EVALUATION OF SOIL FERTILITY STATUS AND OPTIMIZATION OF ITS MANAGEMENT IN SESAME (*Sesamum indicum* L.) GROWING AREAS OF DODOMA DISTRICT

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

A study was conducted in Dodoma district, Dodoma region Tanzania to assess the soil fertility status for sesame production. The study was initiated due to the continuous decline of sesame yield to alarmingly low levels. The objectives of the study were to determine the levels of N, P, K, S, Mg, Ca, Na, Zn, Cu, Fe and Mn in soils and evaluate the response of sesame crop to the application of N, P, K, S and Zn. This was done by analysing soils from twenty sesame growing areas of Dodoma district. The analysis included determination of total N, OC, P, exchangeable bases and micronutrients, and then field experiments were conducted at two sites located at Makutupora and Hombolo villages. The plant samples were analysed for N, P, K, S, Ca, and Zn. The results of soil analysis indicated that all the soils analysed were deficient in N, about 70% had low available P, 90% had low extractable S and 60% had low Ca levels. Also, most of these soils had low Zn levels and only one site had adequate Zn levels. All the soils had adequate levels of Mg, K, Cu, Fe and Mn. The field experiment showed that application of N, P, K, S and Zn increased nutrient contents in sesame at both sites. However, the deficiency was observed in the absolute control treatments. It was further revealed that combined application of sulphur along with Zn and N, P and K significantly increased seed yield and straw dry yield. Following the results from the field exeriments, it was concluded that most of the soils under sesame production in Dodoma district that were analysed through this study were deficient in N, P, S and Zn. However, in order to optimise production and increase sesame yield, these nutrients (N, P, S and Zn) must be applied at rates of 45 kg/ha, 20 kg/ha, 45 kg/ha and 25 kg/ha, respectively.

DECLARATION

I, Daines Leogin Sanga, hereby declare to the senate of the Sokoine University of Agriculture that, this research and associated outputs are the product of my original work and has never been submitted by anyone before or will be submitted for a degree award to any other University.

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The above Declaration is confirmed

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
C:N Ratio	Carbon Nitrogen Ratio
CEC	Cation Exchange Capacity
COSTECH	Commission for Science and Technology
DMY	Dry Matter Yield
DTPA	Diethylenetriamine pentaacetic acid
FAO	Food and Agriculture Organization
FYM	Farm Yard Manure
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
MoAFC	Ministry of Agriculture Food Security and Co-operatives
OC	Organic Carbon
PR	Phosphate Rock
RAA	Regional Agricultural Advisor
SC	Sandy Clay
SCL	Sandy Clay Loam
SDY	Straw dry yield
SL	Sandy Loam
SUA	Sokoine University of Agriculture
SY	Seed yield
TEA	Triethanolamine
TSP	Triple supperphosphate
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United State Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the most ancient oil crops in the world. It had earned a poetic label “Queen of oilseeds” because seeds have high quality poly-unsaturated stable fatty acids which offer resistance to rancidity. Moreover, sesame is a rich source of edible oil (48 – 55%) and protein (20 – 28%) compared with 20% seed oil in other oil seed crops (FAO, 2001). It is a fairly high value food crop, being harvested both for whole seed used in baking, and for the cooking oil extracted from the seed. Sesame has pronounced antioxidant activity, thereby offering high shelf life, and is also called “seed of immortality”.

Sesame is widely cultivated in tropical and sub-tropical parts of the world. India is the major producer of sesame and ranks first, followed by China, Myanmar and Sudan. Tanzania is the 12th largest producer of sesame in the world, and is the 5th in Africa, after Somalia, Sudan, Uganda and Nigeria. The major producing areas in Tanzania include Mtwara, Lindi, Dodoma and Morogoro regions. It is the second cash crop in importance, after grapevine, in Dodoma region, where it has been seriously cultivated and used since 1990’s (MoAFC Central Zone, 2007). Sesame is gaining considerable importance in Dodoma on account of its economic value, especially its export potential, as a non-traditional export crop.

It is mostly grown as a rain fed crop, due to variation in rainfall pattern, the yield is not stable; hence, the farmers cannot get sustained income. Although sesame is now an important crop in Dodoma, its yield is still very low, about 0.68 t/ha. (RAA Dodoma, personal communication, 2010). This is attributed to several factors including pests and diseases, unimproved low yielding varieties, moisture stress, climate in terms of rainfall and temperature and poor soil fertility and imbalanced nutrition particularly N, P, S and Zn. In addition, several pests and diseases attack sesame, with potential to limit economic production. Some of these pests cause moderate to severe yield losses.

The major diseases are leaf spots, especially under heavy rainfall and humidity. The other common diseases are: Fusarium wilt, bacterial wilt especially when the crop is irrigated. However, these diseases do not cause significant problems in Dodoma since there is no heavy rainfall and the crop is not irrigated. . However the crop is highly resistant to diseases such as leaf spot (*Cercoseptoria sesame*) and stem rot (*Fusarium spp*) diseases.
Sometimes moisture tress can cause low yield of sesame. Sesame requires adequate moisture for germination and early growth. Moisture levels before planting and flowering have the greatest impact on yield (Carlson *et al.,* 2008). However, the crop is very drought-tolerant, due to its extensive root system and good harvests can be obtained when rainfall of 300 – 400mm is optimally spread throughout the vegetation period (Kanyeka *et al.,* 2007). Sesame is well suited to Dodoma climate since; varieties which are of short duration (100 – 105 days) are well introduced (Kanyeka *et al*., 2007).

Sesame production is also affected by climate. Improved varieties of sesame require 90 to 150 frost-free days. Daytime temperatures of 25^{o} C to 30^{o}C are optimal; below 20^{o}C, growth is reduced, and at 0^{o}C germination and growth is inhibited (Ashri, 1998). The minimum temperature for germination is around 12°C, yet even temperatures below 18°C can have a negative effect during germination. Pollination and the formation of capsules are inhibited during heat-wave periods above 40°C (Ashri, 1998). According to Olowe and Busari (2000) regions visited by strong, hot winds, the plants only form smaller seeds with lower oil content. Many research studies conducted in Tanzania indicate that sesame crop is well adapted to Dodoma climate due to its adaptability to harsh climatic conditions including warm and dry conditions (MoAFC Central Zone, 2007).

Another cause of low sesame yield in the world is the use of low yielding varieties. At first farmers fail to attain the optimum yield because of the use of local varieties. Nantongo (2002) revealed that some of the local varieties give yield as low as 107 kg/ha and the highest achieved was only 773 kg/ha in Nigeria. It was also reported in Uganda that; the use of unimproved sesame varieties makes farmers lose up to 60% of potential yield as compared to those who use improved varieties (Anyanga *et al*., 2003).

Improved sesame varieties are suggested to increase yield probably due to their high yield potential and resistance to pests and diseases (Ssekabembe *et al.*, 2002). Nowadays, many sesame varieties are ready introduced in the world market. These include improved varieties with a potential average yield of 1 to 1.2 t/ha (FAO, 1998), and many farmers are using these improved varieties to boost their production and income. Low sesame yields in many areas have been attributed to poor soil fertility and imbalanced nutrition (Ssekabembe *et al.,* 2002; Engoru and Bashaasha, 2001). In any cropping system, adequate soil fertility is a key factor if high yield are to be realized and sustained. Soil fertility has been a limiting factor in crop production in many developing countries (Loneragam, 1997). Sanchez *et al.* (1997) also noted that soil fertility depletion in smallholder farmers is the fundamental biophysical root cause of declining per capita food production in Africa and advised that soil fertility replenishment should be considered as an investment in natural resource capital. In addition, Ssekabembe *et al*. (2002) reported that soil fertility degradation was the most limiting constraint to increased sesame production in many producing areas of the world.

The removal and nutrients export is through harvestable portion unless nutrients removed by the crop are replaced either naturally through weathering or through application of fertilizers. Marschner (1995) noted that to sustain crop yields an equivalent amount of nutrients must be applied in the soil as fertilizers to replace those lost through harvesting and other loses for example leaching and runoff.

Central Tanzania typically comprises of light, sandy soils, which provide suitable physical conditions for sesame growth, but these soils are often poor in fertility and receive low rainfall (FAO, 1998; ICRISAT, 1996). Despite this problem, a study by Budotela (1995) revealed that farmers in some areas of Dodoma district hardly apply FYM or inorganic fertilizers, yet nitrogen and available phosphorous are limited in the soils of the area. Therefore, the fertility of the soils where sesame is grown is generally poor.

Most of the factors that cause low yield of sesame and agronomic aspects have been given emphasis and intercropping, pest and disease control, weed management and planting methods have been addressed. Despite that, over the past five years no yields of over 1t/ha has been recorded in Dodoma region. In fact, yields have been declining to as low as 0.68 t/ha at present (RAA Dodoma personal communication, 2010) (see the production trend in Appendix 1). This trend of declining yield is rationalized largely in terms of poor soil fertility since fertilizer use is very little or not at all. It is evident that soil derived nutrients in the area might have been depleted to the point of limiting yield as there is no substantial replenishment of nutrients in the form of fertilizers. The lack of fertilizer use implies continual nutrients depletion which ultimately leads to decline in crop yields.

Budotela (1995) reported the total N content in three villages in Dodoma district to range from 0.06 to 0.08% which is rated as very low according to Landon (1991). The same study indicated that P ranges between 8.2 and 26.9mg/kg and K ranges from 0.66 to 1.33me/100g which according to Landon (1991) would be rated as medium. However, there are no data on the status of other nutrients such as sulphur and micronutrients such as Zn and Mn which have been reported to limit sesame production in other countries. Therefore, it is important to evaluate their status in the soils of Dodoma district. Sulphur has been included in the analysis because it enhances oil formation in oilseed crops and also plays essential roles in various important mechanisms such as Fe/S clusters in enzymes, vitamin cofactors and glutathione in redox homeostasis and detoxification of xenobiotics (Leustek *et al.*, 2000). Zn has been included in the study because it is the most limiting micronutrient in many soil types especially sandy soils (Marschner, 1995). Increased yields through improved management practices of the crop cannot generally be realized by farmers until soil fertility conditions are also improved. Malik *et al.* (2003) noted that soil fertility management through fertilization is the key in determining yields.

In Uganda, a survey by Tenywa *et al.* (2000) revealed that farmers suggested that inorganic fertilizers could increase sesame yields. Another study in Tororo district in Uganda (Osiru, 1999) showed that there is a very good response of pure stand of sesame to NPK fertilizers. Another study in India revealed that the combined application of $ZnSO_4$ at 25 kg/ha + $MnSO_4$ at 5 kg/ha was significantly superior to the treatment receiving NPK alone in enhancing the growth, yield and nutrient uptake of sesame (Chaplot *et al.* (1992). The same study reported that seed and stover yields of 794 and 2 299 kg/ha, respectively, were recorded with the treatment involving soil application of NPK + Zn + Mn in comparison with 540 and 1 223 kg/ha in the control.

The study by Devakumar and Giri (1998) revealed that application of sulphur significantly influenced the yield components in sesame. Similar results were reported by

Subramaniyan *et al.* (1999) on application of S at 45 kg/ha, resulting in higher number of seeds per capsule. Enhanced performances of reproductive parameters was due to the role of S in increased absorption of nutrients and also due to higher rate of assimilate partitioning towards the sink.

Soil fertility management approaches in sesame production in Dodoma district have not been thoroughly studied. It was therefore, necessary to undertake this study to assess the soil fertility status of sesame growing areas of Dodoma district and develop the optimum nutrient combinations for the optimal production of sesame in the district.

The specific objectives of this study were to:

(i) Determine the levels of N, P, K, S, Mg, Ca, Zn, Cu, Fe and Mn in soils of sesame growing areas of Dodoma district.

(ii) Evaluate the response of sesame to application of N, P, K, S and Zn.

(iii) Determine contents of N, P, K, S and Zn in plant samples.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Plant Description

Sesame [*Sesamum indicum* (L.)] is a broadleaf plant that grows to a height of about five to six feet depending on the variety and growing conditions (FAO, 1998; ICRISAT, 1996). Large, white, bell-shaped flowers, each about an inch long, appear from leaf axils on the lower part of the stem, then gradually extend upwards over a period of weeks as the stem keeps elongating. Depending on the variety, either one or three seed capsules will develop at each leaf axils.

Seed capsules are 2 to 4cm long, with eight rows of seeds in each capsule. Some varieties are branched, while others are un-branched (FAO, 1998). The light colored seeds are small and flat, with a point on one end. According to FAO (2001), seed size varies. Since the flowering occurs in an indeterminate fashion, seed capsules on the lower stem are ripening while the upper stem is still flowering. The lowest flowers on a stem may not develop into pods, but pods will generally begin 30 to 60cm off the ground and continue to the top of the stem (ICRISAT, 1996; FAO, 1998).

Sesame is a short season crop, taking about 100 to 110 days from planting to maturity (FAO, 2001). If planted in late December, leaf drop will usually occur in mid April, and the stem will begin drying down. Plants stand upright reasonably well with sturdy stems, but strong winds can force the plant into a leaning position late in the season.

2.2 Diversity of Sesame Growing Areas

2.2.1 Climatic condition

Improved varieties of sesame require 90 to 150 frost-free days (Ashri, 1998). Daytime temperatures of 77^{o}F (25^{o}C) to 80^{o}F (26.7^{o}C) are optimal, below 68^{o}F (20^{o}C) growth is reduced, and at 50^{o}F (0^{o}C) germination and growth is inhibited. Sesame is very drought-tolerant, due in part to an extensive root system (Carlson *et al.,* 2008). However, it requires adequate moisture for germination and early growth.

