that VAM infection may increase growth of the host plants especially when the nutrient supply in the soil is low, is almost universally accepted (Dubey, 1993; Sulochana *et al.*, 1989 Yost and Fox, 1979; Sanders and Tinker, 1973; Voggo, 1971 and Harley 1960b).

Some authors however contend that this is only true for plants grown in soils low in phosphorous (Mason *et al.*, 1991; Marschner, 1986 and Yost and Fox, 1979). It is also well established that tissue concentrations of minerals such as nitrogen, phosphorous and others is higher in mycorrhizal than in non-mycorrhizal plants, and that the main advantage of mycorrhizal infection over non-infection is the improved uptake efficiencies of nutrients from the soil. Stribley *et al.*(1980) suggested that increased carbohydrate utilization together with increased phosphate uptake in mycorrhizal plants means that these plants are carbon limited hence higher tissue mineral concentrations. Probably this explains why increase in the level of nutrients N and P did not significantly affect growth. It explains the ability of VAM infected plants exposed to lower levels of phosphorous and nitrogen to exploit soil regimes of lower nutrient levels which would normally be out of reach of non-mycorrhizal plants. Harley and Smith (1983) maintained that the importance of mycorrhizal infection to a particular variety or species host plant may depend on the phosphate concentration in the soil, the net affinities of root and fungal systems for phosphate and the phosphate requirement of the host. Low yield potential of sesame and infection of roots by VAM fungi could be the reason for lack of response to nitrogen and phosphorous of sesame grown in pots of unsterilized field soil from Siaya. Mycorrhizal infection of these roots was accompanied by higher growth and shoot biomass results obtained in pots with unsterilized soil as compared to acid washed sand and steam sterilized field soil. Dubey (1993) found that soybean plants arising from seed inoculated with mycorrhizal fungi had higher dry weight (DW), pods/plant and higher seed N and P contents than the uninoculated controls. Similarly, Sinharoy *et. al.* (1990) isolated seven strains of VAM fungi from field grown sesame and found four test cultivars of sesame to have enhanced growth as compared to their non mycorrhizal counterparts. Enhanced growth of host plants due to mycorrhizal

infection has been elaborately demonstrated in the preceding sections. Biomass results indicated higher shoot dry matter (DM) at any given level of N in sterilized soil than in unsterilized soil and acid washed sand (Table 12b). Similar observations were made by Abbot and Robson (1977) using P, where they found that in autoclaved soil but not in unsterilized soil, non-mycorrhizal subterranean clover showed higher shoot DM at a given level of P than mycorrhizal clover. According to Abbot and Robson (1977) the mycorrhizal response was eliminated by the addition of phosphate thus indicating that the response to N was linked to phosphate nutrition.

In sterilised soil, infection by VAM fungi was low. The significant growth response to nitrogen and phosphorous nutrition in the sterile media (acid washed sand and sterilized field soil) indicate that sesame responds to N and P application. However when grown in unsterilised soil it obtains its nutrient requirement from VAM fungi.

Growth was higher in the sterilised soil than in sand though both had non-mycorrhizal plants. Sand generally has a poor water and nutrient holding capacity than clays, silts and loams. The field soil retained more of the nutrients supplied and the sesame plants were able to use them over a longer period. In addition the field soil though sterilized, had higher nutrient content (moderate) as compared to acid washed sand whose nutrient content was negligible. This is particularly true of essential nutrients other than N and P which were tested. Sesame plants in the soil thus had more complete nutrient environment to exploit and as such, even earlier in the season they showed superior growth than those in sand media.

Throughout the growing season sesame grown in the sand media were shorter than those grown in soil media. Avnimelech and Scherzer (1972) reported that the level of phosphorous available to radish and lettuce plants during the first few days of growth was found to be critical for proper

growth up to maturity and the change induced by deficiency, inhibit growth even if phosphorus is supplied later. In the soil media phosphorous was available right from the beginning of the experiment hence the plants responded normally when phosphorous was added later. In the sand however inadequate amount of phosphorous (due to rapid percolation into the sand) during early days of growth may have inhibited normal growth response when phosphorous was later added in greater amounts as shown by the growth values for sand grown plants. Biomass showed interaction of N and P to be significant. There was significant response to P at all levels while N response was only significant at the highest levels of P. This indicated that nitrogen nutrition of the plants were probably limited by P availability.

CONCLUSIONS

The application of nitrogen and phosphorous fertilizers and farmyard manure did not significantly affect sesame growth and yield of a local sesame landrace grown in the field at Kibwezi and Siaya over two seasons. Application of nitrogen and phosphorous fertilizer or farmyard manure to local landraces of sesame under field conditions is therefore not beneficial.

Sesame grown at Kibwezi and Siaya were found to have heavy root mycorrhizal infection.

The application of nitrogen and phosphorous nutrients to potted plants grown in unsterilized field soil did not significantly affect sesame dry weight. Nitrogen and phosphorous, however, significantly affected growth of sesame in both acid washed sand and sterilised soil.

Mycorrhiza infected plants showed higher growth than non-mycorrhizal plants.

Sterilised soil also gave higher plant growth than acid washed sand.

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Mycorrhiza infected plants showed higher growth than non-mycorrhizal plants.

Sterilised soil also gave higher plant growth than acid washed sand.

RECOMMENDATIONS

1) Improved cultivars should be tested to determine their response to fertilizer application.
2) Further experiments should be carried out to investigate factors other than mycorrhizal infection which may be inhibiting/masking sesame response to fertilizer application, e.g. root exudates or free living soil microorganisms.
3) Mycorrhizal studies should be carried out so as to compare:

   a) Unfertilized mycorrhizal plants against fertilized mycorrhizal plants to determined whether it is optimal to fertilize or to inoculate the plants for best performance.

   b) The effect of mycorrhizal infection on different organs of the plant during its growth period and the final effect of infection on yield.

