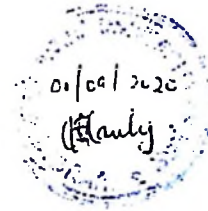


**POTENTIAL OF VERMICULITE AS A SOIL AMENDMENT MATERIAL IN  
IMPROVING PRODUCTIVITY OF TOMATO  
(*LYCOPERSICON ESCULENTUM L.*)**



**FOR REFERENCE  
ONLY**

**BY**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP  
SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE.  
MOROGORO, TANZANIA.**

### ABSTRACT

A pot experiment and laboratory analysis were conducted at Sokoine University of Agriculture (SUA) from October to February 2008, to assess the effectiveness of vermiculite as a soil amendment material for enhancing tomato growth and yield. A 3 x 4 factorial experiment using a split plot arrangement was conducted using sandy, clayey and loamy soils as factor A and four vermiculite levels; 0%, 10%, 20%, and 40% in volume basis were factor B. Growth and yield components of tomatoes were assessed and analyzed to identify their response to vermiculite. Water holding capacity and bulk density of soils mixed with vermiculite was determined using a pF moisture characteristic curve, whereby a 40% vermiculite level retained the highest moisture followed by 20%, 10% and the least was soil without vermiculite. A 40% vermiculite level increased moisture retention by 113%, in sandy soil, 40.7% in loamy soil and 6% in clay soil. Bulk densities were decreasing as the vermiculite level increased which indicated the increase in aeration and drainage in clay soil. Results of pot experiment indicated that the number of tomatoes was remarkably increased by the application of vermiculite especially in sandy soils. Application of 40% vermiculite level on sandy soil increased total dry matter at 28 DAP by 80% while the increase in clay was 40% and 55.4% in loamy soil. The weight and number of tomato harvested in sandy soil with 20% vermiculite level was the highest. Potassium content in tomato plant grown in sandy with 40% vermiculite was 1.62% below the critical value which is 2.50%. This was caused by vermiculite fixation which was increasing as the vermiculite increased and this resulted into low K<sup>+</sup> supply thus lowering tomato yield. It was concluded that 20% vermiculite level was the best rate to be applied on sandy soils in order to increase growth and yield of tomatoes while 40% vermiculite is the appropriate level for loamy and clayey soils.

**DECLARATION**

I, **ELIAH ANDINGENIE KAMWELA**, do hereby declare to Senate of the Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been nor concurrently being submitted for a higher degree award in any other University.



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The above declaration is confirmed



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**DEDICATION**

To my wife Eliza Kamwela, my daughters Hellen, Zawadi, Mercy, and Ruth, my Pastor  
Z. Ryoba, my sister Ruth and the Canaan Church members.

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**LIST OF ABBREVIATIONS AND ACRONYMS**

<b>%</b>	<b>Percent</b>
<b>°C</b>	<b>Degree centigrade</b>
<b>AAS</b>	<b>Atomic Absorption Spectrophotometer</b>
<b>Al</b>	<b>Aluminium</b>
<b>As</b>	<b>Asenic</b>
<b>BD</b>	<b>Bulk Density</b>
<b>Be</b>	<b>Berilium</b>
<b>Ca</b>	<b>Calcium</b>
<b>CEC</b>	<b>Cation Exchange Capacity</b>
<b>cm</b>	<b>Centimeter</b>
<b>Cmole</b>	<b>Centimole</b>
<b>CO<sub>2</sub></b>	<b>Carbon dioxide</b>
<b>Cr</b>	<b>Cromium</b>
<b>Cu</b>	<b>Copper</b>
<b>CV</b>	<b>Coeficient of Variation</b>
<b>DAP</b>	<b>Days After Planting</b>
<b>DM</b>	<b>Dry Matter</b>
<b>DNMRT</b>	<b>Duncan New Multiple Range Test</b>
<b>FAO</b>	<b>Food and Agriculture Organization</b>
<b>Fe</b>	<b>Iron</b>
<b>g</b>	<b>Gram</b>
<b>GDP</b>	<b>Gross domestic product</b>
<b>ha</b>	<b>Hector</b>

HCl	Hydrochloric acid
K	Potassium
Kg	Kilogram
Li	Lithium
LSD	List Significant Difference
m.a.s.l.	Meters above sea level
Me	Mil equivalence
Mg	Magnesium
Mls	Mils
Mn	Manganese
N	Nitrogen
Na	Sodium
P	Phosphorus
P <sub>2</sub> O <sub>5</sub>	Phosphate
Pb	Lead
ppm	Part per million
RCBD	Randomized Complete Block Design
RG	Relative Growth Rate
R-S	Root shoot ratio
S	Sulphur
S/A	Sulphate of Ammonia
SE	Standard error
SUA	Sokoine University of Agriculture
TSP	Triple super phosphate

URT	United Republic of Tanzania
USD	United States of America Soil Science Department
Zn	Zinc