A minimum rainfall of 300 – 400 mm per season (Carlson *et al.*, 2008) is necessary for optimum yields of 0.9t/ha. Moisture levels before planting and flowering have the greatest impact on yield. Sesame does not tolerant to water-logging. Rainfall late in the season prolongs growth and increases shattering losses. Wind can cause shattering at harvest and is cited as one reason for the failure of commercial sesame production in France.

Sesame is sensitive to photoperiod, it is a short-day plant, whose flowering is initiated by day length shortening till it reaches a critical level but varies among varieties. The oil content of the seed tends to increase with increased photoperiod. Because protein content and oil content are inversely proportional, seed with increased oil content has decreased protein content (Ashri, 1998).

2.2.2 Soils and soil fertility

Soil is the common medium for sesame growth. In the production of good quality sesame, both physical and chemical properties of soils are important as far as sesame plant growth and productivity are concerned (Ashri, 1998). Sesame is adaptable to many soil types, but it thrives best on well-drained, fertile soils with neutral pH. It has an extensively branched feeder root system and appears to improve soil structure. Like most alternative crops, sesame's fertility needs are modest.

Nitrogen should be supplied at 27.3kg to 41.0kg/ha with the lower figure for situations where the sesame follows soybeans or another legume in the rotation. The nitrogen requirement of sesame can be met through organic sources, such as leguminous cover crops or animal manure. Phosphorous and potassium needs are not known exactly, but should be comparable to millet or sorghum. Sesame prefers neutral to slightly alkaline pH with moderate fertility. Sesame does not thrive well in heavy clay soils or irrigation water containing high concentrations of salts (Carlson *et al.*, 2008).

2.2.3 Soil texture

Soil texture is an important factor in sesame cultivation as it influences transmission and storage of water, flow of air in soil and capacity of nutrient supply. According to Carlson *et al.* (2008), sesame will perform best on well-drained soils of medium texture such as sandy clay loams. It is adapted to sandy loam soils, provided there is adequate moisture during seedling establishment. It has been grown satisfactorily on silty clay loam soils, but soil crusting can be a problem in establishing sesame when clay content is higher. Ashri (1998) reported that soils ranging from moderately acidic - neutral pH (5.5 and 7.0) are recommended.

2.3 Critical Levels of Nutrients in Soils

The critical levels can be used as approximate lines separating sufficient and deficient levels of a given nutrient (Landon, 1991). Soil test levels above the critical concentrations indicate a low probability of crop response to fertilizer applications of that nutrient. For instance, if N found in a soil test is greater than 10 ppm NO_3^-, this would simply indicate a sufficient level of soil N for crop establishment. Additions of N fertilizer will commonly be required with split in-season applications depending on actual crop conditions. For the other nutrients listed, the critical levels can serve as general indicators of season-long crop nutrient needs.

For soils that have nutrient concentrations below the critical levels, additional amounts of that nutrient provided to the crop through fertilization is recommended. Actual amounts of fertilizer forms of the nutrients needed depend on several factors including the degree of deficiency detected and the form of fertilizer being used. In cases where the nutrient levels in the soil are close to the critical levels, crop response may be positive to fertilization. For the case of total sulphur, if a soil contains < 200 ppm deficiency is likely to happen. For available sulphur if it contains < 3 ppm while for extractable sulphur the upper limit for expected response is 6 – 12 ppm. Details for critical levels of nutrients in soils are given in Appendix 2, as well as critical limits for DTPA-extractable micronutrients.

2.4 Nutrients Requirement of Sesame

Like all other green plants with a root system, sesame obtains its nourishments from the soil (Mengel and Kirkby, 1987). Most soils contain all the nutrient ingredients in large quantities than are required by sesame with the exception of N, P and K. According to Olowe and Busari (2000), nutrient requirements for sesame are similar to those of millet: 60 kg N/ha, 45 kg P_2O_5/ha (20 kg P/ha) and 22 kg K_2O/ha (18kg K/ha). The pH values of 5.6 or above and C: N ratios above 10 are satisfactory.

The reported root feeding zone for sesame is within 10 – 30 cm deep. At this depth the exchangeable bases should be greater than 0.5 me/100g for optimum growth (Landon, 1991). A study in Ghana indicated that incremental application of NPK up to 89 kg/ha significantly increased the average sesame seed yield and this seems to be the optimum level as further increase reduced yield perhaps due to an increase in vegetative growth. Similarly, increasing N and P levels to 90 kg N/ha and 60 kg P_2O_5 /ha respectively, reduces grain yield (Taylor *et al.*, 1986).

Channal *et al.* (1981) reported significant improvement in the growth and yield characters as a result of phosphorus application probably because of the role of P in root development which in turn plays a very important role in the uptake of moisture and nutrients. The response of plant number of leaves, number of pods, seed yield and dry matter yield were significant up to 45 kg P/ha rate. The significant response of leaves, number of pods and seed yield to P application obtained in this study were corroborated by reports of Deshmuhk *et al.* (1990). The significant response of such growth parameters of sesame were recorded in number of leaves and pods as a result of K application. Similarly, Ghosh *et al.* (2002) in India (West Bengal) reported that K had significant influence on the growth parameters such as number of branches, number of capsule and seed yield. Further, the favorable influence of K on these yield attributes helped to increase seed yield and oil content. The highest oil content of 44.25% was observed with K application of 80 kg K_2O/ha. However, this result is contrary to the findings of Weiss (2000) who reported that K is often applied as a compound mixture not because it is required by sesame but can be necessary to maintain nutritional balance where substantial amounts of N and P are applied.

2.5 Sesame Response to Nutrient Application

2.5.1 Nitrogen

Sesame is highly responsive to fertilizer, especially to nitrogen. Even then farmers apply inorganic fertilizers. Adequate application of nitrogenous fertilizers not only improves the crop yield but also maintains soil N status and thus sustains productivity. The response of sesame to N fertilizers varied from 20 to 90 kg/ha under different soil conditions. Each successive increase in N level up to 90 kg/ha increased the various growth parameters viz. plant height, number of branches and dry matter production.

2.5.2 Phosphorus

Phosphorus has been observed to have profound effects on sesame growth and yield. A study in Uganda demonstrated that the application of P fertilizers to sesame increased dry matter and seed yields of sesame which is in agreement with the findings of (Taylor *et al.*, 1986; Schilling and Cattan, 1991; Malik *et al.*, 2003 and Okpara *et al.*, 2007). A study in Mubi, Adamawa State University in Nigeria, observed the increase of seed yield linearly from increased P rates. Seed yield increases were 46% to 86% at 22.5 and 45 kg P_2O_5/ha fertilization, respectively, (Okpara *et al.*, 2007).

2.5.3 Potassium

K nutrition has been reported to increase grain yield of sesame (Dasamahapatra *et al.*, 1990). Results obtained from studies in Nigeria indicated that there was correlation between the levels of K and yield of sesame. Similarly, Ghosh *et al.* (2002) in India (West Bengal) reported that K had significant influence on the growth parameters such as number of branches, number of capsule and seed yield. Further the favourable influence of K on these yield attributes helped to increase seed yield and oil content. The highest oil content of 44.25% was observed with K application of 80 kg K_2O/ha. In the same country another study under rain fed conditions application of K fertilizer at 20 kg K_2O ha^{-1} resulted in highest yield of sesame (Krishnegowda and Krishna, 1977).

2.5.4 Sulphur

Sulphur requirement of sesame is equal to that of phosphorus (Reddappa, 1981). The response of sesame to S for producing high yield ranges between 40 kg/ha (Nagavani *et al.,* 2001; Kathiresan, 2002) and 50 kg/ha (Sarkar and Banik, 2002). It was observed that application of S significantly increased the number of capsules per plant in main stem, primary branches and secondary branches. Similar results were reported by Subramaniyan *et al.* (1999) in India. Among the different S levels, application of S at 45 kg/ha recorded higher number of capsules per plant. Beyond this level, there was a decline in the number of capsules per plant. The possible reason for this kind of result may be due to the nutritional imbalance caused by the highest level of S, i.e. 60 kg/ha. The promising performance in producing higher number of capsules per plant was well-established through the study of Govindarasu *et al.* (1998).

In the same study, a positive relationship was observed between the levels of sulphur and the number of seeds per capsule. Among the different S levels, application of S at 45 kg/ha recorded higher number of seeds per capsule. Enhanced performances of reproductive parameters was due to the role of S in better absorption of nutrients and also due to higher rate of assimilate partitioning towards the sink. These findings are in conformity with those reported by Subramaniyan *et al.* (1999), who observed that the application of sulphur significantly influenced the yield components in sesame.

2.5.5 Zinc and manganese

The response of sesame to zinc and manganese fertilizers has been reported in all agricultural environments. The effect of zinc and manganese may range from complete failure to a significant reduction of yield (Kapur *et al.,* 1986). Zinc and manganese resulted in yield increases both under low and high yielding situations. The results of a study in India revealed that the combined application of $ZnSO_4$ at 25 kg/ha + $MnSO_4$ at 5 kg/ha was significantly superior to NPK treatment in enhancing the growth, yield and nutrient uptake of sesame (Chaplot *et al.,* 1992).

Micronutrient applications significantly increased yield components, viz. number of capsules per plant and number of seeds per capsule. The combined application of Zn and Mn in soil produced the highest number of capsules per plant and number of seeds per capsules. The beneficial influence of micronutrients might be due to the activation of various enzymes and the efficient utilization of applied nutrients resulting in increased yield components (Tiwari *et al.,* 2000; Shanker *et al.,* 1999). Seed and stover yields of 794 and 2 299 kg/ha, respectively, were recorded with soil application of Zn + Mn in comparison to 540 and 1 223 $kgha^{-1}$ in the control treatment. This represented an increase of 47 and 53 per cent over the control treatment. The application of Zn alone as foliar or soil increased the yield in the range of 592 to 611 kg/ha and Mn alone in the range of 602 to 684 kg/ha.

The combined application recorded a yield range of 749 to 794 kg/ha. The positive response of sesame to Zn and Mn application was due to increased growth and yield components as well as an increased availability and better uptake of these nutrients. The study clearly indicated that the application of the recommended dose of NPK along with soil application of $ZnSO_4$ at 25g/ha + $MnSO_4$ at 5g/ha would be beneficial for increasing the productivity of sesame.

2.6 Importance of Sulphur on Growth and Yield of Oil seeds.

In addition to nitrogen, another major nutrient which has been reported to have multiple roles in oilseed crop nutrition is sulphur. As such, sulphur deficiency in soils where these crops are raised is considered a major factor responsible for low oilseed production. Several authors are of the opinion that oilseeds not only respond to applied S but their requirement for sulphur is also the highest among crop plants. Further, low availability of S in soil limits N use efficiency (Leustek *et al.,* 2000). Sulphur is one of the six macronutrients needed for proper plant development, particularly for oil seeds crop (Hell, 1997). Even if sulphur is only 3% to 5% as abundant as nitrogen in plants, it plays essential roles in various important mechanisms such as Fe/S clusters in enzymes, vitamin cofactors, glutathione in redox homeostasis and detoxification of xenobiotics (Leustek *et al.,* 2000).

Sulphur is taken up from the soil by plants in form of sulphate by specific transporters. This sulphate is then reduced to be incorporated in cysteine and in methionine. Organically bound sulphur is mainly reduced to sulphide, but oxidised sulphur is also found in plants, a good example being the sulpholipids of the chloroplast membranes (Hell, 1997). Reduced sulphur incorporated in cysteine and methionine amino acids plays essential roles in catalytic centers and disulphide bridges of proteins (Hell, 1997). Sulphur increases the oil content and gives pungency to oil as it forms certain disulphide linkages.

Yadav and Harishankar (1980) reported that oil yield was significantly influenced by S application. The application of S at 45 kg/ha registered the higher oil yield of 299.6 kg/ha.

The higher oil yield of 305 kg/ha was registered at 60 kg S/ha. Full utilization of carbohydrate for the synthesis of oil with sulphur might have increased oil yield. Oil seed crops require more sulphur than cereal as their oil storage organs are mostly proteins rich in sulphur. Deficiency of sulphur is known to limit N metabolism in plants as well as synthesis of S-containing amino acids and thus exerts adverse effect on both seed and oil yields.

In many studies the application of 60 kg S/ha recorded the highest plant height of 140.9 cm among the S levels. Plant height at harvest stage increased with increased S levels. This might be due to more synthesis of amino acids, increase in chlorophyll content in growing region and improving the photosynthetic activity, ultimately enhancing cell division and thereby increasing the crop growth rate (Intodia and Tomar, 1997; Dubey and Khan, 1993). The study of Govindarasu *et al.* (1998) revealed that S significantly increased the number of capsules per plant in main stem, primary branches and secondary branches. Similar results were reported by Subramaniyan *et al.* (1999). Among the different S levels, S at 45 kg ha^{-1} recorded higher number of capsules in main stem, primary and secondary branches per plant. Beyond this level, there was a decline in the number of capsules per plant. The possible reason for this kind of result may be due to the nutritional imbalance caused by the highest level of S, i.e. 60 kg/ha.

2.7 Factors Affecting Fertility Status of the Soil

2.7.1 Soil pH

The soil reaction is among the most important factors controlling the behaviour of mineral nutrients in soil (Alloway and Ayres, 1990). As pH decreases (acidic condition) the solubility of micronutrient such as Fe, Mn, Al, Cu and Zn increases, with the exception of Mo which decreases with decrease in pH. Depending on the levels of the soil acidity, micronutrients solubility may increase to toxic levels which may affect plant growth and include nutrient imbalances (Alloway and Ayres, 1990).