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APPENDICES

Appendix 1. Assessment of mycorrhizal infection.

The following technique has been adopted by the AMSAL project for selecting a random sample of root fragments for assessment of mycorrhizal infection.

Randomised sampling of root fragments

1. Carefully wash the entire root system, taking care not to damage the fine roots, then cut it up into 1 cm fragments.

2. Place all the fragments in a shallow sampling tray which has been previously marked with 100 dots at random. Mix the fragments well, after adding a small amount of water to aid dispersal. Then select the sample of 100 fragments by removing the fragment (irrespective of its length) which lies closest to each of the 100 dots. Place the selected roots in a small Petri dish. THIS IS THE SAMPLE.

If less than 100 fragments are present (i.e. if the root system is small), select half the fragments in the dish.

3. For weighing, collect the roots which remain in the tray - pour off excess water through muslin and collect together the roots which remain in the tray and those in the muslin. Place in a covered Petri dish. THIS IS THE REMAINDER.

4. Place both the sample and the remainder of the root system, separately on filter paper and gently blot to remove excess moisture. Then place in pre-weighed aluminium foil pouches to obtain fresh weights.

5. Then oven dry the remainder of the root system in a labelled envelope (80°C for seven days). Then weigh to obtain fresh weight.

6. Place the roots sample in a McCartney bottle with a little water to prevent dehydration and store at 4°C.

7. When a number of sample have accumulated, clear and stain them according to the technique described below.

8. After clearing and staining, the fungal tissue appears blue within the cleared plant tissue (which does not retain the stain). Assess total root length and length of infection by the gridline intersect method using a 1.2. cm grid

9. The dry weight of the total root system can be estimated from the ratios of the fresh and dry weights of the remainder of the root system and the fresh weight of the sample.

Staining techniques for assessing mycorrhizal infection in roots

1. Drain off any water and cover roots with 2.5% KOH solution and autoclave at 121°C and pressure of 1.03 x 10^{5}N m^{-2} (15 psi) for three minutes to remove the majority of pigmentation and break down the cell walls for easier penetration of the following chemicals.

2. Pour off the KOH and rinse roots well in tap water until no further brown colouring appears in the rinse water.

3. Cover roots with alkaline hydrogen peroxide (10 ml of 30% H_2O_2, 3 ml of 30% ammonia solution and 587 ml H_2O) at room temperature for 10-20 minutes or until the roots become bleached. Hydrogen peroxide deteriorates quickly and so must be made up immediately prior to use.

4. Rinse in tap water to remove excess reagent.

5. Cover with 1% HCI for about an hour.

6. Pour off HCI but do not rinse, as specimens must remain acidified to accept the stain in the next stage.

7. Cover with 0.05% Trypan blue in acidic glycerol (500 ml glycerol, 50 ml 1% HCI and 450 ml H_2O) and autoclaved at 121°C and pressure of 1.03 x 10^{5} Nm^{-2} for three minutes.

8. Do not rinse the specimens immediately after staining as the stain is n fixed. Leave in the stain for at least 12 hours, after that specimens can b stored temporarily in water, or in acidic glycerol if they are to be kept fo any length of time.

Assessment of mycorrhizal infection

Grid Line Intersect Method

This method basically involves spreading out a root sample onto a petr dish marked with a grid so that no root obscures another.

To estimate total root length of the sample both the horizontal and vertica lines are scanned using a stereo microscope and wherever a root crosses a grid line, this is recorded.

Total root length can then be calculated using the formula:-

$$R_{\text{(total root length)}} = 11/14 \times \text{number of intercepts (N)} \times \text{grid unit}$$

$$R = N \text{ cm}$$

The total number of root intercepts equals the total length of root in cm.

The process is now repeated with the same sample in order to estimate the length of infected root. The horizontal and vertical lines are again scanned but note is only made whenever the root crossing a grid line is infected.

If a 0.5 in x 0.5 in grid is again used the number of intercepts recorded then equals the total length of infected root in cm.

The percentage of root infected can then be estimated:-

$$\frac{\text{Length of infected root}}{\text{total length of root}} \times 100$$

Appendix 2 Rainfall pattern at Kibwezi during the experimental period(mm)

Date	Nov 93	Dec	Jan 94	Feb	Mar	Apr	May	Jun	Jul
1	1.1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	1.3	1.3	-	-	-	-	-	-
4	-	41.3	2.3	-	-	-	-	-	-
5	-	2.6	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-
7	-	29.6	1.5	-	-	-	-	-	-
8	-	4.7	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-
10	3.5	20.1	-	-	-	-	-	-	-
11	-	-	4.6	-	-	-	-	-	-
12	-	2.4	-	5.5	-	-	6.3	-	-
13	-	2.1	-	1.5	-	-	3.2	-	-
14	-	24.8	-	-	-	-	5.0	-	-
15	-	10.7	-	-	-	-	3.1	-	-
16	-	0.3	-	34.6	-	-	3.2	-	-
17	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-
19	-	-	2.5	-	-	-	-	-	-
20	20.7	2.0	-	-	-	10.5	-	-	-
21	5.8	-	-	-	-	-	2.1	-	-
22	19.0	-	-	-	-	-	-	-	-
23	11.7	5.3	-	-	-	-	-	-	-
24	2.8	-	-	-	16.9	-	-	-	-
25	0.2	-	-	-	57.8	8.0	-	-	-
26	-	1.1	-	-	-	7.0	-	-	-
27	-	9.3	-	-	-	-	-	-	-
28	3.7	8.9	-	-	-	-	-	-	-
29	-	-	-		-	-	-	-	-
30	-	-	-		-	-	-	-	-
31		2.5	-		-		-	-	-
TOTAL	6.85	16.9	12.2	41.6	74.7	25.5	22.9	0	0