## CHAPTER ONE

### 1.0 INTRODUCTION

#### 1.1 Back ground information

Tanzania is among the developing countries south of the Sahara, whose economy mainly depends on agriculture (Devereux and Maxwell, 2001). Report by the United Republic of Tanzania (URT) (2004), indicate that the agriculture sector accounted for nearly 60% of the Gross Domestic Product (GDP) in 1995, of which 63% was from crop production. It has been reported that agriculture is the main source of employment and livelihood for more than two thirds of the Tanzania population. Agriculture employs about 90% of the work force for the production of food for domestic consumption, for export as well as for industrial raw materials (URT, 2001). According to URT report (2006), 9 521 592 ha which is 64% of the total area of Tanzania was under crop production. The area under cereals is 4 798 071 ha while fruits and vegetables occupy about 74 257 ha. Among fruits and vegetables, tomato (*Lycopersicon esculentum L.*) is the most popular and widely consumed vegetable in Tanzania. It is grown throughout the country where irrigation water and arable land are available and is mainly grown by small holders. In 2002/03, a total of 129 588 tones of tomatoes were harvested in various parts of Tanzania (URT, 2006).

Tomato is one of the most important vegetables in Tanzania, ranking first in acreage and second only to cabbage in production and economic value (Nono-Womdim *et al.*, 2002). The crop is popular due to its high nutritive value (high in vitamin C and A) and contributes to dietary quality improvement. The crop forms an integral part of the diet of

the people all over the country. It is used as a fresh vegetable, processed and stored through the process of canning for future consumption.

In the semi arid and arid tropical region of Tanzania where sandy soils dominate, low moisture content in soil limit tomato production because sandy soils are poor in nutrient and moisture retention, hence during the dry period moisture stress affects tomato yields and quality (Rweyemamu *et al.*, 1999). Normally tomatoes are grown during the dry season in tropical regions when disease-causing pathogens and flood incidences are low (Phene, 1989). Other problems causing low yield of tomato are water logging condition (which prevent air to reach the root zone) and soil compaction which hinders root growth and penetration for tomatoes grown in clayey soils (Villared, 1980).

Significant portion of the land area of Tanzania lies on the great African plateau with altitude ranging from 1000 – 2000 meters above sea level (m.a.s.l.) with exception of the narrow coastal belt (URT, 2001). The semi-arid zone occupy about one third (29 500 km<sup>2</sup>) of total land of Tanzania (Boesen *et al.*, 1999). Most of this semi - arid areas have sandy and coral soils. These soils are associated with poor moisture retention capacities. The annual rainfall in these areas is less than 800mm and its onset is unpredictable (Boesen *et al.*, 1999; Ngana, 1993).

Soil management strategies thus need to be developed to improve soil characteristics for the enhancement of tomato production. Sewage-sludge and organic compost have been used to improve water retention on sandy soils (Tester, 1990). But sewage-sludge is not readily available to the small household farmers in Tanzania. Vermiculite can also be

used for soil amendment, as it increases moisture retention in sandy soils and aeration in clayey soils (American Vermiculite, 2001). Vermiculite is further used in horticultural production in various parts of the world to improve soil aeration, moisture and nutrient retention (Moetler, 2002; Stasovsk *et al.*, 1991). Vermiculite performs this role very well because of its structure, which roughly resembles a stack of plates. In between these plates, water and nutrients are trapped rather tightly, but plant roots have the ability to extract what they need. Vermiculite is a 2:1 clay mineral with a high cation exchange capacity (CEC) (Hudson, 2002). In addition when vermiculite undergoes decomposition (weathering) substantial amounts of macronutrients such as potassium, magnesium and a number of micronutrients are released into the soils, hence improving the fertility status of the soil.

According to Harris, (1978) vermiculite deposits in Tanzania are found in Mikese Morogoro rural district, Kidete in Kilosa district, Kwekivu and Mzika in Handeni district. Almost 200 tons of vermiculite was mined from Mikese before independence in 1961 (Harris, 1978). The mining was stopped just before Tanzania became independent in 1961 due to difficulty in obtaining a satisfactory market for the product, since then mining of vermiculite in Tanzania almost collapsed.

## **1.2 Justification**

A greater proportion of Tanzania can be described as arid or semi-arid on the basis of having a probability of less than 25% receiving 750 mm of rainfall per annum (Nieuwolt, 1977). Nearly throughout the country, potential evapotranspiration exceeds rainfall for more than nine months in a year and soils which are found in these regions are usually poor in water and nutrient retention. Heavy clay, clay loam, loamy sand, sandy loam, and

sandy clay are found in altitudes of 1 500 - 2 000 m above sea level and usually associated with poor drainage and are of low agricultural potential (URT, 2001). Yield of tomatoes in Morogoro region is low with an average of 3.50 t/ha compared to the national tomato yield average of 8 t/ha (Nono-Womdim *et al.*, 2002). Unfavorable soil conditions (physical and chemical properties), are among the factors causing low yield of tomato in Morogoro. Morogoro and Tanga regions are among the main potential tomato producers in Tanzania, contributing to about 27.3% of all tomato production in Tanzania (URT, 2006).