In several studies, significant negative correlation between the concentrations of micronutrients and pH has been reported (Bhandari and Randhawa, 1985; Chibba and Sekhon, 1985; Dhane and Shukla, 1995). The availability of P and bases, namely Mg, K and Ca is significantly impaired under low pH (Wilson, 1969). Phosphorus deficiency in acidic soils is due to the activity of Al and Fe with the consequent formation of insoluble complexes with P (Chibba and Sekhon, 1985).

On the other hand, at soil pH above eight Ca activitiy increases and thus reacts with P to form calcium triphosphate which is an insoluble compound (Brady, 1996). Wilson (1969) suggested the optimum pH for East African soils to be 5.6 for oilseeds production at which minimum P fixation was observed with relatively good supply of bases for the growth of the oilseeds plant. In other studies, several workers reported low pH values <5.6 in sesame growing soils of the world (Othieno, 1973; Dey, 1969).

2.7.2 Soil organic matter

Organic matter is a large reservoir of essential plant nutrients in soils (Wilson, 1969). The contribution of organic matter to plant growth is due to its positive chemical, biological and physical properties of the soil. Many micronutrient cations are strongly adsorbed by the soil organic matter. Fulvic acid tends to form complexes (chelates) with Fe^{3+} , Cu^{2+}, Zn^{2+}, Al^{3+}, Mn^{2+} and other polyvalent cations (Doran and Smith, 1987). These complexes shield the cations from hydrolysis and precipitation reactions as a result improving their availability in alkaline soils and decrease their toxicity in acidic soils. Several workers have reported positive and high correlations between DTPA extractable micronutrients

(Zn, Mn, Cu and Fe) and organic carbon (Bhandari and Randhawa, 1985; Chibba and Sekhon, 1985).

In other studies, negative significant correlation between DTPA-extractable Mn and organic carbon (r= -0.26) and non-significant correlation between Cu, Zn and other soil properties (pH, organic carbon, $CaCO_3$) and CEC have been reported (Vadivelu and Bandyopadhyay, 1995). A negative correlation (r= -0.23) between DTPA-extractable Fe and organic carbon was recorded at Rajasthanin India (Hazra and Biswapati, 1988).

2.7.3 Nutrient interactions

The availability of one nutrient may affect the availability and uptake of the other nutrient. Several studies have revealed that the availability of nitrogen improved the availability of phosphorus and vice versa (Mengel and Kirkby, 1987). A study on the effect of various fertilizers on the leaf nutrient content of corn plant showed a decrease in the level of K and Mg with higher application of nitrogen (Burgess, 1992). Similar results have been reported in Kenya by Owuor and Wanyoko (1991). In the same study, high levels of N fertilizers caused reductions in Mg, Mn, Zn and Cu contents in soils.

2.7.4 Environmental factors

Temperature and moisture within acceptable ranges will have an influence on the biochemical activities of the plant cells and the availability and uptake of the nutrients by the plant (Bonheure and Wilson, 1992). For example soil temperature and moisture control the availability and uptake of N, P, Ca and Zn. Moisture stress is often associated with deficiencies of phosphorus and calcium and may affect the uptake of these nutrients during the dry season (Mengel and Kirkby, 1987). The soil temperature plays a great role in nutrient content as leaf N content tends to be lower during the cool season (Tolhurst, 1971).

2.7.5 Soil type

Levels of nutrients may differ from one soil type to another. Soils inherit different minerals from their parent materials. These minerals have a wide variety of the chemical composition and a wide range of weathering rates (Trohel and Thompson, 1993). Total zinc content in basic eruptive rocks (basalt and gabbro) ranges from 70 to 130 mg/kg while metamorphic rocks (schist) and certain sedimentary rocks (clays) have about 30 mg/kg (Aubert and Pinta, 1977). The availability of P in Andosols is likely to be a problem. These soils rapidly adsorb and precipitate phosphorus (Milley and Donahue, 1995). Oxisols, on the other hand, are characterized by low exchangeable nutrients (Foth, 1990). Therefore supply and availability of nutrients to plants differ from soil to soil.

2.7.6 Cation exchange capacity

The cation exchange capacity is a measure of the soil's ability to retain cations. It measures the quantities of sites on soil surfaces that can retain positively charged ions by electrostatic forces. The positively charged ions include Ca^{2+}, Mg^{2+}, K^+, NH_4^+, Na^+ and Mn^{2+} (Mwinuka, 2001). Also Fe^{2+} and Cu^{2+} are positively charged ions but their quantities are too small to be considered (Biswas, 1987). According to Landon (1991), the higher the CEC the more the fertile and the more productive the soil is.

2.8 Sources of Nutrients in Soils

2.8.1 Fertilizers

The main nutrients applied routinely as fertilizers to agricultural soils are N, P and K. Worldwide; the consumption of nitrogenous fertilizer is much higher than that of the other fertilizers. This is due to the fact that in most of the agricultural systems, soil N supply is below the minimum requirement of crops to rich maximum yields (Galvis-Spinola *et al.*, 1998). However, the nutrient and rate at which it is applied is based on soil testing and the requirement of the crop to be grown. All nutrients ought to be supplied in sufficient levels to meet optimal crop performance. If the soil cannot supply them then they have to be supplied through fertilization. According to FAO (2000), application of N, P, and K should include other elements such as Ca, Mg, S and micronutrients such as Zn, where necessary.

2.8.2 Crop residues

The harvested crop contains some amounts of nutrients extracted from soil. Large quantities of nutrients in harvested parts of crops have been reported. At Lyamungu in Kilimanjaro, Tanzania, Vaje *et al.* (1999) observed that maize stems contained an average of 46kg N/ha at harvesting. If the same is returned into the soil some of the contained nutrients are released. The released nutrients will depend on residue management and C: N ratio of the residues. The proportion of phosphorus cycled back to the soil in grain crops, assuming all residues are returned into the soil, is in the order of 40%, in contrast with about 50 to 70 % for N and 90% for K (Sanchez *et al.*, 1997).

2.9 Critical Nutrient Concentrations in Oil seed Crops

Each essential nutrient has a certain specific role to play in the plant and their presence in above critical nutrient concentrations is a must for a plant to complete its life cycle. The critical limits are quite often employed for a wide variety of soils and crops, even though these critical limits may be different not only for crop species but also for different varieties of a given crop (Tandon, 1992).

The response of crop plants to the insufficiency or sufficiency of specific nutrients has helped to generate information on the critical or the critical limits of each of the elements. Critical limits determine whether immediate action, such as foliar spraying, is needed to correct a deficiency (Singh and Agarwal, 2007). Conclusion can also be drawn as to whether the amount of fertilizer applied at sowing time was sufficient or should be increased for the next crop. When the concentration is in the toxicity range, special countermeasures are required but no application is called for. The critical nutrient concentrations for various crops have been well established; the critical nutrient concentrations for 90% yield for oilseed crops are presented in Appendix 3.

2.10 Agronomic Constraints to Sesame Production

2.10.1 Poor management practices

In many areas, low sesame yield is partly attributed to improper agronomic practices such as inappropriate fertiliser levels, dependence on lower yielding cultivars and poor planting systems (FAO, 1998). It has been shown that increased seed yields can be enhanced significantly by improving these management practices; for example, yield of up to 2 250 kg/ha is possible with improved agronomic practices in India and 2 000 kg/ha in USA, Central America and Venezuela under commercial production (Nantongo *et al*., 2000). These constraints to sesame production need to be addressed in order to increase yields per hectare.

2.10.2 Intercropping

Intercropping is a traditional practice that is well entrenched among tropical farmers, but it still requires improvement. Intercropping is defined as the practice of growing two or more crops simultaneously in the same area in a year or growing season (Van Rheenen *et* *al.,* 1981). It is extensively practised by smallholder farmers in many parts of the developing countries.

According to Nantongo *et al*. (2000) intercropping is associated with certain advantages like: (a) improved soil erosion control, (b) insurance against crop failure, (c) spreading labour and harvesting more evenly throughout the season, (d) facilitating production of many commodities in a limited area, (e) efficient utilisation of resources, (f) transfer of N_2 fixed by legumes to the companion crops and (g) control of spread of diseases and pests, but most important of all is that it (h) helps in improving yields. One way of maximizing use of the scarce resources such as land for agriculture is the intercropping of food crops (Barnes and Addo-Kwafo, 1994).

Sesame is cultivated under a wide range of cropping systems (Baskaran and Solaimalai, 2002) and most of the sesame growers in developing countries grow the crop as an intercrop. FAO (1998) and ICRISAT (1996) indicated that sorghum, maize, finger millet, pigeon peas and sunflower are the common crops intercropped with sesame in Tanzania while Engoru and Bashaasha (2001) reported groundnuts as the most common crop intercropped with sesame in Soroti district in Uganda. On the other hand, finger millet has been shown to be the main crop in sesame based mixtures in Tororo district of eastern Uganda, where 53% of the farmers grow sesame as an intercrop and only 28% as pure stand (Ssekabembe *et al*., 2002).

2.10.3 Plant population and spacing

Among agronomic practices, plant density plays a vital role in influencing the growth and yield of sesame. Nantongo (2002) identified plant population as a factor that influences yield even in crop mixtures. Quayyum *et al*. (1990) reported that wider plant and narrow

row spacing (33.3 x 104 and 11.1 x 104), respectively, induced earliness in flowering and maturity and grain yields were more at wider plant row spacing. Gnanamurthy *et al.* (1992) also concluded that yield of sesame varied with plant density with high and low plant populations decreasing yield significantly. On the other hand, Ssekabembe *et al*. (2002) indicated that sesame yields increase with increase in plant population.

While standard populations have been recommended for the major crops, little information is available with respect to the population of minor crops grown alongside with the major crops in crop mixtures (Gnanamurthy *et al.*, 1992). This has resulted in minor crops e.g. sesame being grown at populations that are either too low or too high, making it impossible to achieve desirable results. Manivannan *et al*. (1993) observed that plant population has a significant effect on sesame leaf area index, which increased with increase in plant population in the sesame mixture. In the same way, number of branches per plant, number of capsules per plant and sesame yield increased with increase in plant population. Furthermore, plant population also had an effect on dry matter produced which reduced with increase in plant population.

2.10.4 Planting methods

Another cause of low sesame yield is the predominance of the broadcast method of sowing. It has been reported in Uganda that farmers fail to attain the optimum plant population required for maximum yield because seeds are not broadcast evenly (Ssekabembe *et al.*, 2001). Some parts of the field are over-sown while other parts are sparsely sown. Sowing sesame in row is reported to be rare in the world. Engoru and Bashaasha (2001) reported that 95% of farmers in Nigeria sow their seeds by broadcasting since the method is not labour intensive and this is their traditional way of growing sesame. Similarly, Manivannan *et al*. (1993) indicated that sowing by broadcasting is done by most farmers in India, resulting in uneven density of plants.

Initially, there is a good germination but at a later stage during stress conditions, the crop suffers moisture stress (Prasad and Kendra, 2001). On the other hand, Manivannan *et al*. (1993) reported that sowing sesame through broadcasting is partly responsible for increasing labour requirements for weeding and due to shortage of labour, sesame is commonly weeded once and this could be probably one of the factors responsible for poor yields. According to Nyende *et al*. (2001), it is practically difficult to achieve a uniform plant population density in the field with the broadcast method of sowing.

According to Ssekabembe *et al*. (2002) broadcasting the seed often results in undue crowding of plants in some places and low plant population in others. The variation in plant density results in variation in yield per hectare leading to reduced yield per unit area (Anyanga and Obong, 2001). In addition, weeding and chemical spraying has been proved to be very hard in case of broadcasted crops. Row planting in sesame can ease weeding (Ssekabembe *et al*., 2001). Studies with finger millet in Eastern Uganda have shown that row planting significantly increased plant growth and yield over broadcasting and it was consistently more profitable than broadcast finger millet. Tenywa *et al*. (2000) concluded that row planting enables more efficient weed control than broadcast planting and saves production costs.

Mpairwe *et al*. (2002) showed that row planting was superior to broadcasting for fodder, biomass and cereal grain production irrespective of cropping system probably due to minimized competition in the mixture. Planting in rows also has an advantage of efficient utilisation of light, water resources and soil nutrients than broadcasting (Andrew and

Kassam, 1976; Nyambo *et al.*, 1982). Therefore, in order to increase sesame yields, there is need to improve management practices of the crop and one way of doing this is to plant the crop in rows, possibly with the use of planters or mixed with sand and row planted directed by a rope or string.

2.10.5 Pests and diseases.

Sesame is resistant to insect pests and diseases (Tripathi and Galhotra, 1992). The major diseases are leaf spots, especially under heavy rainfall and humidity. The other common diseases are: *Fusarium* wilt, bacterial wilt especially when the crop is irrigated, southern blight, charcoal rot, cotton root rot, and phyllody virus which produces almost sterile plants. Engoru and Bashaasha (2001) reported that *Fusarium* wilt takes heavy toll every year in India. Root and stem rot caused by *Macrophomina phaseolina* is also a very serious and destructive disease, which is present in all sesame-growing areas. In Uganda, insects and diseases have been reported as the most serious biological constraints to sesame production (Ssekabembe *et al*., 2001). The most serious diseases of sesame in Uganda are leaf spots and *Fusarium* wilt (Nantongo *et al*., 2000).