(Source: Dwa Estate Metrological Station)

Appendix 3 Rainfall pattern at Siaya during the experimental period(mm)

Date	Nov 93	Dec	Jan 94	Feb	Mar	Apr	May	Jun	Jul
1	35.6	44.0	-	-	2.6	-	115.7	-	6.0
2	-	0.6	-	-	-	-	3.5	-	0.3
3	31.6	3.2	-	-	0.2	-	0.5	-	0.5
4	-	10.3	-	-	-	36.3	-	-	0.8
5	70.9	28.8	-	-	2.1	7.8	2.2	-	-
6	-	15.0	-	-	1.9	8.3	5.0	-	0.7
7	-	-	-	-	-	2.5	-		-
8	0.3	1.6	-	-	-	8.3	5.6	8.9	-
9	-	-	-	3.3	-	-	-	-	-
10	21.5	-	2.2	-	-	-	2.1	-	-
11	2.4	-	3.7	0.4	-	8.8	25.3	-	8.6
12	0.9	3.8	-	0.9	-	-	-	-	-
13	-	2.2	-	0.8	0.5	11.2	0.2	-	6.4
14	-	-	-	-	4.8	-	-	-	-
15	-	3.7	-	-	9.3	5.8	0.7	-	7.0
16	-	-	-	-	-	22.2	2.1	-	0.1
17	-	18.3	-	8.8	5.2	-	34.9	1.0	0.2
18	-	-	-	-	28.2	-	-	1.1	1.4
19	-	-	1.3	-	2.6	3.1	-	-	-
20	-	-	-	-	-	21.0	-	5.8	-
21	1.3	-	-	-	-	-	15.0	2.1	-
22	-	-	-	-	1.2	-	-	-	-
23	-	-	4.2	4.2	2.7	-	-	1.4	0.7
24	-	-	-	-	-	10.6	-	-	-
25	-	6.3	-	-	3.0	30.8	23.0	-	-
26	-	-	-	-	1.4	-	-	1.5	5.1
27	6.5	-	28.3	-	-	-	-	-	-
28	7.2	-	-	-	8.6	21.6	9.8	26.4	-
29	14.0	-	-		-	-	0.3	-	-
30	-	-	2.6		-	12.6	-	0.1	1.2
31		-	-		-		-		32.6
TOTAL	192.2	97.8	42.3	18.4	74.3	210.9	245.9	48.3	71.6

(Source: Kadenge Metrological Station)

Appendix 4a Maximum and Minimum temperatures at Kabete during the trial 1 experimental period (°C).

MONTH	APRIL		MAY		JUNE'95	
DATE	max	min	max	min	max	min
1	*	13.4	*	15.6	*	11.6
2	*	14.3	*	14.5	*	14.3
3	*	14.9	*	14.8	*	13.9
4	*	14.9	*	15.0	*	14.2
5	*	15.3	*	13.8	*	11.7
6	*	14.7	*	15.1	*	13.2
7	*	15.3	*	15.6	*	13.5
8	*	14.9	*	15.9	*	12.3
9	*	15.5	*	15.5	*	13.0
10	*	15.6	*	15.0	*	9.1
11	*	14.6	*	14.5	*	10.1
12	*	14.5	*	15.2	*	11.9
13	*	14.7	*	15.1	*	9.5
14	*	15.2	*	15.1	*	9.3
15	*	15.0	*	15.1	*	10.6
16	*	15.2	*	14.3	*	13.3
17	*	14.2	*	14.4	*	13.6
18	*	14.4	*	13.2	*	12.8
19	*	15.2	*	13.7	*	13.9
20	*	14.7	*	14.0	*	12.8
21	*	14.7	*	14.2	*	12.0
22	*	14.2	*	14.3	*	10.2
23	*	14.4	*	14.4	*	9.4
24	*	15.2	*	13.0	*	13.1
25	*	15.7	*	13.4	*	13.1
26	*	14.5	*	13.8	*	12.8
27	*	16.5	*	10.7	*	12.1
28	*	14.4	*	13.5	*	12.4
29	*	16.8	*	11.4	*	13.0
30	*	14.4	*	12.9	*	11.9
31			*	14.2		

* - Data not available.
(Source: Kabete Metrological Station.)

Appendix 4b Maximum and Minimum temperatures at Kabete during the trial 2 experimental period (°C).

MONTH	JANUARY		FEBRUARY		MARCH'96	
DATE	max	min	max	min	max	min
1	24.1	12.0	25.1	12.2	25.0	14.7
2	23.4	13.3	26.6	12.7	26.3	14.5
3	24.3	13.8	25.6	13.7	25.2	13.8
4	24.5	13.8	26.1	13.6	26.0	12.1
5	23.4	14.7	28.1	13.9	23.9	15.0
6	24.3	14.2	23.2	15.4	25.2	12.6
7	24.6	12.8	24.3	14.4	26.5	14.5
8	23.9	14.1	24.6	14.5	25.1	15.7
9	25.4	11.6	24.0	17.4	26.5	15.8
10	24.8	12.8	26.3	12.8	27.4	15.4
11	25.2	14.1	27.7	13.7	25.0	15.0
12	25.6	15.1	25.7	15.2	24.9	15.8
13	25.0	13.1	26.5	12.9	25.3	15.6
14	24.6	13.6	26.9	13.0	25.7	15.0
15	23.5	11.7	27.3	13.5	25.4	16.0
16	25.7	12.2	28.6	15.4	27.7	16.6
17	24.4	15.0	25.8	14.6	26.5	15.6
18	23.7	12.4	24.5	14.8	25.9	15.4
19	24.4	13.1	25.7	14.6	26.9	15.0
20	25.0	12.2	26.2	13.1	25.2	14.4
21	21.8	13.9	26.7	13.9	24.5	15.5
22	22.2	13.2	27.0	13.2	24.2	15.5
23	24.3	11.5	26.7	13.1	24.0	15.0
24	24.7	13.8	26.3	13.7	24.8	14.0
25	24.7	12.7	25.4	14.6	26.1	12.6
26	25.6	11.8	26.0	13.6	26.5	13.0
27	23.4	13.3	25.0	14.4	22.8	14.5
28	24.2	11.7	24.2	12.1	24.9	13.8
29	24.2	13.2	25.0	12.2	23.1	14.4
30	24.8	13.1			23.9	14.7
31	25.0	13.6			23.3	15.4