Ways of improving the soil characteristics that negatively affect tomato growth and yield need to be given due consideration. In many countries, vermiculite is used in soil amendment for vegetable production (Wall, 1972). Vermiculite is mixed with soil in order to enhance soil moisture and nutrient retention capacities of sandy soils, improve soil aeration and reduce soil compaction in clayey soils (Jayabalakrishnan, 2007). If soil amendment strategies which improve soil physical and chemical properties are given consideration especially in sandy and clayey soils, tomato production and yield per unit area will certainly increase.

### **1.3 Objectives**

#### **1.3.1 General objective**

The overall objective of the study was to assess the effectiveness of vermiculite as an inorganic soil amendment material on various soil types for enhancing tomato growth and therefore to increase yield.

### **1.3.2 Specific objectives**

- (i) To establish the chemical and physical properties of the clayey, loamy and sandy soils to be used for pot experiment.**
- (ii) To assess the effects of applying vermiculite on the physical and chemical properties of clayey, loamy and sandy soils.**
- (iii) To evaluate growth and yield of tomatoes using increasing levels of vermiculite to clayey, loamy, and sandy soils.**

## CHEPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Tomato growth

Plant growth, development and yield is the product of the interaction of soil, environment and plant properties (Gardner *et al.*, 1985). Soil is the natural medium for plant root growth from which plant roots absorb nutrients, water and air also provide anchorage to plant. Maximum plant growth depends on the soil having the appropriate biological, chemical, and physical conditions necessary for the root system to maximize the absorption of plant nutrients and water and to enable the biochemical reactions to take place in the plant.

#### 2.2 Tomato production in Tanzania

Tomatoes are grown all over the country, mainly as cash crop although some small quantities are cultivated for household use. Morogoro region has the largest planted area of tomato (6 159 ha or 19.3 % of the total tomato planted area in Tanzania) followed by Iringa, Tanga, Ruvuma, Mwanza Kagera, and Kilimanjaro (URT, 2006). However production levels are low ranging from 3.99 t/ha to 8.2 t/ha (URT, 2006). Cal J determinate tomato which was used as a test crop is a most popular variety grown in Morogoro region locally known as Dumudumu. Its yield as tested at AVRDCs experimental farms Arusha ranged from 13 – 20 t/ha. Among the factors causing low yield of tomatoes are inadequate rainfall, poor soil condition, low nutrient content and availability, insect pests and disease infections (URT report, 2006). In Tanzania, tomatoes are normally grown during the dry season, but also large quantities are grown during the rainy season in certain regions. This is due to increasing demand and high

price of tomatoes during the rainy season. URT report (2006) indicates that the households growing tomatoes during rainy season in Tanzania was 97 812 which is equal to two percent of the total crop growing household in Tanzania in rainy season, compared to 47 581 households growing during dry season in 2003.

### **2.3 Growing conditions for tomatoes**

#### **2.3.1 Soil condition**

Tomatoes perform very well on deep and well-drained soils such as sandy loams, silt or clay loam. Water logging conditions can easily affect tomato root respiration and cause death of a whole plant (Phene, 1989). The optimum pH range is from 6 – 7.

#### **2.3.2 Climatic conditions**

The optimum temperature range for tomato growth is between 20°C – 27°C. Temperature above 30°C or below 10°C causes poor tomato fruit setting (Lin *et al.*, 2007). High temperature condition adversely affects the vegetative and reproductive processes and ultimately reduces yield and quality of tomatoes. Also interfere both availability, uptake of nutrient by the roots and the shoot growth rate and hence affect mineral nutrient content in plant. High temperature affects physiological and biochemical processes such as photosynthesis, enzyme activity, membrane integrity, electron transport in chloroplast, stomatal conductance to CO<sub>2</sub> diffusion and photoassimilate translocation (Abdelmageed *et al.*, 2003).

### 2.3.3 Nutrient requirements

Tomatoes are considered 'heavy feeders' because of their rapid growth and long production season. Production of one tonne of tomato fruit removes about 1.4 to 3.6 kg N, 0.22 to 0.61 kg P<sup>5+</sup> and 1.9 to 4.6 kg K<sup>+</sup> from the soil. The period of greatest N, P and K requirement for tomato is from about ten days after flowering to just before the fruit begins to ripen (Dangler and Locasio, 1990). This is the period when most assimilates are translocated to the fruits. Potassium is required for fruit set and enlargement. Its deficiency affect the quality of tomato fruits. Important growth stages for potassium uptake include seedling establishment when maximum nutrient efficiency uptake occurs, and early fruiting when the maximum rates of K accumulation take place (Dangler and Locasio, 1990).