2.10.6 Weed problems

During the initial stages of growth, sesame is a poor competitor with weeds. A weed free seed-bed is recommended since cultivation in a sesame field is not easy. The fine fibrous roots are easily damaged. Row planting allows shallow inter-row cultivation. Pre-planting herbicides such as treflan can be used to control grass. The most common weeds being *Striga* (witchweed - *Striga asiatica*) and spear grass (*Imperata cylindrica*) (Engoru and Bashaasha, 2001). It has been shown that sesame is very intolerant of the weeds and losses have been significant in a non-weeded situation. Ssekabembe *et al*. (2001) showed that farmers in Uganda with a weed control problem required extension education in order to acquire skills for better weed control strategies. The *Striga asiatica* is difficult to control as it can only be recognised after it has flowered and caused loss. This is because in its initial growth the weed looks exactly like the finger millet crop. In addition, use of chemicals is limited since the weed and the crop belong to the same family and the herbicides used to control the weed affect the crop too.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Materials

The experimental materials used were improved sesame seeds, an early maturing variety (100 – 110days) namely Lindi 02 collected from Naliendele Research Institute. Nitrogen was supplied through Urea [CO $(NH_2)_2$], Phosphorus was supplied through Triple Super Phosphate (TSP), Potassium was supplied through KCl, Sulphur was supplied through Sulphate of Ammonia [$(NH_4)_2SO_4$] and Zinc was supplied through zinc sulphate ($ZnSO_4$).

3.2 Description of the Experimental Sites

The study involved two trials in two different sites. One trial was conducted at Makutupora research institute and another trial was conducted at Hombolo village under farmer field. Makutupora research institute is located at Veyula ward which lies between latitudes 6^o $20^,$ and 6^o $00^,$ south of the Equator and between longitudes 35^o $43^,$ and 35^o $5^,$ east of the Greenwich at an altitude of 1 140 m above sea level.

The area is characterised by low and erratic rainfall in most parts of it, whereby the undulating plains and hilly areas experiences low rainfall, unreliable and unevenly distributed which is about 400 - 500 mm per annum. Soil distribution in the area includes reddish -brown sandy clay soils, classified as Ustic Torriorthents (Budotela, 1995). Hombolo site is located about 45 km North East of the Dodoma Municipality along Dodoma Morogoro road. It lies between latitude $35^o57^,$ and longitude $5^o45^,$ and altitude of 1 020 above sea level. The area is in central part of Tanzania with unimodal type of rainfall which normally starts towards the end of November and stops in April. The long term mean annual rainfall is about 550 mm.

The soil is fairly uniform in terms of colour and texture. It has been classified as typical Ustorthents in the US soil Taxonomy while in FAO – UNESCO it is Dystric Regosol (FAO, 1977). They are shallow soils with a structure of the surface weakly developed. The sand fraction of its profile is dominated by quartz minerals. Textural class is sandy clay loam (Letayo, 2001).

3.3 Methodology

The experiment was preceded by a visit of about 20 important sesame growing areas. The purpose of the visit was to learn the history of the farms in terms of type and rate of fertilizer applied. The tool used was interactive discussion with individual farmer. Soil samples were collected from all 20 sites visited to represent the sesame growing areas of Dodoma district. Based on the cost and time limitation only two sites with different agro-ecological conditions were selected for trial establishment.

Table 1: Areas of Dodoma district from where the experimental soils were collected

S/No	Sesame growing area (Villages)	Location Sampled	Type of Fertilizer applied and its rate
1.	Nala	06^{o} 04’ 41’’ S and 035^{o} 37’ 04.2’’ E at an altitude of 1 212m asl.	None
2.	Lugala	06^{o} 09’ 43.5’’ S and 035^{o} 30’ 49.3’’ E at an altitude of 1 225m asl.	None
3	Chigongwe	06^{o} 03’ 27.9’’ S and 035^{o} 32’ 36.5’’ E at an altitude of 1 021m asl.	None
4	Zuzu	06^{o} 52’ 04.8’’ S and 035^{o} 04’ 41.6’’ E at an altitude of 1 240m asl.	None
5	Msalato A	06^{o} 04’ 22.5’’ S and 035^{o} 44’ 55.8’’ E at an altitude of 1 140m asl.	None
6	Msalato Kibaoni	06^{o} 02’ 58.1’’ S and 035^{o} 45’ 27’’ E at an altitude of 1 090m asl.	None
7	Veyula	06^{o} 02’ 20’’ S and 035^{o} 45’ 23.5’’ E at an altitude of 1 140m asl.	None
8	Makutupora	05^{o} 50’ 25.4’’ S and 035^{o} 46’ 3.7’’ E at an altitude of 1 091m asl.	*FYM (1t/ha)
9	Hombolo	05^{o} 45’ S and 035^{o} 57’ E at an altitude of 1 020m asl.	None
10	Mpunguzi	06^{o} 23’ 46.9’’ S and 035^{o} 44’ 45.3’’ E at an altitude of 1 069m asl.	None
11	Mbabala	06^{o} 12’ 50.9’’ S and 035^{o} 43’ 57.9’’ E at an altitude of 1 104m asl.	None
12	Matumbulu	06^{o} 19’ 50.2’’ S and 035^{o} 44’ 40.3’’ E at an altitude of 1 124m asl.	None
13	Nkulabi	06^{o} 48’ 23.2’’ S and 035^{o} 51’ 44’’ E at an altitude of 1 060m asl.	None
14	Vikonje	06^{o} 00’ 19’’ S and 035^{o} 44’ 16.4’’ E at an altitude of 1 123m asl.	None
15	Mchemwa	05^{o} 04’ 50.5’’ S and 035^{o} 43’ 30.3’’ E at an altitude of 1 102m asl.	Urea (220kg/ha) and *FYM (1t/ha)
16	Chihanga	05^{o} 23’ 30.5’’ S and 035^{o} 27’ 58’’ E at an altitude of 1 184m asl.	Urea (280kg/ha) rate? *FYM (1t/ha)
17	Gawaye	05^{o} 40’ 52.6’’ S and 035^{o} 36’ 7.3’’ E at an altitude of 1 040m asl.	*FYM (1t/ha)
18	Kisima cha ndege	05^{o} 50’ 20.6’’ S and 035^{o} 46’ 01.9’’ E at an altitude of 1 088m asl.	None
19	Sejeseje	06^{o} 03’ 37.1’’ S and 035^{o} 40’ 10.6’’ E at an altitude of 1 132m asl.	*FYM 1t/ha
20	Kitelela	06^{o} 03’ 17.0’’ S and 035^{o} 45’ 15.0’’ E at an altitude of 1 124m asl.	*FYM 1t/ha

* FYM – Farm Yard Manure

3.3.1 Soil sampling and sample preparation

Soil samples were collected from twenty different sites in Dodoma district (Appendix 4) in order to evaluate the fertility status of soils at the beginning of the study. The soil at each location was sampled to a depth of 0 – 30 cm to include top and sub soils. Sampling was done randomly over the entire site by using a hand hoe, spade and field knife. This was done in order to take care of the suspected fertility gradient due to farmyard manure application in the past season in some of the farms. The selected sites are given in Table 1. From each site, eight samples were randomly collected and composited to obtain one soil composite sample. Each soil portion from each site was thoroughly mixed and reduced to one kg by quartering. These composite soil samples were air dried ground and sieved through a 2 mm sieve to obtain a fine earth fraction for analysis and fertility status evaluation.

3.3.2 Field experiment

3.3.2.1 Land preparation, planting and crop management

This involved the collection and removal of previous crop residues, grasses and weeds from the field on which sesame was previously cultivated. Land preparation was done two weeks before planting which was done by conventional tillage system by tractor and levelling was done by hand hoe. After levelling, about 900 m^2 of land for each site was divided into six treatments whereby treatment one was an absolute control in which no nutrient was applied, in treatment two only N was applied at a rate of 45 kg/ha, in treatment three N and P were applied at a rates of 45 kg/ha and 20 kg/ha, respectively, in treatment four N, P and K were applied at rates of 45 kg/ha, 20 kg/ha and 16 kg/ha, respectively, in treatment five N , P, K and S were applied at rates of 45 kg/ha, 20 kg/ha, 16 kg/ha and 45 kg/ha respectively and in treatment six N , P, K, S and Zn were applied at rates of 45 kg/ha, 20 kg/ha, 16 kg/ha, 45 kg/ha and 25 kg/ha respectively. Treatment size was 4.5m x 4.5m plots as shown in Appendix 5. Then treatments were designated as shown below:

1. Absolute Control (No nutrients added)
2. $N_{45} P_0K_0S_0Zn_0$
3. $N_{45}P_{20}K_0S_0Zn_0$
4. $N_{45}P_{20}K_{16}S_0Zn_0$
5. $N_{45}P_{20}K_{16}S_{45}Zn_0$
6. $N_{45}P_{20}K_{16}S_{45}Zn_{25}$

3.3.2.2 Sowing and fertilizer application

As per the treatment specifications (Appendix 6) the basal dose of fertilizer (50% N and entire P, K, S and Zn) were applied at sowing. The rest of the nitrogen was top-dressed at six weeks after sowing. Planting was done on 10 January, 2012 and germination took place on 17 January, 2012. Seed at the rate of 3 kg/ha, was mixed with sand and sown per hill at spacing of 50 cm by 20 cm. Thinning was done three weeks after germination, leaving two plants per hill. Hand hoe weeding was done two times throughout the season to make sure that the field remained weed free. Diseases and insects were not a problem in the season and there was no pest control program carried out.

3.3.2.3 Plant leaves sampling and preparation

Recently matured 50 leaves (3 to 4 leaf from the flower at the end of the branch) of sesame plants from each plot were randomly sampled at complete flowering. The leaves were washed in clean water and rinsed twice in clear water. The samples were then placed in brown paper bags and dried in the oven at $70^{o}C$ for 72 hours to constant weight. The samples were weighed to obtain dry matter yield and then chopped to pieces and ground using a cyclone sample mill and sieved through 0.5 mm sieve ready for plant analysis for N, P, K, S, Mg, Ca, Zn and Cu.

3.3.3 Laboratory analyses

3.3.3.1 Soil pH

Soil pH was measured in water using a pH meter at the ratio of 1:2.5 soils: water as described by McLean (1982).

3.3.3.2 Cation exchange capacity and exchangeable bases

The CEC of the soil was determined using the ammonium acetate saturation method as described by Chapman (1965). Five g of the soil were saturated with neutral normal NH_4OAC, shaken for 30 minutes and filtered by using Buckner funnel with number one filter paper. The filtrate was used to determine exchangeable K, Ca, Mg and Na using atomic adsorption spectrophotometry. Excess NH_4OAC was removed by washing twice with methanol. The NH_4^+ - saturated soil was equilibrated with 4% KCl, shaken for 30 minutes and filtered. The filtrate was used for the determination of NH_4^+ by micro-kjeldahl distillation in the presence of 40% NaOH and the NH_3 liberated was collected in 4% boric acid (with mixed indicator) and titrated with standard 0.1N H_2SO_4. The titre was used for the determination of the CEC of the soil.

3.3.3.3 Particle size analysis

The particle size analysis was determined by the hydrometer method after dispersion with sodium hexametaphosphate as described by Day (1965). The textural class was determined using the USDA textural class triangle (USDA, 1975).

3.3.3.4 Total nitrogen

Total nitrogen was determined by micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). One g of soil was digested with concentrated H_2SO_4 in presence of mixed catalyst (K_2SO_4, $CuSO_4$ and selenium powder mixed in the ratio of 10:10:1 by weight). The digest was distilled in the presence of 40% NaOH. The ammonia liberated was collected in 4% boric acid (with mixed indicator) and then titrated with standard H_2SO_4. The titre was used to calculate the total N of the soil sample.

3.3.3.5 Extractable phosphorus

Available P was extracted by the Bray-1 procedure (Bray and Kurtz, 1945). The extracting solution containing NH_4F 0.025 HCl was used. A sample of 3 g air-dried soil was placed in a plastic bottle, with 25 ml of the extracting solution added, shaken for one minute and filtered. Five ml of the filtrate was pipetted and placed in 50 cm^3 volumetric flask with 20 ml distilled water. The P was determined in the filtrates by spectrophotometry at 884 nm following colour development by the molybdenum blue method (Murphy and Riley, 1962).

3.3.3.6 Organic carbon

The organic carbon was determined using Wakley and Black method (Allison, 1965). To a 1g soil sample, 10 ml of 1M $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 were added to oxidize organic carbon. The amount of dichromate reduced was used to estimate the organic carbon content of the soil.

3.3.3.7 Extractable sulphur (SO_4 - S)

Extractable S was analyzed using the turbidimetric method as described by Moberg (2000). Twenty five ml of sulphur extracting solution (stock solution) was added in 100ml plastic bottle containing 5 g air-dried soil sample then shaken for 30 minutes and filtered. Ten mls of the filtrate was pipetted and 10 ml of the acid seed solution was added in the pipetted sample. Then 5 ml of the turbdimetric reagent was added in each of the filtrate and allowed to stand for 20 minutes. Sulphur was determined in the filtrates by spectrophotometry at wavelength of 535 nm (Moberg, 2000).

3.3.3.7 DTPA-extractable micronutrients

DTPA extractable micronutrients in all soil samples were determined using the procedure by Lindsay and Norvell (1978). The extractant contained 0.005M DTPA (diethylenetriaminepentaacetic acid), 0.01M $CaCl_2.H_2O$ and 0.1 M TEA (triethanolamine) adjusted to pH 7.3. Twenty g of air dried soil were mixed with 40 ml of extracting solution and shaken for two hours and then filtered. The micronutrients zinc, copper and manganese were determined by atomic absorption spectrophotometer, using appropriate standards.