(Source: Kabete meteorological station)

Appendix 5 Results of the laboratory analysis for nutrients (N and P) of the soil from the experimental sites.

SAMPLE AND SEASON	SIAYA		KIBWEZI	
	Trial 1	Trial 2	Trial 1	Trial 2
pH (In water)	6.15	6.25	8.25	8.01
pH (In 0.01M $CaCl_2$)	5.10	5.14	7.54	7.42
%N	0.12	0.14	0.15	0.10
%C	1.82	1.71	1.62	1.60
K (meq/100g soil)	2.05	2.00	4.00	4.04
Na (meq/100g soil)	0.10	0.10	0.12	0.10
Ca (meq/100g soil)	3.30	3.35	7.00	6.80
Mg (meq/100g soil)	3.62	3.58	4.30	4.33
CEC (meq/100g soil)	9.07	10.03	15.42	16.27
P (ppm)	30.10	28.80	63.70	63.50

The soils were analyzed using the procedures described in Methods of soil Analysis Part 2 (Page *et. al.*, 1986).

Appendix 6a ANOVA Table for plant height (cm) of sesame. Fertilizer experiment, Siaya trial 1

Source	SS	df	MS	F	P
Blocks	144.54	2	72.27	0.37	0.70 ns
Main Effects					
p	583.26	3	194.42	0.99	0.41 ns
n	505.28	3	168.43	0.85	0.48 ns
Interaction					
p x n	1164.29	9	129.37	0.66	0.74 ns
Error	5917.70	30	197.26		
Total	8315.07	47			

Appendix 6b ANOVA table for plant height (cm) of sesame. Fertilizer experiment, Siaya trial 2

Source	SS	df	MS	F	P
Blocks	221.89	2	110.94	2.92	0.07 ns
Main Effects					
p	121.56	3	40.52	1.07	0.38 ns
n	299.20	3	99.73	2.62	0.07 ns
Interaction					
p x n	397.39	9	44.15	1.16	0.35 ns
Error	1141.19	30	38.04		
Total	2181.22	47			

Appendix 6c ANOVA table for plant height (cm) of sesame. Fertilizer experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	671.67	2	335.84	2.07	0.14 ns
Main Effects					
p	550.80	3	183.60	1.13	0.35 ns
n	1039.07	3	346.36	2.13	0.12 ns
Interaction					
p x n	2892.15	9	321.35	1.98	0.08 ns
Error	4875.78	30	162.53		
Total	10029.47	47			

Appendix 6d ANOVA table for plant height (cm) of sesame. Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	38.94	2	19.47	0.16	0.86 ns
Main Effects					
p	154.08	3	51.36	0.41	0.74 ns
n	708.16	3	236.05	1.91	0.15 ns
Interaction					
p x n	1473.93	9	163.77	1.32	0.27 ns
Error	3715.37	30	123.85		
Total	6090.48	47			

Appendix 7a ANOVA table for podding length (cm) of sesame. Fertilizer experiment, Siaya trial 1

Source	SS	df	MS	F	P
Blocks	432.36	2	216.18	1.07	0.36 ns
Main Effects					
p	480.60	3	160.20	0.79	0.51 ns
n	1526.90	3	508.97	2.52	0.08 ns
Interaction					
p x n	1129.54	9	125.50	0.62	0.77 ns
Error	6065.04	30	202.17		
Total	9634.45	47			

Appendix 7b ANOVA table for podding length (cm) of sesame. Fertilizer experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	28.51	2	14.25	0.19	0.82 ns
Main Effects					
p	44.10	3	14.70	0.20	0.90 ns
n	320.06	3	106.69	1.45	0.25 ns
Interaction					
p x n	459.69	9	51.08	0.70	0.71 ns
Error	2204.76	30	73.49		
Total	3057.12	47			

Appendix 7c ANOVA table for podding length (cm) of sesame,Fertilizer experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	70.99	2	35.50	0.42	0.66 ns
Main Effects					
p	134.42	3	44.81	0.53	0.67 ns
n	590.17	3	196.72	2.32	0.10 ns
Interaction					
p x n	1157.94	9	128.66	1.52	0.19 ns
Error	2539.92	30	84.66		
Total	4493.44	47			

Appendix 7d ANOVA table for podding length (cm) of sesame,Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	26.23	2	13.11	0.17	0.85 ns
Main Effects					
p	170.32	3	56.77	0.72	0.55 ns
n	396.05	3	132.02	1.66	0.20 ns
Interaction					
p x n	1060.33	9	117.81	1.49	0.20 ns
Error	2379.70	30	79.32		
Total	4032.62	47			

Appendix 8a ANOVA table for total pods/plant of sesame. Fertilizer experiment, Siaya trial 1

Source	SS	df	MS	F	P
Blocks	46.40	2	23.20	0.06	0.94 ns
Main Effects					
p	188.02	3	62.67	0.15	0.93 ns
n	497.25	3	165.75	0.41	0.75 ns
Interaction					
p x n	4045.01	9	449.45	1.10	0.39 ns
Error	12265.46	30	408.85		
Total	17042.14	47			