### 2.4 Nutrient uptake

Acquisition of mineral nutrients by soil-grown plants requires two complementary processes: (a) the growth of roots to reach the nutrients; and (b) the transport of nutrients from the bulk soil to the root (Jungk and Claassen, 1997). Therefore, nutrient uptake is governed by the interactions at the soil–root interface, including (a) root morphology and growth rate; (b) nutrient absorption kinetics of the root and (c) soil nutrient supply. Root system usually grows poorly in compacted soils due to low supply of water and nutrient (Bennie, 1991). This affects the shoot growth and thus transpiration rate is reduced, these reduce the mineral nutrient uptake. But inhibition of root elongation is not necessarily correlated with inhibited uptake of mineral nutrients because compacted soil increases the contact between roots and soil thereby also delivery rate for mineral nutrients (Silberbush *et al.*, 1983; Shierlaw and Alston, 1984). It is necessary to assess the nutrient

status of tomato plant material to know whether they fall within the acceptable range or not. In that case it is advisable to take young mature leaves. Taking leaves higher or lower on the plant will have serious effects on the level of nutrients especially for mobile elements. Young mature leaves of tomato are good indicator because its deficiency and toxicity range of many elements is wider compared to old or young leaves. Example, potassium in young mature leaves of tomato range between 1.5 – 5.5% compared to 3.0 – 3.5% in young leaves (Marschner, 1997).

The amount of nutrients taken up by tomato crop depends on the number of fruits, root density and the amount of dry matter produced which in turn is influenced by a number of genetic and environmental variables (Shukla and Naik, 1993). Lin *et al.* (2007) found that soil structure, moisture content and drainage, high soil temperature increases the mobility and absorption of nutrients. However, Bergmann (1992) observed reduction in K and Ca absorption at high temperature. Varieties which take long time to mature require more nutrients than short-duration ones, mainly because of their higher production of dry matter (Shukla and Naik, 1993).

### **2.5 Root and shoot development**

Normally tomatoes are not sown direct to the field but they are grown in nurseries and when reaches three weeks are transplanted in the field. During transplanting a tap root can be broken or curved sidewise or even upwards, as a result several large lateral roots arise at the points where the curving occurs or directly above them (Phene, 1989). Roots absorb nutrients from soil; transpiration pull and mass flow take them to the branches

and leaves. Therefore a certain ratio between roots and shoots should be reached for the plant to perform well.

Root-shoot (R-S) ratio has physiological significance, since it can reflect type of tolerance to drought stress (Haase and Rose, 1993). Although R-S ratio is genetically controlled, it is also strongly influenced by environment. Water stress reduces shoot growth because the nutrient supply to the shoots is decreased during water stress condition. But contrarily to shoot growth, root growth is increased during the water stress condition. This is the physiological adaptation during the drought condition which enables the plant to increase its ability to extract water from the soil (Gardner *et al.*, 1985). The R-S ratio balance is based on the truth that, a certain amount (surface area or dry mass) of transpiring foliage needs a certain amount (surface area or dry mass) of roots to absorb soil water and offset transpirational losses. A low R-S ratio means that roots are abundant with respect to the foliage area, and that the seedling has high water stress avoidance potential (Bernier *et al.*, 1995). A high ratio means that the roots are not abundant as shoot, and that the seedling is more likely to suffer from water stress, particularly in droughty sites or under conditions of high evaporative demand (Haase and Rose, 1993). Root-shoot ratio is thus used to evaluate the drought avoidance potential of seedlings (Haase and Rose, 1993).

Root-shoot ratio of many crops is smaller in compacted soils than in loosened soils (Atwell, 1990). This might be caused by limited nutrient and water supply to the shoots. Peterson *et al.* (1991b) identified another probable cause to be the increase of ethylene and decrease of oxygen thus reduced root respiration in the root zone.

## **2.6 Influence of soil properties**

The capacity of soil and artificial soil substrates to transform nutrients plays a key role in occurrences of nutrient deficiency and excess (Bergmann, 1992). Lack of knowledge regarding the amount of nutrients available to the plant and the application of adequate quantities of fertilizer can lead to the appearance of nutrient deficiency, and in some cases excessive (Bergmann, 1992).

Change in pH value in either direction due to the application of fertilizers, can lead to nutrient deficiency or excess due to immobilization or increased nutrient release, respectively (Mengel and Kirkby, 1978). Nutrient availability and uptake are reduced in acid soils, leading to deficiency of phosphorus potassium, magnesium, sulfur, and molybdenum, but excessive aluminium, iron and manganese toxicity (Mengel and Kirkby, 1978).