3.3.3.8 Plant sample analysis

Plant samples were digested using the wet oxidation procedure of Moberg (2002). One half g of ground plant sample was weighed and placed into digestion tubes. Five ml of 68% HNO_3 were added into each tube and the mixture was left to stand overnight. The tubes were then placed in a digestion block with temperature set at 125^oC for 1 hour, then taken off and cooled. After cooling, 5 ml of H_2O_2 were added into each tube and heated at 70^oC on the digestion block until the reaction stopped. This treatment was repeated until the digest was colorless. The digest was then heated at the digestion block at 180^oC near dryness. After cooling, 10 ml of 10% HNO_3 were added and the dissolved digest transferred quantitatively to 100 ml volumetric flask, which was filled to the mark with distilled water. The solution was analyzed for N, P, K, S, Ca and Zn. Phosphorus and sulphur were determined by wet digestion with nitric acid method (Murphy and Riley, 1962). Potassium was determined using a flame spectrophotometer fitted with a filter at 768 nm. Nitrogen was determined by micro Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982).

3.3.4 Harvesting of sesame grain

At maturity sesame shoots in each plot were harvested and sun-dried. After sun-drying they were threshed winnowed and weighed for each plot and recorded as grain yield per plot ($20.25m^2$).

3.3.5 Dry matter yields of sesame shoot straws

After threshing, winnowing and weighing sesame grains, shoot straws in each plot were weighed and the weight was recorded as dry matter yields of sesame shoot straws per plot.

3.3.6 Data analysis

The dry matter yield of sesame leaves and sesame shoot straw, nutrients contents in sesame plants and the seed yields in response to application of N, P, K, S and Zn were subjected to analysis of variance (ANOVA) using the MSTA-C computer package. The treatment means were compared using Duncan’s New Multiple Range Test at 5% level of significance.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil fertility status of some sesame growing soils of Dodoma district

4.1.1 Soil pH

The soil pH values (Table 2) ranged from 3.96 to 6.72. Landon (1991), categorized pH values as follows: > 8.5 = very high, 7.0 – 8.5 = high, 5.5 – 7.0 = medium and < 5.5 = low. In view of this, all soils in the study had low to medium pH. The pH of most of the soils in the study areas were within the satisfactory range for sesame production which is 5.5 – 7.0, as reported by Ashri (1998). The acidic nature of the soils could probably be due to the acidic nature of the parent materials and somehow extensive weathering of the soils and leaching.

4.1.2 Organic carbon

The organic carbon data for the soils in the areas studied ranged from 0.64 to 1.96% as presented in Table 2. Baize (1993), categorized organic carbon contents of < 0.60% as very low, 0.60 – 1.25% as low and (1.26 – 2.50%) as medium. Based on these categories, soils in this study ranged from very low to medium organic carbon content (Table 2). These levels are similar to those from other studies done by Budotela (1995) in selected grape producing areas of Dodoma region (0.68% OC). Also Letayo (2001) reported very low OC content (0.65%) in millet and groundnut soils of some areas from Dodoma region. Thus, many soils of Dodoma seem to be low in organic carbon.

Table 2: Soil pH and nutrient contents in some sesame growing soils of Dodoma district

Village name	pH	OC(%)	Total N (%)	Avail P(mg/kg)	S mg/kg	CEC Cmol/kg	Ca Cmol/kg	Mg Cmol/kg	Na Cmol/kg	K Cmol/kg	BS(%)
Mpunguzi	3.9	0.97L	0.12	8.9	7.2	7.2	2.71	1.05	0.15	0.34	59.0
Matumbulu	4.1	0.76L	0.16	7.1	7.6	7	2.34	0.85	0.15	0.34	56.3
Chigongwe	4.6	1.04L	0.16	2.0	5.8	6.6	2.71	0.92	0.17	0.36	63.0
Vikonje	4.8	0.92L	0.11	1.2	1.4	9.2	3.61	1.18	0.16	0.51	59.3
Nkulabi	6.2	0.64L	0.15	10.2	18.5	12.4	6.69	2.93	0.22	0.72	69.0
Chihanga	6.7	1.67M	0.22	25.0	4.3	15.2	12.9	3.27	0.17	0.77	112.5
Mchemwa	6.4	1.35M	0.19	18.3	0.7	13.8	11.36	3.23	0.17	0.72	112.2
Makutupora	5.6	0.99L	0.17	20.4	6.5	11.8	5.41	1.87	0.15	0.62	68.2
Hombolo	4.7	0.99L	0.16	1.3	0.7	7.8	3.97	1.3	0.15	0.59	77.1
Lugala	3.8	0.19VL	0.13	8.3	9.8	6.6	1.17	0.4	0.15	0.26	28.5
Mbabala	5.9	0.79L	0.14	12.1	4.3	8.4	5.41	1.88	0.2	0.62	96.5
Veyula	5.4	1.39M	0.17	21.7	1.8	8.4	2.8	1.1	0.18	0.51	54.6
Sejeseje	5.9	1.19L	0.15	14.6	7.9	6.6	2.98	1.18	0.16	0.82	77.9
Zuzu	4.9	1.95M	0.17	1.3	9.4	9.4	3.61	1.18	0.16	0.51	58.1
Kisima cha ndege	6.3	0.64L	0.15	16.3	8.3	11.8	6.67	2.43	0.16	0.72	84.6
Kitelela	5.7	1.64M	0.15	3.4	6.5	7.6	3.97	1.69	0.13	0.38	81.2
Nala	4.3	1.83M	0.18	5.8	9.1	6.8	1.98	0.7	0.2	0.46	49.1
Gawaye	6.4	0.99L	0.22	22.4	10.0	12.6	8.21	2.65	0.17	0.67	92.9
Msalato kibaoni	4.8	0.76L	0.16	2.9	5.8	6.6	2.72	2.65	0.18	0.36	62.9
Msalato A	6.2	0.64L	0.22	25.6	18.5	12.2	6.62	2.9	0.28	0.75	86.5

Letters associated with OC% are ratings according to Baize (1993) where; VL= Very Low, L= Low, M= Medium

4.1.3 Total nitrogen

The values for total N as presented in Table 2 ranged from 0.11 to 0.22%. According to Landon (1991), these values were rated as low in total N. This means that all the soils analyzed had low total N contents. Budotela (1995) reported very low N contents in soils of some grape producing areas of Dodoma region (0.06 – 0.08%N). Also Letayo (2001) reported very low N content (0.056%N) in millet and groundnut soils of some areas from Dodoma region. These continue to give evidence that N is a limiting nutrient in many soils of Dodoma region. Thus, use of nitrogen fertilizers is necessary for increasing yields in these types of soils on which sesame is also grown.

4.1.4 Available phosphorus

The ranges for extractable Bray-I-P are shown in Table 2. The available P ranged from 1.19 to 25.62 mg/kg. Landon (1991) categorized extractable Bray-I-P as; > 50 mg/kg as high, 15 – 50 mg/kg as medium and < 15 mg/kg as low. Based on this classification, only seven soils out of 20 had medium available P, the rest had low P contents. The low P content in most of the soils studied could be due to the low pH values in many soils in the study (Table 2). According to Tisdale *et al.* (1993), P availability is low in acid soils as well as in calcareous soils. In most cases, pH of 6 – 7 is optimum for adequate P availability in soils. In addition, the low P content in all thirteen soils studied is probably due to continuous sesame production (more than 4 years) (Appendix 1) without replenishment of P taken up by sesame crop. It is therefore evident that, P application will be necessary in those soils in order to increase and sustain sesame production.

4.1.5 Extractable sulphur

The data for extractable sulphur ranged from 0.73 – 18.51 mg/kg as indicated in Table 2 below. According to the categorization by Landon (1991), eight soils out of twenty soils tested are below the critical range 6 – 12 mg/kg, while ten soils were within the critical range. Soils from Nkulabi and Msalato A had higher S contents above the critical range for expected response to S application. Thus, this implies that application of sulphur fertilizers in all eighteen soils may significantly increase both yields and yield components of sesame.

4.1.6 Cation exchange capacity (CEC)

The Cation Exchange Capacity (CEC) ranged from 6.6 to 15.2 cmol(+)/kg (Table 2). According to Landon (1991), all soils in the study had low CEC values. It appears that the low CEC levels in all soils may be due to the influence of soil texture and the type of clay minerals and the soil organic matter contents. Clayey soils are reported to have higher CEC than Sandy soils mainly due to charges resulting from isormorphous substitution (Rhoades, 1982)

4.1.7 Exchangeable bases

4.1.7.1 Calcium

The values of calcium for soils tested are shown in Table 2. The ranges of calcium was from 1.17 to 12.9 cmol(+)/kg. Landon (1991) categorized levels of exchangeable calcium and indicated that < 4 cmol(+)/kg is considered as low and > 10 cmol(+)/kg is considered as high. This implies that twelve soils out of twenty in the study are low in calcium supply to plants. Two out of twenty samples had high content of calcium while the rest had calcium contents between 4 and 10 cmol(+)/kg. The low calcium content in all twelve soils may be due to the low pH values. Soils with pH 5.0 or lower are likely to be deficient in calcium (Chapman, 1973).

4.1.7.2 Magnesium

The data for exchangeable magnesium are presented in Table 2. The exchangeable Mg ranged from 0.40 to 3.27 cmol(+)/kg. Landon (1991), reported that soils having < 0.5 cmol(+)/kg are magnesium deficient and soils having > 4.0 cmol(+)/kg had high magnesium content. According to Landon (1991), all soils in the study are of adequate magnesium levels except the soils from Lugala village.

4.1.7.3 Sodium

The values of sodium for the soils tested are shown in Table 2. The ranges of this values were 0.13 to 0.28 cmol(+)/kg. Based on the categorization by Landon (1991), > 1 cmol(+)/kg Na^+ contents is in high range. Thus, all soils in the study are of low to medium range. Soils having Na^+ contents > 1 cmol(+)/kg are considered as alkali or sodic soils (Landon, 1991).

4.1.7.4 Potasssium

The results of exchangeable K^+ cmol(+)/kg are presented in Table 2. The exchangeable K^+ varies from 0.26 to 0.82 cmol(+)/kg. Soils from all locations had medium to high exchangeable K^+ (Landon, 1991). Budotela (1995), reported high exchangeable K^+ in selected grape producing areas of Dodoma district. On the other hand soils from some groundnut and millet areas of Dodoma were reported to have low exchangeable K^+ (0.26 – 0.35 cmol(+)/kg) (Letayo, 2001). Some of these areas are also used for sesame cultivation at times.

4.1.8 Micronutrient contents

4.1.8.1 Zinc

The amounts of the DTPA extractable Zn are shown in Table 3. The values range from 0.06 to 2.87 mg Zn/kg. Most of the soils in the study have Zn levels below the critical level of 1 mg/kg proposed by Landon (1991), with exception of six villages out of twenty villages studied. Thus, 70% of the soils in this study are deficient in Zn and some might become deficient in the future if Zn fertilizers will not be applied. Tisdale *et al.* (1993) categorized zinc contents in soils as follows 0 – 2.5 as low, 2.6 – 4.5 as medium and > 4.5 mg/kg is high.

Based on this categorization, all soils in the study contain low DTPA Zn contents with exception of the soils in Chihanga village which had zinc contents of 2.87 mg/kg (Table 3). The low Zn contents in most of the soils probably is due to high content of free Fe, Al and Mn ions which caused adsorption of Zn to non exchangeable form on their hydrated oxides surface (Phogat *et al.*, 1994). MacBride (1981) observed that the presence of other divalent cations such as Ca^{2+} greatly reduces the efficiency of heavy metals adsorption by permanent charge soil colloids.

It is therefore expected that, soil clays with exchangeable complexes dominated by divalent cations such as Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and Al^{3+} would demonstrate relatively weak affinity for Zn. This effect should be especially pronounced for acid soils where Al^{3+} and Mn^{2+} ions probably occupy most of the exchange sites. Also the lower Zn levels may be due to the fact that most of these areas suffer continuous cropping without Zn additions in form of fertilizers.

4.1.8.2 Iron

The DTPA Fe levels under the areas studied ranged from 3.17 to 70.16 mg/kg (Table 3). All soils under the study have DTPA Fe content higher than the critical levels of 4.5 mg/kg, reported by Tandon (1995) except the soils from Chihanga and Gawaye. Thus, all the soils had sufficient Fe contents for plant growth with exception of Chihanga and Gawaye soils. The high levels of Fe in all soils could be attributed to the low pH and nature of the parent material from which the soil were formed (Alloway and Ayres, 1990).

4.1.8.3 Copper

The DTPA-extractable copper ranged from 2.84 to 2.86 mgCu/kg (Table 3). All the soils in the study have higher DTPA extractable Cu than the critical level of 0.2 to 0.4 mgCu/kg reported by Tandon (1995). Thus, all soils had sufficient Cu for plant growth.

4.1.8.4 Manganese

The DTPA-Mn levels under the areas studied ranged from 1.35 to 24mg/kg (Table 3). Tisdale *et al.* (1993) categorized Mn as follows: 0 – 0.5 as low, 0.6 – 1.0 as medium and > 1.0 as high. Based on the above mentioned critical ranges, all soils under the study have DTPA Mn content higher than the critical limit of 1.0 mg/kg reported by Tisdale *et al.* (2003). The high levels of Mn in the soils could be due to low pH that favors the dissolution of Mn minerals in soils (Alloway and Ayres, 1990).