Appendix 8b ANOVA table for total pods/plant of sesame. Fertilizer experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	10761.73	2	5380.87	17.29	0.00 ***
Main Effects					
p	1270.60	3	423.53	1.36	0.27 ns
n	454.59	3	151.53	0.49	0.69 ns
Interaction					
p x n	3952.01	9	439.11	1.41	0.23 ns
Error	9335.66	30	311.19		
Total	25774.60	47			

Appendix 8c ANOVA table for total pods/plant of sesame Fertilizer experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	410.87	2	205.44	2.05	0.15 ns
Main Effects					
p	99.60	3	33.20	0.33	0.80 ns
n	434.24	3	144.75	1.45	0.25 ns
Interaction					
p x n	1101.35	9	122.37	1.22	0.32 ns
Error	3000.91	30	100.03		
Total	5046.97	47			

Appendix 8d ANOVA table for total pods/plant of sesame Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	2248.39	2	1124.20	3.69	0.04 *
Main Effects					
p	362.49	3	120.83	0.40	0.76 ns
n	733.97	3	244.66	0.80	0.50 ns
Interaction					
p x n	2910.06	9	323.34	1.06	0.42 ns
Error	9138.74	30	304.62		
Total	15393.65	47			

Appendix 9a ANOVA table for number of podding branches of sesame. Fertilizer experiment, Siaya. trial 1

Source	SS	df	MS	F	P
Blocks	0.52	2	0.26	0.39	0.68 ns
Main Effects					
p	0.59	3	0.20	0.29	0.83 ns
n	1.22	3	0.41	0.61	0.61 ns
Interaction					
p x n	13.10	9	1.46	2.17	0.05 ns
Error	20.08	30	0.67		
Total	35.51	47			

Appendix 9b ANOVA table for podding branches/plant of sesame. Fertilizer experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	7.94	2	3.97	2.61	0.09 ns
Main Effects					
p	5.06	3	1.69	1.11	0.36 ns
n	1.41	3	0.47	0.31	0.82 ns
Interaction					
p x n	9.97	9	1.11	0.73	0.68 ns
Error	45.55	30	1.52		
Total	69.92	47			

Appendix 9c ANOVA table for podding branches of sesame. Fertilizer experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	6.19	2	3.09	9.14	0.00***
Main Effects					
p	0.50	3	0.17	0.49	0.69 ns
n	2.67	3	0.89	2.62	0.07 ns
Interaction					
p x n	5.91	9	0.66	1.94	0.08 ns
Error	10.16	30	0.34		
Total	25.42	47			

Appendix 9d ANOVA table for podding branches of sesame. Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	5.34	2	2.67	3.41	0.05 *
Main Effects					
p	2.03	3	0.68	0.86	0.47 ns
n	4.74	3	1.58	2.02	0.13 ns
Interaction					
p x n	3.20	9	0.36	0.45	0.89 ns
Error	23.52	30	0.78		
Total	38.84	47			

Appendix 10a ANOVA table for yield(kg ha^{-1}) of sesame. Fertilizer experiment, Siaya trial 1

Source	SS	df	MS	F	P
Blocks	16295.03	2	8147.52	1.15	0.33 ns
Main Effects					
p	5133.44	3	1711.15	0.24	0.87 ns
n	24494.28	3	8164.76	1.16	0.34 ns
Interaction					
p x n	51767.01	9	5751.89	0.81	0.61 ns
Error	212043.88	30	7068.13		
Total	309733.64	47			

Appendix 10b ANOVA table for yield (kg ha^{-1}) of sesame. Fertilizer experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	30890.14	2	15445.07	1.21	0.31 ns
Main Effects					
p	14733.62	3	4911.21	0.39	0.76 ns
n	35896.71	3	11965.57	0.94	0.43 ns
Interaction					
p x n	222629.61	9	24736.62	1.94	0.08 ns
Error	381987.47	30	12732.92		
Total	686137.55	47			

Appendix 10c ANOVA table for yield (kg ha^{-1}) of sesame. Fertilizer experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	51489.29	2	25744.64	0.16	0.86 ns
Main Effects					
p	509389.32	3	169796.44	1.03	0.39 ns
n	368482.12	3	122827.37	0.75	0.53 ns
Interaction					
p x n	1230299.47	9	136699.94	0.83	0.59 ns
Error	4926629.65	30	164220.99		
Total	7086289.84	47			

Appendix 10d ANOVA table for yield (kg ha^{-1}) of sesame. Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	93273.46	2	46636.73	1.78	0.19 ns
Main Effects					
p	28526.34	3	9508.78	0.36	0.78 ns
n	48045.11	3	16015.04	0.61	0.61 ns
Interaction					
p x n	100857.56	9	11206.40	0.43	0.91 ns
Error	787411.73	30	26247.06		
Total	1058114.20	47			

Appendix 11a ANOVA table for pod size (cm^2) of sesame. Fertilizer experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	3.16	2	1.58	14.67	0.00 ***
Main Effects					
p	0.24	3	0.08	0.75	0.53 ns
n	0.07	3	0.02	0.22	0.88 ns
Interaction					
p x n	0.74	9	0.08	0.77	0.65 ns
Error	3.23	30	0.11		
Total	7.43	47			

Appendix 11b ANOVA table for pod size (cm^3) of sesame. Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	0.06	2	0.03	0.73	0.49 ns
Main Effects					
p	0.11	3	0.04	0.81	0.50 ns
n	0.14	3	0.05	1.10	0.37 ns
Interaction					
p x n	0.22	9	0.02	0.56	0.82 ns
Error	1.29	30	0.04		
Total	1.82	47			

Appendix 12a ANOVA table for plant height (cm) of sesame. Manure experiment Siaya trial 1.