A soil with a good physical structure and texture must have pores and channels of many sizes that will allow rainfall and irrigation to penetrate without producing runoff that will wear away topsoil layers and beneficial organic matter. Anaerobic conditions develop when air exchange is inadequate causing roots to lose their ability to absorb nutrients and water, as result photosynthesis rates decline, stomata close, and shoot growth slows (Kozlowski, 1985). The presence of soil organic matter helps to form and maintain air passages and channels. In addition to preventing erosion, compaction caused by maintenance equipment and mowers is minimized when soils drain properly.

### **2.6.1 Soil texture**

The effect of poor soil texture and structure can be modified by using soil conditioners. Soil conditioners act to improve soil aeration, drainage, moisture-holding capacity and tilth, or workability, of the soil. Commonly used soil conditioners include compost, peat moss, sawdust, wood chips, composted animal manures, green manure crops, coarse sand, vermiculite, sludge, bentonite and perlite (Suganya and Sivasamy, 2006), (Mokhtaruddin *et al.*, 2001). By incorporating coarse, rather than fine sand, and organic matter into a garden soil, the gardener can, over time, produce a desirable loamy-type soil. The addition of fine sand to some soils, especially clay, however, will be detrimental to the soil structure.

A well-aggregated soil is generally the most desirable condition for plant growth, especially in the critical early stages of germination and seedling establishment. The shapes, sizes, and densities of aggregates and consequent soil porosity will generally vary within the profile. Aggregate size distribution is a determinant of pore-size distribution, which directly affects the water holding capacity of the soil and strongly influences drainage and aeration.

#### **2.6.1.1 Clayey soils**

Three textural classes are known which have clayey properties. Normally clay (contain of at least 40% clay), sand clay (contain of at least 35% clay) and silt clay (contain of at least 40% clay) (Brady and Well, 1996). Soils with high levels of clay have small particle size and are frequently compacted, and have few air pockets. Clay particles are fine, flat, and packed tightly together. These characteristics result in a plant-resistant soil

that stunts root growth and is nearly impossible to till because of its weight and density. High levels of clay may encourage root rot on some plants due to constantly soggy soil. Although clay is rich in minerals, its impenetrable mass discourages soil-friendly organisms from working the soil. Since the structure of clayey soils is easily compactable, water absorption and retention is a problem. Pores of clay are very small and fill quickly and poorly drained (Brady and Well, 1996). This condition causes oxygen deficiency and accumulation of carbon dioxide and other phytotoxic substances in the soil environment, primarily acetic acid and other volatile fatty acids may accumulate in concentration that is phytotoxic. These acids are detrimental to roots elongation and growth (Marschiner, 1997). The acids that are mostly accumulating in waterlogged condition are acetic acid, propionic acid, butyric acid, and valenic acid. Affected roots fail to absorb water and nutrients, which cause poor fruit setting, reduce growth, promote diseases and fungus growth in tomato (Phene, 1989).

The purpose of soil amendment with clay soil is to improve soil aggregation, increase porosity and permeability, and improve aeration and drainage. Clay soils can be effectively amended through the addition of fibrous organic matter such as peat, wood chips, straw and vermiculite.

#### **2.6.1.2 Sandy soils**

Soils dominated by the properties of sand comprise at least 70% of the material by weight, less than 15% of the material is clay. The two textural classes with sandy properties are sand and loamy sand (Brady and Well, 1996). Sandy soils contain larger mineral particles separated by wide open pore space. The spaces between the soil

particles allow water to drain too fast, carrying beneficial nutrients away from the plant roots. Sandy soils dry out quickly even after a heavy down pore because it contain little organic material. Sandy soils heat up fast during the day, and cool down quickly when the sun goes down. This alternation of soil temperature change causes stress on plants. Sandy soils are otherwise potentially unproductive due to their poor physical and chemical properties. Management of sandy soils through proper reclamation measure to increase crop productivity assumes a great deal of interest in a day wherein the available land area for cultivation is declining all the time (Suganya and Sivasamy, 2006).

When amending sandy soils, the goal is to increase the soil's ability to hold moisture and store nutrients (Nono-Womdim *et al.*, 2002). To achieve this, composted organic matter, aged manure, sphagnum peat, or vermiculite are mixed with sandy to improve water retention, stabilize roots, hold nutrients and establish an environment attractive to earthworms and other helpful organisms. Due to leaching, sandy soils have very little clay particles, which can form organic-clay complexes therefore have low cation exchange capacity (CEC). Mulching is one of the strategies used for moisture conservation, but vermiculite serves both, moisture conservation and increase cation exchange capacity in sandy soils (Hudson, 2002).

#### **2.6.1.3 Loamy soils**

Loamy soils compose about 40% sand, 20% clay, and 40% silt (Brady and Well, 1996). Loamy soils contain many sub divisions, loam in which sandy is dominant is called sandy loam, in the same way silt loam and clay loam where silt and clay respectively are dominant. This combination is ideal because it allows water, air, and nutrients to flow

downward to the roots of the plants. Loamy soils are generally considered the most suitable for tomato production (Hegde, 1997). These soils are lightweight, non-compacted texture, and provide a secure anchor for root systems while still permitting the roots to spread evenly, providing a perfect home for worms and other soil-benefiting organisms.