Table 3: Micronutrient contents and soil physical properties of some sesame growing soils of Dodoma district

Village name	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	SAND %	SILT %	CLAY %	Texture class
Mpunguzi	0.06L	4.7	2.8	59.8	68.4	1.3	30.3	SCL
Matumbulu	0.13L	6.0	2.8	45.5	68.4	3.3	28.3	SCL
Chigongwe	0.06L	23.9	2.8	24.8	78.4	3.3	18.3	SL
Vikonje	0.08L	3.6	2.9	32.0	70.4	3.3	26.3	SCL
Nkulabi	1.63H	12.4	2.9	15.0	54.4	1.3	44.3	SC
Chihanga	2.87H	1.3	2.9	3.3*	64.4	5.3	30.3	SCL
Mchemwa	2.09H	1.7	2.8	8.2	62.4	5.3	32.3	SCL
Makutupora	0.56L	2.5	2.8	14.0	62.4	1.3	36.3	SCL
Hombolo	0.08L	3.7	2.9	31.2	74.4	1.3	24.3	SCL
Lugala	0.13L	3.8	2.8	56.0	70.4	3.3	26.3	SCL
Mbabala	1.96H	6.4	2.8	25.6	64.4	1.3	32.3	SCL
Veyula	0.77L	17.3	2.9	55.1	70.4	1.3	28.3	SCL
Sejeseje	0.46L	6.0	2.8	48.6	70.4	1.3	28.3	SCL
Zuzu	0.29L	1.7	2.8	26.5	64.4	3.3	32.3	SCL
K/cha ndege	0.60L	1.5	2.9	5.1	62.4	3.3	34.3	SCL
Kitelela	0.79L	15.7	2.8	25.1	68.4	1.3	30.3	SC
Nala	0.19L	13.7	2.8	70.1	70.4	3.3	26.3	SCL
Gawaye	1.55H	1.4	2.8	3.2*	66.4	3.3	30.3	SCL
M/kibaoni	0.04L	24.0	2.8	25.1	78.4	3.3	18.3	SL
Msalato A	1.61H	3.7	2.8	32.3	54.4	1.3	44.3	SC

Letters associated with Zn levels are ratings according to Landon (1991) where L= Low, H= High.

*Fe levels which are rated as low according to Tandon (1995)

SCL: Sandy Clay Loam; SL: Sandy Loam; SC: Sandy Clay

4.1.8.5 Soil texture

Soils from all villages sampled were of medium texture (Table 3). The textural properties of these soils favour sesame production as reported by Carlson *et al.* (2008) that sesame will perform best on well-drained soils of medium texture such as sandy clay loams. It is adapted to sandy loam soils, provided there is adequate moisture during seedling establishment. It has been grown satisfactorily on sandy clay loam soils, but soil crusting can be a problem in establishing sesame when clay content is higher.

4.2 Effect of N, P, K, S and Zn on Sesame Leaf Dry Matter Yields at Makutupora and Hombolo Sites

The response of sesame to N, P and K applied to both Makutupora and Hombolo sites are presented in Table 4. There were significant ($P<0.05$) increases in dry matter yields due to application of N, P, K, S and Zn over the control at both sites. The dry matter yield of the control at both Makutupora and Hombolo were the lowest (3.63 g/plot and 2.39 g/plot), respectively. Application of all these nutrients together recorded the highest dry matter yields in both sites (13.67 g/plot and12.35 g/plot) as opposed to application of these nutrients in lesser combinations.

The significant increase upon application of N shows that, nitrogen was limiting in these soils. Increase in dry matter yields due to addition of P over the treatment receiving N alone indicates that P was also a limiting nutrient in these soils. There was significant ($P<0.05$) increase in dry matter yields due to application of N or N in combination with P and K over the control but no significant increase in dry matter yields when K was added in the treatment receiving N and P. This implied that K was not a limiting nutrient in both soils of Makutupora and Hombolo. Higher dry matter yield was obtained in the treatment receiving N, P, K and S. However, much higher dry matter yield was obtained when Zn was supplied in the treatment receiving N, P, K and S in both sites. Application of 45 kg S/ha and 25 kg Zn/ha might have helped in terms of vigorous root growth, formation of chlorophyll, resulting in higher photosynthesis. The results of this investigation are in support with the findings of Reddappa (1981). Similar results were reported by Sreemannarayana and Raju (1993). Stimulated photosynthetic activity and synthesis of chloroplast and protein due to S and Zn supply might have resulted in higher dry matter production as reported in soybean crop (Mishra and Agarwal, 1994). Therefore, it is apparent that S and Zn were deficient in this soil and their supplementation was necessary for optimum sesame growth and maximum yields.

Table 4: Sesame leaf dry matter yields from a field experiment of Makutupora and Hombolo sites

	Dry matter yields (g/plot)	
Treatments	Makutupola	Hombolo site
Absolute control	3.63e	2.39e
$N_{45}P_0K_0S_0Zn_0$	6.98d	5.27d
$N_{45}P_{20}K_0S_0Zn_0$	7.95c	7.64c
$N_{45}P_{20}K_{16}S_0Zn_0$	7.42c	7.08c
$N_{45}P_{20}K_{16}S_{45}Zn_0$	10.35b	9.86b
$N_{45}P_{20}K_{16}S_{45}Zn_{25}$	13.67a	12.35a
CV%	2.5	2.7

F – Statistics table are given in Appendix 7

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

The lack response to K may be due to relatively high levels of K in these soils (Table 2). The K contents at Makutupora and Hombolo were 0.62 cmol/kg and 0.59 cmol(+)/kg, respectively, which are above the critical level (0.5cmol/kg) reported by Landon (1991). Also Bray-1 P value at makutupora was 20.38 mg/kg, which is considered as adequate for sesame while at Hombolo it was 1.31 mg/kg, which is considered as low (Landon, 1991).

The highest response due to application of all five nutrients in combination was due to the better supply of all these nutrients. This is in accordance with the law of minimum which states that “If two or more factors are limiting or nearly limiting, addition of one will have a little effect on growth and yield, whereas provision of both or all will have much greater influence on yields” (Tisdale *et al.,* 1993).

However, there were smaller yield responses at Hombolo site than at Makutupora site, though the levels of N, P, K, S and Zn added to the soils were the same. This suggested that there was some other yield limiting factors. The other reason for the lower yield responses at Hombolo site than at Makutupora site may be due to differences in some physical chemical properties of soils from these sites. The soil from Hombolo had pH value of 4.75 and calcium level of 3.79 cmol/kg, this is considered low (Landon, 1991). Also Hombolo had lower P and S contents in soil, which, otherwise should have resulted in higher responses.

The results in this study confirm the findings of Mishra and Agarwa (1994) in soybean and Gangadhara *et al.* (1990) for sunflower. In India, the study by Channal *et al*. (1981) has also revealed higher dry matter yields in the treatment receiving N, P, K, S, Zn and Fe as compared with other treatments and control. Similar response of N, P, K and S as obtained in this study have been reported by Rao *et al.* (1994); Schilling and Cattan (1991) in Burkina Fasso. Ahmad *et al*. (2001) reported increase in sesame dry matter yield from N and P fertilization and non increase due to K fertilization for the soils of Mubi in Nigeria. In Tanzania, responses of various crop to N and P have also been reporten in several studies, (Semoka and Shenkalwa, 1985; Semoka *et al.,* 1996) for soils of Morogoro district in the case of rice.

Also, Mnguu (1997) reported a significant increase in dry matter yields due to K in one soil which had exchangeable K value lower than the critical limit of 0.26 cmol(+)/kg but no response in soils which had exchangeable K values higher than the critical limit. Thus, the results from this study show that the soils of both Makutupora and Hombolo are deficient in N, S and Zn and without use of fertilizers supplying these nutrients, yields in small farmers' fields will continue to be low and will possibly continue to decline.

4.3 Nutrient Concentration in Sesame Leaves

4.3.1 Nitrogen

Data for N contents in sesame leaves from experimental site at both Hombolo and Makutupora villages, as a result of use of N, P, K, S and Zn, are presented in Tables 5 and 6 respectively. The contents of N in sesame leaves varied from 1.46% to 4.41% at Hombolo and 1.68 – 4. 91% at Makutupora sites respectively. These values are ranged in deficient to sufficient (Tandon, 1995; Landon, 1991; Havlin *et al.* (2003). According to Tandon (1995), deficiency was observed when recently matured leaves, i.e third leaf of any plant contain <3.8%, sufficient when contain 3.8% to 4.8% and high when they contain >4.8% N. Landon (1991) classified 2% as low N content in plant. Also according to Havlin *et al.* (2003), the general sufficient or optimal range of nitrogen in plants is 2.0 to 5.0% N.

Based on these categorizations, the deficiency levels were observed in the absolute control (1.46% and 1.68%) at Hombolo and Makutupora respectively. The lowest N content in the absolute control treatment is based on the concept that the content of a particular nutrient is directly proportional to its availability in the soil (Mengel and Kirkby, 1987). However, the mineral content in plant does not only depend on its availability in soil, but it is also affected by various other factors such as kind of plant organ/tissue, age and the supply of other nutrients (Lund, 1970).

The other treatments in both sites had sufficient levels of N. The sufficiency levels of N contents in sesame leaves of other three treatments at both sites are probably due to the application of N fertilizer in the soils. This implies that for sesame production N fertilizer application in soil is important while at the same time nutrient balance should be considered in order to achieve high yields (Wilson, 1969). The treatment receiving S and Zn recorded higher N contents than the other two treatments. This could be due to the fact that sulphur significantly improved the nitrogen accumulation in oilseed crops. The improvement in nitrogen accumulation is due to the improvement in nitrate reductase activity in the leaves of sesame.

Sulphur not only improved the N accumulation in plants, but also the partitioning of N toward the economic part i.e. the seed, as evident from the higher nitrogen harvest index of the sesame grown with sulphur treatments (Babhulkar *et al.,* 2000). These results are in conformity with the findings of Sahrawat and Islam (2007) who studied the essentiality of sulphur nutrition and interaction between S and N in optimizing seed and oil yield on sesame in India and observed that, among the sulphur treatments, of 45 kgS/ha in the form of gypsum in split doses and 30 kgS/ha in single dose were better than 20 kgS/ha at improving the N accumulation as well as the seed and oil yield, and quality.

4.3.2 Phosphorus

The content of phosphorus in sesame leaves grown at Hombolo experimental site varies from 0.08 to 0.28% (Table 5) while that for Makutupora site varies from 0.19% to 0.41% (Table 6). Tandon (1995) reported deficiency to occur when P content in the recently matured leaf, i.e third leaf of a plant, was below 0.19% while the range of 0.19 – 0.25% P was considered sufficient and values above 0.25% were considered high.

Table 5: Nutrient contents in sesame leaves collected from field experiment at Hombolo site

Treatments	N (%)	P (%)	K (%)	S (%)	Ca (%)	Zn (mg/kg)
T1	1.46	0.08	2.39	0.02	0.18	10.0
T2	4.36	0.16	2.91	0.03	0.32	13.3
T3	4.36	0.26	3.67	0.05	0.21	10.0
T4	4.32	0.22	5.06	0.06	0.23	13.3
T5	4.34	0.25	5.17	0.19	0.21	16.7
T6	4.39	0.28	5.20	0.29	0.25	33.3

T1=Absolute control, T2= $N_{45}P_0K_0S_0Zn_0$, T3= $N_{45}P_{20}K_0S_0Zn_0$, T4= $N_{45}P_{20}K_{16}S_0Zn_0$, T5= $N_{45}P_{20}K_{16}S_{45}Zn_0$, T6= $N_{45}P_{20}K_{16}S_{45}Zn_{25}$

Many other workers have reported the critical levels of P in plant leaves as follows: Landon (1991) classified P contents ranging from 0.36 – 0.44% as sufficient and above 0.44% as high. Bonheure and Wilson (1992) reported values of critical levels of P and observed a deficiency level when plant leaves contain <0.35%, at 0.35 – 0.40% it was subnormal, at 0.40 – 0.50% it was normal and above 0.50% was excess. Also, Havlin, *et al.* (2003) reported P deficiency to occur when a recently matured leaf, i.e third leaf of a plant, contains < 0.15% and above 0.17% the plant is considered adequately supplied with P.

Based on the given critical levels, the P nutritional status of sesame plant grown at Hombolo experimental site would be rated in deficient to sufficient range, while that of and Makutupora village ranged from sufficient to high for sesame production. At

Makutupora even Hombolo sites, the absolute control treatment and the treatment receiving N only had P sufficient while treatments receiving P in combination with N and/or K and S were highly supplied with P content.

The sufficient P content in the absolute control from experimental plot at Makutupora site indicates that P availability in Makutupora soil was adequate for sesame production. The slight increase in P content (0.24%) and (0.16%) at Makutupora and Hombolo sites, respectively, in the treatments receiving N only implies that adequate supply of nitrogen had a positive impact in improving availability of P for plant uptake. These results are supported by the findings of Jones *et al.* (1982) that N supply increased P uptake due to its effect on root growth. However, the lowest leaf P content (0.19%) at Makutupora and (0.08%) at Hombolo were observed in the absolute control treatments (Tables 5 and 6).

Table 6: Nutrient contents in sesame leaves collected from Makutupora site

Treatments	N	P	K	S	Ca	Zn
	(%)	(%)	(%)	(%)	(%)	(mg/kg)
T1	1.68	0.19	2.42	0.03	0.21	10.0
T2	4.64	0.24	2.94	0.05	0.33	13.3
T3	4.68	0.39	3.70	0.06	0.39	16.7
T4	4.77	0.31	5.09	0.06	0.26	16.7
T5	4.91	0.37	5.20	0.28	0.26	23.3
T6	4.94	0.41	5.23	0.33	0.34	46.7

T1=Absolute control, T2= $N_{45}P_0K_0S_0Zn_0$, T3= $N_{45}P_{20}K_0S_0Zn_0$, T4= $N_{45}P_{20}K_{16}S_0Zn_0$
T5= $N_{45}P_{20}K_{16}S_{45}Zn_{0,}$ T6= $N_{45}P_{20}K_{16}S_{45}Zn_{25}$

Higher leaf P contents (0.41%) and (0.28%) at Makutupora and Hombolo sites were observed in the treatments receiving Zn together with N, P, K and S (Tables 5 and 6). This confirms that phosphorus fertilization is necessary to improve phosphorus availability in these soils, and possibly in other areas of Dodoma district having similar soils. However, there was a relatively high phosphorus level at Makutupora experimental site than that of Hombolo experimental site. This may be due to the relatively high P contents in the soil of Makutupora area.