Source	SS	df	MS	F	P
Blocks	824.68	2	412.34	3.69	0.09 ns
Main Effects					
mnr	297.94	3	99.31	0.89	0.50 ns
Error	670.45	6	111.74		
Total	1793.07	11			

Appendix 12b ANOVA table for plant height (cm) of sesame. Manure experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	313.36	2	156.68	2.34	0.18 ns
Main Effects					
mnr	207.50	3	69.17	1.03	0.44 ns
Error	402.01	6	67.00		
Total	922.86	11			

Appendix 12c ANOVA table for plant height (cm) of sesame. Manure experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	152.37	2	76.19	0.32	0.73 ns
Main Effects					
mnr	227.88	3	75.96	0.32	0.81 ns
Error	1409.17	6	234.86		
Total	1789.42	11			

Appendix 11b ANOVA table for pod size (cm^2) of sesame. Fertilizer experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	0.06	2	0.03	0.73	0.49 ns
Main Effects					
p	0.11	3	0.04	0.81	0.50 ns
n	0.14	3	0.05	1.10	0.37 ns
Interaction					
p x n	0.22	9	0.02	0.56	0.82 ns
Error	1.29	30	0.04		
Total	1.82	47			

Appendix 12a ANOVA table for plant height (cm) of sesame. Manure experiment Siaya trial 1.

Source	SS	df	MS	F	P
Blocks	824.68	2	412.34	3.69	0.09 ns
Main Effects					
mnr	297.94	3	99.31	0.89	0.50 ns
Error	670.45	6	111.74		
Total	1793.07	11			

Appendix 12b ANOVA table for plant height (cm) of sesame. Manure experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	313.36	2	156.68	2.34	0.18 ns
Main Effects					
mnr	207.50	3	69.17	1.03	0.44 ns
Error	402.01	6	67.00		
Total	922.86	11			

Appendix 12c ANOVA table for plant height (cm) of sesame. Manure experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	152.37	2	76.19	0.32	0.73 ns
Main Effects					
mnr	227.88	3	75.96	0.32	0.81 ns
Error	1409.17	6	234.86		
Total	1789.42	11			

Appendix 12d ANOVA table for plant height (cm) of sesame. Manure experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	138.41	2	69.21	0.14	0.87 ns
Main Effects					
mnr	326.79	3	108.93	0.22	0.88 ns
Error	2935.87	6	489.31		
Total	3401.07	11			

Appendix 13a ANOVA table for podding length (cm) of sesame. Manure experiment, Siaya trial 1.

Source	SS	df	MS	F	P
Blocks	91.39	2	45.69	0.29	0.76 ns
Main Effects					
mnr	503.23	3	167.74	1.05	0.43 ns
Error	954.02	6	159.00		
Total	1548.63	11			

Appendix 13b ANOVA table for podding length (cm) of sesame. Manure experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	152.96	2	76.48	0.99	0.43 ns
Main Effects					
mnr	160.78	3	53.59	0.69	0.59 ns
Error	465.33	6	77.55		
Total	779.07	11			

Appendix 13c ANOVA table for podding length (cm) of sesame. Manure experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	573.26	2	286.63	1.83	0.24 ns
Main Effects					
mnr	175.31	3	58.44	0.37	0.78 ns
Error	941.07	6	156.85		
Total	1689.64	11			

Appendix 13d ANOVA table for podding length (cm) of sesame. Manure experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	44.65	2	22.32	0.16	0.86 ns
Main Effects					
mnr	134.32	3	44.77	0.32	0.81 ns
Error	834.15	6	139.02		
Total	1013.11	11			

Appendix 14a ANOVA table for total pods/plant of sesame. Manure experiment Siaya trial 1.

Source	SS	df	MS	F	P
Blocks	607.45	2	303.72	1.18	0.37 ns
Main Effects					
mnr	2844.94	3	948.31	3.70	0.08 ns
Error	1538.83	6	256.47		
Total	4991.22	11			

Appendix 14b ANOVA table for total pods/plant of sesame. Manure experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	658.96	2	329.48	1.07	0.40 ns
Main Effects					
mnr	1519.86	3	506.62	1.64	0.28 ns
Error	1852.55	6	308.76		
Total	4031.37	11			

Appendix 14c ANOVA table for total pods/plant of sesame. Manure experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	161.97	2	80.99	0.35	0.72 ns
Main Effects					
mnr	150.57	3	50.19	0.21	0.88 ns
Error	1402.17	6	233.69		
Total	1714.71	11			

Appendix 14d ANOVA table for total pods/plant of sesame. Manure experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	2519.01	2	1259.50	4.67	0.06 ns
Main Effects					
mnr	2108.04	3	702.68	2.60	0.15 ns
Error	1619.10	6	269.85		
Total	6246.15	11			

Appendix 15a ANOVA table for podding branches/plant of sesame.Manure experiment, Siaya trial 1.

Source	SS	df	MS	F	P
Blocks	0.08	2	0.04	0.05	0.96 ns
Main Effects					
mnr	2.78	3	0.93	1.02	0.45 ns
Error	5.44	6	0.91		
Total	8.30	11			

Appendix 15b ANOVA table for podding branches of sesame. Manure experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	1.13	2	0.56	0.43	0.67 ns
Main Effects					
mnr	6.62	3	2.21	1.67	0.27 ns
Error	7.92	6	1.32		
Total	15.67	11			

Appendix 15c ANOVA table for podding branches/plant of sesame. Manure experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	4.67	2	2.34	5.97	0.04 *
Main Effects					
mnr	1.45	3	0.48	1.23	0.38 ns
Error	2.35	6	0.39		
Total	8.47	11			

Appendix 15d ANOVA table for podding branches/plant of sesame. Manure experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	3.02	2	1.51	1.89	0.23 ns
Main Effects					
mnr	2.22	3	0.74	0.93	0.48 ns
Error	4.79	6	0.80		
Total	10.03	11			

Appendix 16a ANOVA table for yield (kg ha^{-1}) of sesame. Manure experiment Siaya trial 1.