### **2.6.2 Soil compaction**

Soil compaction has marked effects on performance of many agricultural species, it restricts the volume of soil explored by roots and affect shoot growth (Atwell, 1990). Dawkins *et al.* (1983) found that the shoot: root ratio in peas was smaller when grown in compacted than loosened soil.

Soil compaction causes the soil bulk density to increase with the accompanying decrease in total porosity. Compaction reduces total air-filled (non capillary) pore space and reduces average pore size, increases mechanical resistance to root penetration, and can increase or decrease water holding capacity, depending on the amount of compaction, and initial bulk density and pore size distribution. With the loss of macro-pore space, water infiltration and gas diffusion is reduced, soil oxygen concentration is decreased and carbon dioxide concentration can increase, possibly to toxic levels. This deterioration in quality of the soil environment renders the soil less favorable for root growth (Craul, 1992). The forces of the roots necessary for displacement of soil particles readily become limiting and root elongation rates decrease (Passioura, 1991) quoted by Marschner (1997). Estimated bulk density to prevent root penetration varies from 1.74 g/cc and above. Compacted soil reduces soil water storage and crop water use efficiency

(Radfold, 2001), as results can cause flower abortion and poor fruit setting for tomatoes (Zegbe, 2007). In dry soils, despite increasing soil strength root growth is usually much less depressed than shoot growth, leading to a typical increase in root/shoot dry weight ratio in response to drought stress, Sharp (1988) noted that maize seedlings without drought stress the root/shoot dry weight ratio was 1.45 compared with 5.79 under drought stress. When plant is grown in substrates with low mechanical impedance such as vermiculite, the root system of draught stressed plants continue to grow by elongation of the existing roots and initiation of new roots (Stasovski and Peterson, 1991).

The most suitable method of estimating soil compaction is to compare bulk density (BD) of the compacted soil with non-compacted soil (Plaster, 2003). The average non-compacted tilled loam has bulk density of about 1.3 g/cc, compaction can raise the BD to about 1.8 g/cc (Sharp *et al.*, 1988) this amounts to reduction of pore space from 50% to almost 30%, other method is by using penetrometer. Heilman (1981) noted that pore space of 27 – 30% could restrict root penetration.

## **2.7 Soil amendment**

Soil amendment is an activity whereby any material is mixed with soil to improve its physical properties, including water retention, permeability, water infiltration, drainage, aeration, structure and tilth, or workability (Tester, 1990). The goal is to provide a better environment for roots. To be effective, an amendment must be mixed thoroughly with soil. Commonly used soil amendment include compost, peat moss, sawdust, wood chips, composted animal manures, green manure crops, coarse sand, vermiculite and perlite. Application of soil additives / amendments such as vermiculite results in a significant

increase in the CEC of soil. Patil *et al.* (1985) observed an increase of 63.9 per cent over control, followed by application of humic acid (59.3 per cent) in CEC. The increase in CEC of the soil as a result of application of vermiculite can be attributed to its high CEC in vermiculite.

### **2.7.1 Vermiculite as a soil amendment material**

The term vermiculite applies to a group of minerals characterized by their ability to expand into long, worm-like strands when heated. There are two keys to the unique properties of vermiculite. The first is its laminar (or layered) crystalline structure, which provides the hinged plates that make the material expand or unfold in a linear manner, like an accordion. The second is the fact that it contains water molecules within their internal surface (Jayabalakrishnan, 2007). This water flashes into steam when heated to force the layers open. This expansion process is called exfoliation. In its expanded form, vermiculite has a very low density and thermal conductivity, which makes it attractive for use as a soil amendment, lightweight construction aggregate, and thermal insulation filler (Hombostel, 1991). Expanded vermiculite also has a very large chemically active surface area, which makes it useful as an absorbent in some chemical processes.

### **2.7.2 Occurrence of vermiculite**

Vermiculite is a clay mineral occurring as veinlets and isolated masses within the pegmatite intrusions hosted by ultra basic rocks rich in magnesium silicate minerals (Douglas, 1989). It is a 2:1 secondary phyllosilicate clay mineral with a general chemical formula  $Mg_x Fe(Al_x Si_{4-1})_{10}(OH)_2 4H_2O$  where  $x = 0.6$  to  $1.5$  (Douglas, 1989). Vermiculite is formed by alteration of a micaceous mineral. Trioctahedral vermiculite

replaces feldspar, dioctahedral vermiculite contain no mica and is formed by precipitation from gels. According to Harris, (1978) vermiculite deposits in Tanzania are found in Mikese Morogoro rural district, Kidete in Kilosa district, Kwekivu and Mzika in Handeni district.