4.3.3 Potassium

The K contents in sesame leaves from experimental sites at Hombolo and Makutupora villages are shown in Tables 5 & 6. K contents in sesame leaves in this study ranged from 2.39 – 5.20% and 2.42% to 5.23% at Hombolo and Makutupora sites, respectively. Tandon (1995) reported the critical ranges for K contents in plant leaves as follows: < 1.8% as low, 1.8 – 2% as sufficient and > 2% as high. Bonheure and Wilson (1992) also reported values of critical levels of K and observed a deficiency level when plant leaf contained <1.16%; at 1.16 – 2% it was subnormal, at 2 – 3% it was normal, and above 3% was excess. General sufficiency or optimal range of K contents in plant for 90% crop yield is 1.0 – 5.0% (Havlin *et al.,* 2003).

Based on these categorizations, all treatments from experimental plots at both sites had higher K contents in sesame leaves, which is a reflection of high K contents in the soils of both Hombolo and Makutupora villages. This implies that if other factors are at optimum, these soils have high potential for sesame production with respect to K availability.

4.3.4 Sulphur

The sulphur contents of sesame leaf samples collected from the experiments at Hombolo and Makutupora villages are presented in Tables 5 & 6. The sulphur contents ranged from 0.02 – 0.29% and 0.03 – 0.33%, respectively. Tandon (1995) reported the critical levels of sulphur to be 0.1% in a recently matured leaf i.e the third leaf of a plant. In other studies, Bonheure and Wilson (1992) reported the ratings of sulphur contents in plant leaf as follows: - <0.05% as deficient, 0.05 – 0.1% as subnormal, 0.1– 0.3% as normal and above 0.3% as excess.

Also the general sufficiency or optimal range of S contents in plant for 90% crop yield is 0.1 – 0.3% according to Havlin *et al.* (2003). Based on these categorizations, the sesame plants from T1, T2, T3 and T4 of both sites are considered to be of low in S contents. The low sulphur contents in these treatments are the consequence of low levels of sulphur in the soils of Hombolo and Makutupora villages (Table 2). There was an increase of sulphur contents in the T5 and T6 at both Hombolo and Makutupora, being 0.19 and 0.29 and 0.28% and 0.33%, respectively.

The sufficiency S contents of sesame leaves in the treatments receiving N, P, K and S or Zn, probably could be due to the use of S containing fertilizer in these soils, which implies that for sesame production, use of sulphur-containing fertilizer is important while considering the synergistic relationship of S and Zn and other micronutrients (Pasricha and Aulakh, 1991). Also, S has been thought to have multiple roles in oilseed crop nutrition, since it is a major constituent of amino acids which constitute the building block of protein (Leustek *et al.*, 2000).

Application of S and Zn recorded higher plant S contents than in the other treatments, at both sites. The higher sulphur contents in sesame leaves of this treatmet is probably due to the interaction effect of sulphur and zinc which is synergistic. These results are in agreement with the findings of Shukla and Prasad (1979) in groundnut. Application of sulphur and micronutrients together with N, P and K significantly increased the nutrient contents.

Application of S plus Fe and Zn together with N, P and K recorded higher contents of nitrogen, phosphorus, potassium and sulphur than those in plots receiving N, P and K alone and the lowest was recorded in the absolute control. These findings are in agreement with the results reported by Pasricha and Aulakh (1991), who observed synergistic relationship of S and Zn in influencing uptake of other nutrients.

4.3.5 Calcium

Tables 5 & 6 show calcium contents in sesame plants grown at Hombolo and Makutupora sites. The contents of calcium from Hombolo ranged from 0.18 – 0.32% while that from Makutupora they ranged from 0.21 – 0.39%. Tandon (1995) reported the critical values for Ca contents in plant leaves as follows: - < 0.4% as low, 0.4 – 0.6% as sufficient and above 0.6% as high. Also, Havlin *et al.* (2003) reported the general sufficiency or optimal range of Ca contents in plant leaf for 90% crop yields to be 0.1 – 1.0%. Based on categorizations reported by Tandon (1995), all sesame leaf samples collected from experiment at Hombolo and Makutupora sites had low calcium contents. However, the results contradict the levels of calcium in soils (Table 2). This is probably due to the high levels of K in the soil which inhibited the uptake of calcium.

These findings are in agreement with the results reported earlier from poorly Ca supplied acidic soils of East Africa (Wilson, 1969). The leaf Ca content in plants was higher contrary to the levels of Ca in the soil. The reverse is also true, based on the concept that the content of a particular nutrient in plant is directly proportional to its availability in the soil (Mengel and Kirkby, 1987).

Several workers have reported the competition between Ca^{2+} and other cations such as K^+, Mg^{2+}, NH_4^+ and H^+ in soils (Burges, 1992; Landon, 1991; Owuor, 1989). It is then thought that relatively high concentration of one nutrient which competes with the other in the soil would occupy more exchange sites and would consequently be taken up more by plants.

4.3.6 Zinc

Data for zinc contents of sesame leaf samples from experiments at Hombolo and Makutupora villages ranged from 10.0 – 33.3 mg/kg and 10.00 – 46.67mg/kg, respectively (Tables 5 and 6). These values range from deficient to sufficient according to Tandon (1995) who gave the sufficiency range to be 20 – 200 mg/kg. Bonheure and Wilson (1992) categorized Zn nutritional status in recently matured leaf, i.e. third leaf of a plant, as follows: < 20 mg/kg as deficient, 20 – 25 mg/kg as sub-normal, 25 – 50 mg/kg as normal and above 50 mg/kg as excess. On the other hand, Landon (1991) categorized the concentration of Zn in matured plant leaves as follows: < 25 mg/kg as deficient, between 25 and 150 mg/kg as sufficient and above 150 mg/kg is excess or toxic. Also, Havlin *et al*. (1993) reported the general sufficiency or optimal range of Zn contents in plant leaves for 90% crop yields to be between 20 and 100 mg/kg.

There were slight increases in Zn contents over the control in the treatments receiving N, P, K and S in both sites. However, the lowest Zn contents were recorded in the absolute control, which is a reflection of the low Zn levels in the soils of Hombolo and Makutupora villages (Table 3). The slight increase in Zn contents over the control in the treatments receiving N, P, K and S implies that these nutrients enhance plant ability to take up more Zn from the soil.

The Zn contents in sesame leaf samples of treatments receiving N, P, K and S alone were below the critical concentration of 20 mg/kg established by (Tandon, 1995; Bonheure and

Wilson, 1992; Landon, 1991; and Havlin *et al*., 1993). This confirms that these soils were deficient in Zn and thus, N, P, K and S alone could not improve Zn availability to the optimum level in the soil. The sufficiency level of Zn contents of sesame leaves collected from experimental sites at both Hombolo and Makutupora villages was observed in the treatment receiving N, P, K, S and Zn. This was due to the application of Zn fertilizer in these soils, which implies that for sesame production application of Zn fertilizer in these soils is important while considering the interaction effect of Zn and other nutrient elements like N, P and S (Wilson, 1969).

Several workers have reported increase in Zn content upon Zn application. For example Patiel *et al.* (1979) reported sufficiency Zn content (23 mg/kg) in Zn deficient soils of Mubi, Nigeria. Sutaria and Patel (1987) also reported similar results in some soils of Nigeria in groundnut. In India, Gangadhara *et al.* (1990) reported high Zn concentration (25 mg/kg) in sesame leaf due to addition of Zn fertilizer in a Zn deficient soil.

4.4 Effect of N, P, K, S and Zn on Sesame Seed and Straw Yields from Experiments at Hombolo and Makutupora Villages

The data presented in Table 7 shows the effects of N, P, K, S and Zn on seed yields and straw dry matter production of sesame. N fertilizer significantly influenced both seed and straw yield. The significant response of yield and yield characters to N application is an indication of the role N in plant nutrition. N is one of the limiting nutrients in most soils of Dodoma, and plays an important role in vegetative growth, number of branches, leaves, pods, and seed per pod. Seed yield and straw dry matter yield from experimental sites at both Hombolo and Makutupora villages were increased due to application of N fertilizer. The significant increase in seed yield and straw yield when 45 kg N/ha was supplied indicating that the crop needs is met at this level. The present findings are in conformity with the results obtained by Subramanian *et al*. (1979) who reported significant increase in the seed yield at 60 kg N/ha.

Supplying K to the treatment receiving N and P showed a decrease of both seed and straw yield. However, the decreases were not statistically significant (p>0.05). Supplying P at Hombolo and Makutupora sites to the treatment receiving N significantly increased both seed and straw yield. The results indicate significant improvement in the growth and yield characters as a result of phosphorus fertilizer application. This was not surprising, considering the role of P in root development which in turn plays a very important role in the uptake of moisture and nutrients as well as providing anchorage. Its essentiality is noted as it is a constituent of cell nucleus and functions in cell division as energy provider (Subramanian *et al.*, 1979).

Among the five nutrients supplied, 45 kg S/ha together with 25 kg Zn/ha registered the highest sesame seed yield (1 393.8 kg/ha) and straw dry matter production (1 881 kg/ha) at Hombolo village (Table 7). Seed yiedls (1 461 kg/ha) and straw dry matter production (1 926 kg/ha) at Makutupora village (Table 8) which were significantly superior over the NPK (45 kgN/ha, 20 kgP/ha, 10 kgK/ha) treatment and the controls. The yield determining components such as seed weight and straw weight were significantly influenced by the application of N, P, K, S and Zn.

Table 7: Sesame seed yield and straw dry matter yield at Hombolo site

Treatments	Seed yields (kg/ha)	Straw dry matter yields (kg/ha)
Absolute control	141.0 a	709 a
$N_{45}P_0K_0S_0Zn_0$	651.9 b	983 b
$N_{45}P_{20}K_0S_0Zn_0$	874.1 c	1139 c
$N_{45}P_{20}K_{16}S_0Zn_0$	867.4 c	1126 c
$N_{45}P_{20}K_{16}S_{45}Zn_0$	933.3 d	1519 d
$N_{45}P_{20}K_{16}S_{45}Zn_{25}$	1393.8 e	1881 e
CV%	2.1	4

F – Statistics table are given in Appendix 8

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

Higher seed yields (933.3 kg/ha and 1 461 kg/ha) and straw dry matter yields (1 519 kg/ha and 1 926 kg/ha) at Hombolo and Makutupora sites Table 7 and 8, respectively, were obtained with the addition of sulphur together with N, P and K. Seed yiels and straw dry matter yields of sesame at both sites were increased gradually with increase in the number of nutrient elements added and was significantly superior when Zn was applied together with N, P, K and S. The beneficial influence of micronutrients might be due to the activation of various enzymes and the efficient utilization of applied nutrients resulting in increased yield components as reported by Shanker *et al.* (1999).

Shanker *et al.* (1999) reported the highest seed and straw yields of 794 and 2 299 kg/ha in a treatment where Zn, Mn and S were combined in comparison with 540 and 1 223 kg/ha in the control. The results are also in conformity with the findings of Patel and Singh (1995) in sunflower and Sharma and Bhadhani (1995) in apples. Combination of levels of sulphur and micronutrients had significant influence on seed yield. Also the findings are in general agreement with the results reported by Pasricha and Aulakh (1988) who observed that addition of sulphur resulted in significantly higher dry matter and seed yield (2.6 t/ha) and seed nutrient content.

Table 8: Sesame seed yield and straw dry matter yield from Makutupora site

Treatments	Seed yield (kg/ha)	Straw dry yield (kg/ha)
Absolute control	197.4 a	907 a
$N_{45}P_0K_0S_0Zn_0$	793.8 b	1249 b
$N_{45}P_{20}K_0S_0Zn_0$	889.7 c	1370 c
$N_{45}P_{20}K_{16}S_0Zn_0$	903.7 c	1398 c
$N_{45}P_{20}K_{16}S_{45}Zn_0$	1086.4 d	1778 d
$N_{45}P_{20}K_{16}S_{45}Zn_{25}$	1461.7 e	1926 e
CV%	1.5	1.2

F – Statistics table are given in Appendix 9

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

At Hombolo site, there were smaller yield responses than at Makutupora site though the levels of N, P, K, S and Zn supplied were the same. The smaller yield responses at this site than at Makutupora site is also consistent with the small values of dry matter production, which indicated that there was some other yield limiting factors. The other reason for the low yield responses may be due to differences in some physical chemical properties of soils from these sites. This soil had pH value of 4.75 and calcium levels of 3.79 cmol(+)/kg which are considered to be low according to Landon (1991). The present study clearly indicated that the use of the recommended dose of NPK along with soil application of Zn at 25 kg/ha + S at 45 Kg/ha would be beneficial for increasing the productivity of sesame in Dodoma district.

4.5 Summary of the Results

The results indicated that all soils sampled had low total N, and 70% of the soils were deficient in P, 90% had low extractable S and 70% had low Zn levels. All the soils had adequate levels of Mg, K, Cu, Fe and Mn, but all had marginal to low levels of Na. However, all the soils had suitable physical conditions for sesame production. Use of N, P, and S generally increased sesame seed yield from both sites and all five nutrients together gave the highest seed yields. Zinc, together with NPKS, further increased sesame seed yields and straw dry yields in both sites. The study also showed that increased nutrient contents of sesame leaves were consistent with the dry matter yield increases. Most of the soils under sesame production in the district were deficient in N, P, S and Zn and require fertilization using these nutrients.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results of the current study it was concluded that:-

1. N, P, S and Zn were the major nutrients deficient in all villages, and are responsible for low sesame yields. However, S and Zn were the most serious problem.
2. Most of the soils under sesame production in Dodoma district were deficient in N, P, S and Zn. Therefore, its use is beneficial to increase sesame yield.