Source	SS	df	MS	F	P
Blocks	10807.44	2	5403.72	0.57	0.59 ns
Main Effects					
mnr	14317.80	3	4772.60	0.50	0.69 ns
Error	56757.68	6	9459.61		
Total	81882.92	11			

Appendix 16b ANOVA table for yield (kg ha^{-1}) of sesame. Manure experiment, Siaya trial 2.

Source	SS	df	MS	F	P
Blocks	68687.30	2	34343.65	3.41	0.10 ns
Main Effects					
mnr	14595.52	3	4865.17	0.48	0.71 ns
Error	60366.79	6	10061.13		
Total	143649.60	11			

Appendix 16c ANOVA table for yield (kg ha^{-1}) of sesame. Manure experiment, Kibwezi trial 1.

Source	SS	df	MS	F	P
Blocks	168935.56	2	84467.78	3.52	0.10 ns
Main Effects					
mnr	43487.53	3	14495.84	0.60	0.64 ns
Error	143831.57	6	23971.93		
Total	356254.67	11			

Appendix 16d ANOVA table for yield (kg ha^{-1}) of sesame. Manure experiment, Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	225.41	2	112.71	0.03	0.97 ns
Main Effects					
mnr	26805.82	3	8935.27	2.76	0.13 ns
Error	19438.48	6	3239.75		
Total	46469.71	11			

Appendix 17a ANOVA table for pod size (cm^2) of sesame. Manure experiment, trial 2.

Source	SS	df	MS	F	P
Blocks	0.01	2	0.00	0.04	0.96 ns
Main Effects					
mnr	0.11	3	0.04	0.63	0.62 ns
Error	0.35	6	0.06		
Total	0.46	11			

Appendix 17b ANOVA table for pod size (cm^2) of sesame. Manure experiment Kibwezi trial 2.

Source	SS	df	MS	F	P
Blocks	0.27	2	0.14	1.08	0.40 ns
Main Effects					
mnr	0.27	3	0.09	0.72	0.58 ns
Error	0.76	6	0.13		
Total	1.30	11			

Appendix 18a ANOVA table for plant height (cm) of sesame at 30 DAE, trial 1, Kabete.

Source	SS	df	MS	F	P
Blocks	7.12	2	3.55	0.06	0.95 ns
Main Effects					
N	590.50	4	147.62	2.31	0.06 ns
P	349.66	4	87.42	1.37	0.25 ns
M	9713.40	2	4856.70	75.95	0.00***
Interaction					
N x P	654.43	16	41.15	0.64	0.84 ns
N x M	1973.58	8	242.20	3.79	0.00***
P x M	104.72	8	13.09	0.20	0.99 ns
N x P x M	1269.69	32	36.68	0.62	0.94 ns
Error	9463.72	148	63.94		
Total	24094.82	224			

Appendix 18b ANOVA table for plant height (cm) of sesame at 37 DAE, trial 1, Kabete.

Source	SS	df	MS	F	P
Blocks	390.59	2	195.29	0.98	0.38 ns
Main Effects					
N	1028.12	4	257.03	1.29	0.28 ns
P	2871.03	4	717.75	3.60	0.01 **
M	29113.58	2	14556.79	73.08	0.00***
Interaction					
N x P	1033.00	16	64.56	0.32	0.99 ns
N x M	3869.78	8	483.72	2.43	0.02 *
P x M	903.163	8	112.90	0.57	0.80 ns
N x P x M	3077.20	32	96.16	0.48	0.99 ns
Error	71768.54	148	199.20		
Total	120470.00	224			

Appendix 18c ANOVA table for plant height (cm) of sesame at 44 DAE, trial 1, Kabete.

Source	SS	df	MS	F	P
Blocks	1649.62	2	824.81	2.32	0.10 ns
Main Effects					
N	2269.20	4	567.30	1.59	0.18 ns
P	4389.22	4	1097.31	3.08	0.02 *
M	58551.35	2	29275.67	82.30	0.00***
Interaction					
N x P	3458.97	16	216.19	0.61	0.87 ns
N x M	12670.31	8	1583.78	4.45	0.00***
P x M	1093.62	8	136.70	0.38	0.93 ns
N x P x M	7499.73	32	234.37	0.66	0.92 ns
Error	52646.72	148	355.72		
Total	144228.72	224			

Appendix 18d ANOVA table for plant height (cm) of sesame at 51 DAE, trial 1, Kabete.

Source	SS	df	MS	F	P
Blocks	4874.62	2	2437.31	3.52	0.03 *
Main Effects					
N	6133.31	4	1533.33	2.22	0.07 ns
P	13188.00	4	3297.00	4.77	0.00 **
M	145965.02	2	72982.51	105.50	0.00***
Interaction					
N x P	6110.07	16	381.88	0.55	0.91 ns
N x M	22659.24	8	22832.41	4.09	0.00***
P x M	5120.08	8	6400.11	0.93	0.50 ns
N x P x M	11917.22	32	372.41	0.54	0.98 ns
Error	102379.22	148	691.75		
Total	318346.58	224			

Appendix 18e ANOVA table for biomass (g/5 plants) of sesame at 51 DAE, trial 1, Kabete.