### **2.7.3 Physical and chemical properties of vermiculite**

When heated, vermiculite expands by losing water to form what is called exfoliated or expanded vermiculite (Van Straiten, 2002; Bates and Jackson, 1987). Exfoliated vermiculite can therefore be used as an additive to mulch, potting soil and growing mixes (American Vermiculite Corporation, 2001; Potter, 2001) as it possesses most of the favorable properties of growth media including high CEC and high water retention capacities (Hudson, 2002). Exfoliated or expanded vermiculite is characterized by a high water holding capacity of 20 – 55% of its volume, cation exchange capacity (CEC) of between 82 – 150 Cmole/kg (Rowell, 1996) and pH of 6.0 – 9.8 (Landis, 1990; Schundler, 2004). Interlayer water in vermiculite facilitates both the easy migration of cations in interlayer space and the ease of ion exchange. In ion exchange reactions involving vermiculites and ion pairs from Ca, Mg, Sr, Be, Na, Li, complete exchange of the adsorbed ions by the counter ion is easily accomplished (Dixon and Weed, 1989).

### **2.7.4 Uses of vermiculite for soil amendment**

World statistics show that nearly 40% of vermiculite is used for agriculture related activities while the remaining is used in the engineering sector (Simandly *et al.*, 1999) According to Moetler (2002) vermiculite is used in horticultural production in various parts of the world for improving soil aeration, moisture and nutrient retention. Sabrah *et*

*al.* (1993) recommended the rate of 4% by weight which is nearly 20% by volume as the best rate for moisture improvement in pot experiment for a sand soil in Saudi Arabia. When mixed with soils, the particles of vermiculite increase the water and nutrient retention in sandy soils and porosity in loamy and clayey soils (Sabrah *et al.*, 1993). In addition when vermiculite added to soils undergoes decomposition (weathering) substantial amounts of macro-nutrients such as potassium, magnesium and a number of micro-nutrients are released into the soils, hence improving fertility status of the soils.

#### **2.7.5 Mineral nutrient content in Mikese vermiculite**

Following total chemical analysis conducted on Mikese vermiculite at Omac Laboratory Ireland (Marwa, 2007, personal communication) Mikese vermiculite has the characteristics as shown in Appendix 1. The amount of macronutrients such as K, Na, Ca, and Mg and micronutrient such as zinc, copper, manganese, iron and sulphur in Mikese vermiculite are within the acceptable range to be used in vegetable production (Harrison, 1992). The other elements which are not relevant in crop production are present in small amounts and the amounts of toxic or poisonous element are low such that they are not harmful to the user. The above laboratory analytical results indicate that, Mikese vermiculite does not contain harmful chemical and is environmentally-friendly therefore can be used for agricultural production (Harrison, 1992).

#### **2.8 Soil water retention**

Water is a limiting factor for crop production worldwide (Zegbe *et al.*, 2007) and therefore it is necessary to adopt techniques which will improve soil water retention. The amount of water stored in soil depends on the physical and chemical properties of that

soil. A soil with good physical structure, high organic matter, pores and channels of many sizes will allow water to penetrate deep in the soil and at the same time store a considerable amount of water (Brady and Well, 1996). Sandy soils which contain large amount of macro pores with low organic matter have low water holding capacity. To increase the water holding capacity of such soil, organic compost, and mulch have been used so often by many small holders to improve soil water retention (Tester, 1990). In general, organic matter additions to a soil will increase its ability to hold water and nutrients in an available state. Also vermiculite has been used extensively in horticultural production in various parts of the world to improve soil aeration, nutrient and water retention (Moetler, 2002). In addition will also increase soil biological activity which will affect the availability of nutrients in the soil. Soil which has received organic matter has increased microbial populations and more varied fungal species than soils receiving synthetic fertilizer applications (Tester, 1990). Available soil water is defined as the difference between field capacity and permanent wilting point and field capacity of a soil is the water content at which the internal drainage of water through the soil profile due to gravity becomes negligible measured at 0.1 bar and 0.33 bar of tension for finer-textured soils (loams, silt loams) (Kozłowski, 1985). Permanent wilting point is usually taken as the soil water content at 15 bars of tension (Tan, 1995). Permanent wilting point can vary widely for different crops. Tomato which is considered as heavy feeder due to its fast growth and high water and nutrient requirement have its wilting point from 0.2 – 0.05 m<sup>3</sup>m<sup>3</sup> (Zegbe *et al.*, 2007).



## 2.9 Tomato growth and yield analysis

Growth is the term used to describe irreversible changes in size (Arnold and Hunt, 1978), often to describe changes in form and occasionally describe changes in number, all as applied in the quantitative study of plant performance. Generally agronomists define growth as an increase in dry matter. This definition includes the process of differentiation, which contributes greatly to dry matter accumulation. Dry weight accumulation is commonly used as parameter characterizing growth because it usually has the greatest economic importance.