5.2 Recommendations

From the findings of the current study the following are recommended.

1. N, P, S and Zn must be applied to the rates of 45 kg/ha, 20 kg/ha, 45 kg/ha and 25 kg/ha, respectively, in order to increase sesame yields in the district.
2. However, the rates tested might not be optimum; therefore, further study is recommended to establish optimum rates of these nutrients on sesame production in Tanzania.
3. Further research should be conducted to assess the suitability of Minjingu mazao fertilizer to the soils of Dodoma to supply P, S and Zn.
4. Further research is recommended on the effect of sulphur and zinc supplementation on increasing oil and protein contents in sesame seeds.
5. The findings of this study may not cut across other crops. It would, therefore, be rational to extend this study to cover other oilseed crops.

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APPENDICES

Appendix 1: Sesame Production trend in Dodoma district

Season	2005/2006	2005/2006	2007/2008	2008/2009
Production (t/ha)	0.65	0.57	0.61	0.51

Source; RAA Dodoma personal communication, (2010)

Appendix 2: Critical levels of nutrients in soil

Nutrients	High	Medium	Low
N (% of soil by weight)	0.5 – 1.0	0.2 – 0.5	0.1 – 0.2
Available P (ppm)	> 50	50 – 15	<15
Available K (me/100g soil)	>0.6	0.6 – 0.15	<0.15

Source; Landon (1991)

Critical limits for DTPA-extractable micronutrients in soil

Availability	Zn	Cu	Fe	Mn
Very low	0 – 0.5	0 – 0.1	0 – 2	0 – 0.5
Low	0.5 – 1.0	0.1 – 0.3	2 – 4	0.5 – 1.2
Medium	1 – 3	0.3 – 0.8	4 – 6	1.2 – 3.5
High	3 – 5	0.8 – 3	6 – 10	3.5 – 6
Very high	> 5	> 3	> 10	> 6

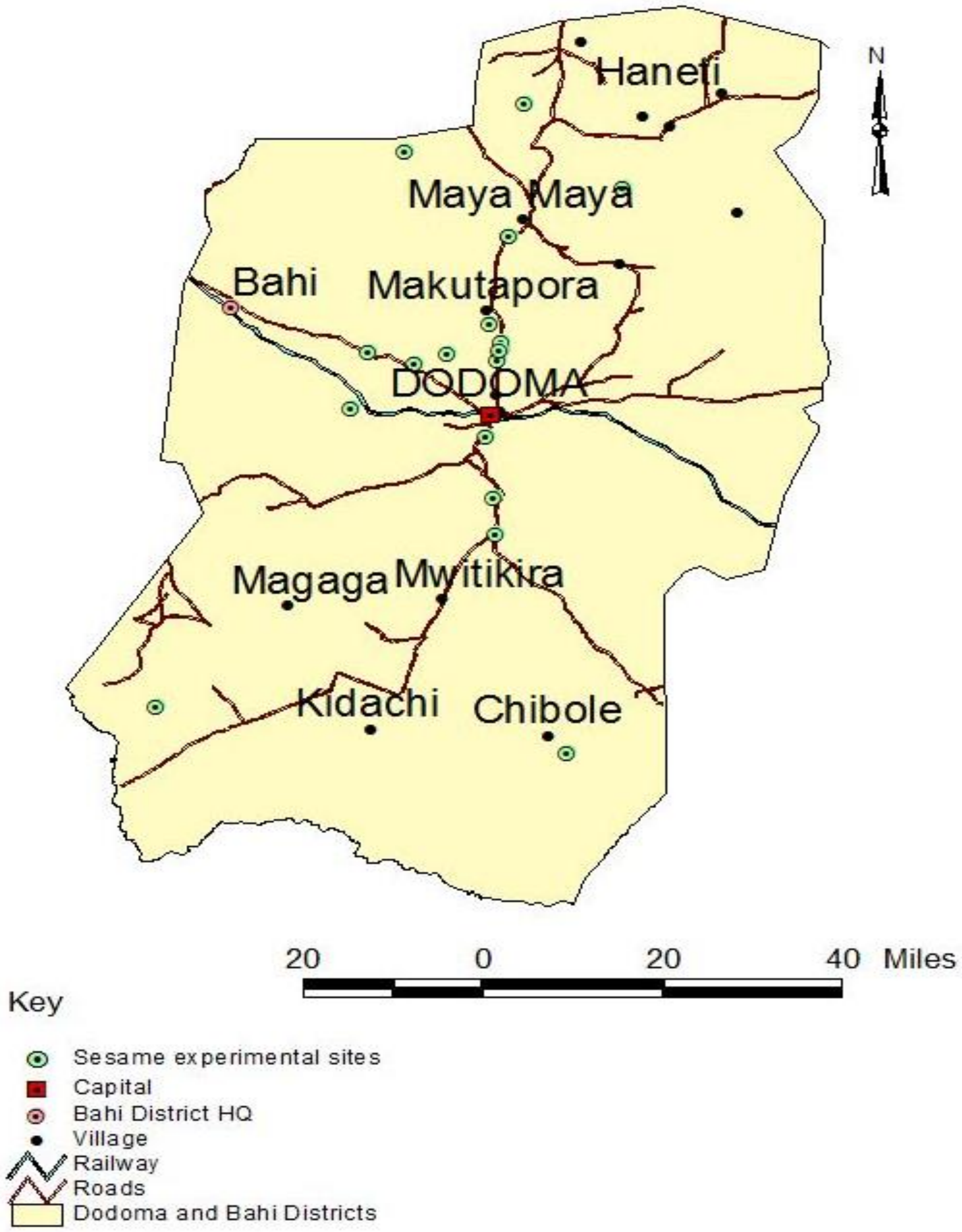
Source; Landon (1991)

Appendix 3: Critical nutrient concentrations in oil seed crops

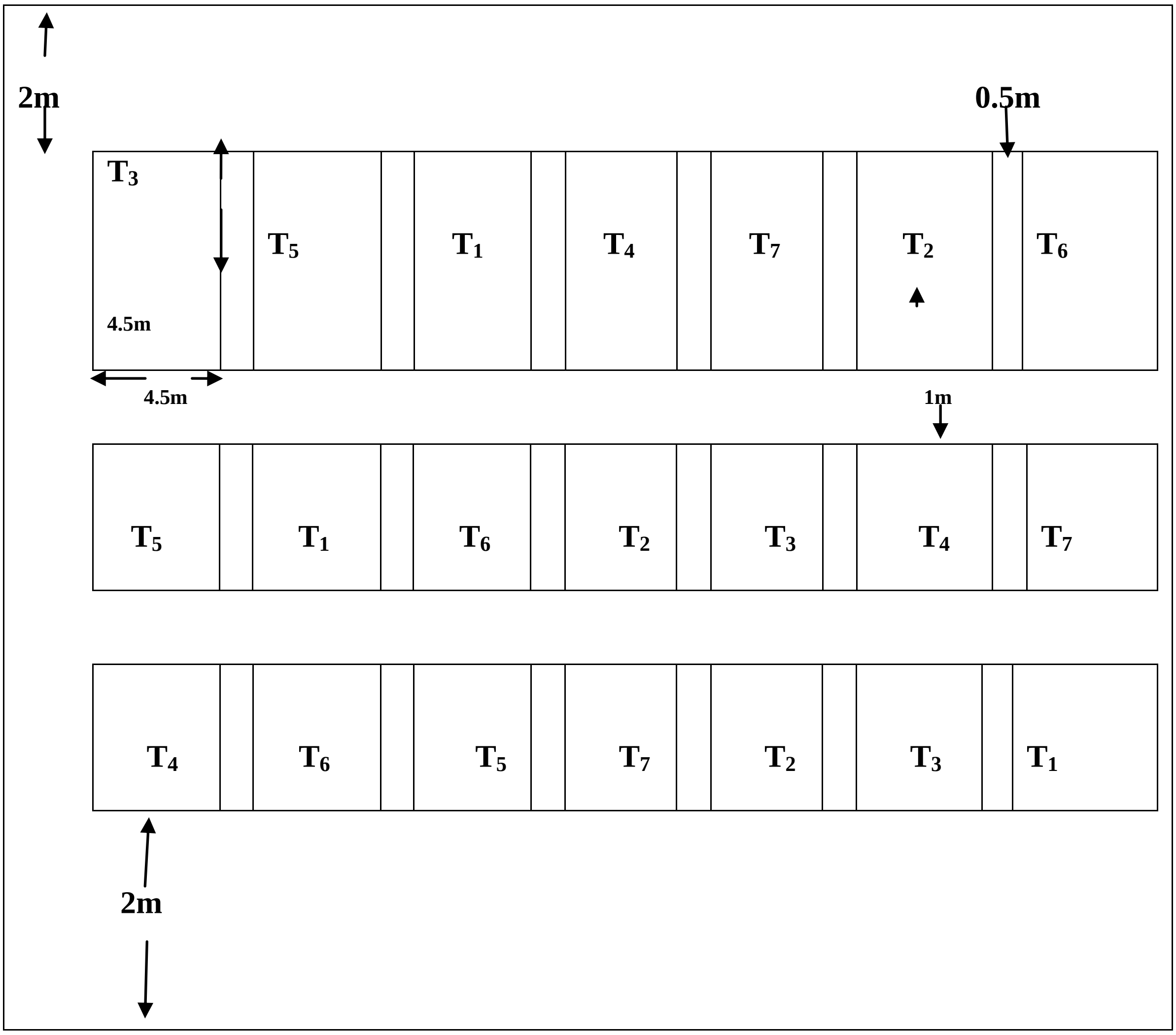
Macronutrients	**Percentage (%)**	**Micronutrients**	**mg/kg**
N	3.5	Cu	5
P	0.3	Zn	20
K	2.5	Fe	50
S	0.5	Mn	30
Ca	0.4	Mo	0.3
Mg	0.2	Bo	25

Source: Havlin *et al.,* (2003)

Appendix 4: A map of Dodoma District showing locations from was experimental soils collected



Appendix 5: Field layout of the trial



Appendix 6: Nutrient sources and amount applied in each plot

Fertilizer source	Amount applied (g/plot)
UREA	198 in T_2, T_3 and T_4 , 17.6 in T_5 and 67 in T_6
TSP	198 in T_3, T_4, T_5, and T_6
$(NH_4)_2SO_4$	287 in T_6 and 396 in T_5
KCl	67 in T_4, T_5, and T_6
$ZnSO_4$	126 in T_6

Appendix 7: F – statistics for Dry matter yield (g/plot) at Makutupora and Hombolo Makutupora site – ANOVA table

```
  K                Degrees of  Sum of      Mean       F
Value   Source      Freedom   Squares     Square     Value     Prob
---------------------------------------------------------------------
  1   Replication     2         0.496       0.248     5.5841    0.0235
  2   Factor A        5       172.555      34.511   776.9685    0.0000
 -3   Error          10         0.444       0.044
---------------------------------------------------------------------
      Total          17       173.495
---------------------------------------------------------------------
   Coefficient of Variation: 2.53%
```

Hombolo site – ANOVA table

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	0.548	0.274	6.9957	0.0126
2	Factor A	5	181.025	36.205	923.8162	0.0000
-3	Error	10	0.392	0.039		
	Total	17	181.965			

Coefficient of Variation: 2.66%

Appendix 8: F – statistics for seed yield and straw Dry matter yield (kg/ha) at Hombolo site

Seed Yield – ANOVA table

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	3185.252	1592.626	5.6832	0.0225
2	Factor A	5	2504683.637	500936.727	1787.5680	0.0000
-3	Error	10	2802.337	280.234		
	Total	17	2510671.226			

Coefficient of Variation: 2.07%

Straw Dry Yield – ANOVA table

```
  K                  Degrees of   Sum of        Mean       F
Value    Source       Freedom    Squares       Square     Value    Prob
------------------------------------------------------------------------
  1    Replication    2     11545.376      5772.688     1.1302      0.3610
  2    Factor A       5   2549860.199    509972.040    99.8433    0.0000
 -3    Error         10     51077.256      5107.726
------------------------------------------------------------------------
    Total            17     2612482.831
------------------------------------------------------------------------
Coefficient of Variation: 5.78%
```

Appendix 9: F – statistics for seed yield and straw dry matter yield (kg/ha) at Makutupora site

Seed yield – ANOVA table

```
  K                  Degrees of   Sum of        Mean        F
Value    Source       Freedom    Squares       Square     Value      Prob
------------------------------------------------------------------------
  1    Replication          2       210.950       105.475        0.5636
  2    Factor A             5   2563818.859    512763.772   2739.7648   0.0000
 -3    Error               10      1871.561       187.156
------------------------------------------------------------------------
       Total          17   2565901.370
------------------------------------------------------------------------
    Coefficient of Variation: 1.54%
```

Straw dry yield – ANOVA table

```
  K                    Degrees of   Sum of        Mean         F
Value    Source        Freedom    Squares       Square       Value         Prob
---------------------------------------------------------------------------
  1    Replication       2         223.746         111.873         0.3972
  2    Factor A           5      2031668.000    406333.600   1442.7524   0.0000
 -3     Error            10         2816.378         281.638
---------------------------------------------------------------------------
       Total              17       2034708.124
---------------------------------------------------------------------------
    Coefficient of Variation: 1.17%
```