Source	SS	df	MS	F	P
Blocks	2239.74	2	1119.37	16.08	0.00***
Main Effects					
p	2706.35	4	676.59	9.72	0.00***
n	226.48	4	673.92	0.81	0.52 ns
m	11348.84	2	5673.92	81.50	0.00***
Interaction					
p x n	684.53	16	42.72	0.61	0.87 ns
p x m	750.44	8	93.81	1.35	0.22 ns
n x m	988.30	8	123.54	1.77	0.09 ns
p x n x m	1944.62	32	60.77	0.87	0.66 ns
Error	10303.90	148	69.62		
Total	31190.21	224			

Appendix 19a ANOVA table for plant height (cm) of sesame at 30 DAE, trial 2, Kabete.

Source	SS	df	MS	F	P
Blocks	153.51	2	76.75	0.34	0.72 ns
Main Effects					
p	582.83	4	145.71	0.64	0.64 ns
n	1585.32	4	396.33	1.73	0.15 ns
m	16543.48	2	8271.74	36.11	0.00***
Interaction					
p x n	3136.79	16	196.05	0.86	0.62 ns
p x m	3139.88	8	392.49	1.71	0.10 ns
n x m	766.06	8	95.76	0.42	0.91 ns
p x n x m	5440.86	32	170.22	0.74	0.84 ns
Error	33906.89	148	229.10		
Total	65260.89	224			

Appendix 19b ANOVA table for plant height (cm) of sesame at 37 DAE, trial 2, Kabete.

Source	SS	df	MS	F	P
Blocks	272.68	2	136.34	0.28	0.76 ns
Main Effects					
p	1934.40	4	483.60	0.98	0.42 ns
n	5048.61	4	1262.15	2.56	0.04 *
m	44627.82	2	22313.91	45.33	0.00***
Interaction					
p x n	7226.52	16	451.66	0.92	0.55 ns
p x m	6976.72	8	872.09	1.77	0.09 ns
n x m	2576.31	8	322.04	0.65	0.73 ns
p x n x m	10479.27	32	327.48	0.67	0.91 ns
Error	72852.82	148	492.25		
Total	151995.13	224			

Appendix 19c ANOVA table for plant height (cm) of sesame at 44 DAE, trial 2, Kabete.

Source	SS	df	MS	F	P
Blocks	581.68	2	290.84	0.34	0.71 ns
Main Effects					
p	5625.66	4	1406.41	1.64	0.17 ns
n	6684.81	4	1671.20	1.95	0.10 ns
m	94575.50	2	47287.77	55.31	0.00***
Interaction					
p x n	12173.10	16	760.82	0.89	0.58 ns
p x m	19366.36	8	2420.80	2.83	0.01 **
n x m	7290.78	8	906.35	1.06	0.39 ns
p x n x m	22061.27	32	689.42	0.81	0.76 ns
Error	126536.82	148	854.98		
Total	294856.03	224			

Appendix 19d ANOVA table for plant height (cm) of sesame at 51 DAE, trial 2, Kabete.

Source	SS	df	MS	F	P	
Blocks	2784.60	2	1392.30	1.07	0.35	ns
Main Effects						
p	16546.03	4	4136.51	3.18	0.02	*
n	9980.34	4	2495.10	1.92	0.11	ns
m	173842.03	2	86921.01	66.76	0.00	**
Interaction						
p x n	15967.70	16	997.98	0.77	0.72	ns
p x m	29651.70	8	3706.49	2.85	0.01	**
n x m	28921.94	8	3615.21	2.78	0.01	**
p x n x m	29523.63	32	922.61	0.71	0.87	ns
Error	192698.24	148	1302.02			
Total	499916.23	224				

Appendix 19e ANOVA table for biomass (g/5 plants) of sesame at 51 DAE, trial 2, Kabete.

Source	SS	df	MS	F	P	
Blocks	440.44	2	220.22	0.96	0.38	ns
Main Effects						
p	44140.64	4	11035.16	48.22	0.00	**
n	2457.41	4	614.35	2.68	0.03	*
m	17602.07	2	8801.04	38.46	0.00	**
Interaction						
p x n	6492.65	16	406.79	1.77	0.04	*
p x m	50912.65	8	6364.11	27.81	0.00	**
n x m	5030.78	8	629.85	2.75	0.01	**
p x n x m	4857.23	32	152.80	0.66	0.91	ns
Error	33869.50	148	229.85			
Total	165803.93	224				

Appendix 20a ANOVA table for mycorrhizal infection rate (% infection/cm) of sesame at 51 DAE, trial 1, Kabete.

Source	ss	df	MS	F	P
Blocks	70.70	2	35.35	1.35	0.26ns
Main Effects					
p	76.87	4	19.22	0.73	0.57ns
n	40.92	4	10.23	0.39	0.82ns
m	440378.66	2	220189.30	8380.10	0.00**
Interaction					
p x n	461.87	16	28.87	1.10	0.36ns
p x m	216.64	8	27.08	10.30	0.42ns
n x m	67.26	8	8.41	0.32	0.96ns
p x n x m	850.25	32	26.57	1.01	0.46ns
Error	3888.74	148	26.28		
Total	446051.91	224			

Appendix 20b ANOVA table for mycorrhizal infection rate (% infection/cm) of sesame at 61 DAE, trial 2, Kabete.

Source	SS	df	MS	F	P
Blocks	6.63	2	3.32	0.11	0.95ns
Main Effects					
p	75.14	4	18.79	0.62	0.65ns
n	143.25	4	35.81	1.19	0.32ns
m	457797.03	2	228898.50	7585.74	0.00**
Interaction					
p x n	374.77	16	23.42	0.78	0.71ns
p x m	136.86	8	17.11	0.57	0.80ns
n x m	247.26	8	30.91	1.02	0.42ns
p x n x m	743.07	32	23.22	0.77	0.81ns
Error	4465.87	148	30.17		
Total	463989.89	224			

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