When investigating plant growth the best way is to find the performance of the plant by investigating the amount of the material increased per unit material per unit of time. This is called the relative growth rate (RGR). The relative growth rate provides the convenient integration of the combined performance of the various parts of the plant. It is especially useful when the need arises to compare species and treatment differences on a uniform basis. But when calculated at a whole plant level, it tells nothing of the causal processes which contribute to the plants gross performance. To calculate the relative plant growth rate of tomato, each sub component of the tomato plant growth such as root and shoot, leaves, stem and root, leaves of varying ages, petiole, stem, plant height, main and lateral roots can be measured (Zegbe *et al.*, 2007; Arnold and Hunt, 1978). Other plant growth parameters are leaf area index, dry matter production, and root and shoot dry matter (Gardner *et al.*, 1985). Tomato yield components such as plant height, number of flowers, number of fruits, number of trusses and plant stand influences the yield of tomatoes (Reuben *et al.*, 1999). When these paths of influences are high certainly the yield of tomato will also be high.

## CHAPTER THREE

### 3.0 MATERIALS AND METHODS

#### 3.1 Location

A glass house experiment was conducted in the Department of Crop Science and Production at the Sokoine University of Agriculture Morogoro Tanzania, from October 2007 to March 2008.

#### 3.2 Materials

Three soil types (sandy, clayey, and loamy), vermiculite and tomato Cal J variety were used for experiment.

#### 3.3 Methodology

##### 3.3.1 Soil collection

A random survey, sampling, followed by laboratory analysis was carried out in several sites before final soil collection. Sandy, clayey, and loamy soils were identified based on the laboratory analysis results obtained. Two hundred (200 kg) of each soil type (sandy, clayey and loamy) were collected from 0 - 20 cm depth by using a hand hoe and spade. Soils were carried in sacks and transported to the soil preparation room, air dried crushed and sieved through 8 mm mesh sieve.

Sandy soil was collected on the western part of Mazimbu campus (7 km from Morogoro town). The site lies on the lower part of pineplains along Mindu hills in flood plains. According to Msanya *et al.* (2001) the soil is moderately deep, well to excessive drained,

brown friable sandy loam classified as Cambisols. The soil has high contents of feldspars hydrous mica and low Fe- Oxyhydroxide.

Loamy soil was collected on the eastern part of Mazimbu campus, in the valley flood plains near Ngerengere river. The soil is deep, moderately to imperfectly drained, greyish brown. Stratified micacious clay loam classified as Fluvisols (Msanya *et al.*, 2001).

Clay soil was collected on the northern part of Mazimbu campus, in the lower part of flood alluvial plain along Ngerengere valley. According to Msanya *et al.* (2001) the soil is deep, poor to very poor drained, dark brown with deep crack. The soil is classified as a Vertisol composed of weatherable minerals biotite and chlorite.

After thorough mixing, one kilogram of each soil was ground and sieved by 2 mm mesh sieve. This fine earth soil was used for laboratory analysis only to determine the physical and chemical properties.

### **3.3.2 Soil analysis**

Soil analysis was carried out in the Laboratory of Soil Science Department of Sokoine University of Agriculture using various methods as summarized in Table 1.

**Table 1: Analysis conducted and methodologies**

Soil parameter	Method used	Authority
pH	1:2.5 water suspension	Okalebo <i>et al.</i> (1993)
Electrical conductivity	1:2.5 soil water ratio	..
Exchangeable bases (K, Ca, and Mg)	Ammonium acetate and analyzed by AAS	..
Particle size	Hydrometer using USD system	..
Bulk density	Core method	..
Extractable micronutrient (Cu,Zn, and Fe)	DTPA extract	..
Total nitrogen	Macro-kjeldahl	..
Available phosphorus	Bray 1	..

### 3.3.3 Vermiculite excavation

Vermiculite was excavated by using hand hoe and spade at the abandoned vermiculite mine in Mikese ward, Morogoro region (about 40 km east of Morogoro municipal). The vermiculite was transported to the Mineral Center Kunduchi Dar-es-salaam where it was heated at 600 °C in the furnace for two hours, the heating converted vermiculite to exfoliated vermiculite with very low bulk density to 0.4 g/cm<sup>3</sup>. Exfoliated vermiculite was used for pot experiment.

### **3.3.4 Soil vermiculite mixture**

Eight (8) kg of the soil was mixed with vermiculite based on the following vermiculite percentage by volume, 0%, 10%, 20%, and 40%. Furthermore each mixture was mixed with 2.32 g of TSP and 1.4 g of S/A which is 1/3 of the application rate of Ammonium Sulphate fertilizer (equivalent to 225 kg P<sub>2</sub>O<sub>5</sub> /ha, and 1/3 of 190 kg N/ ha, respectively) and transferred to the pots of 10 L capacity.

### **3.3.5 Soil water retention analysis**

The soil vermiculite mixture samples were analyzed for water holding capacity, by which moisture characteristics were determined using a porous membrane (pressure plates) as described by Tan (1995).

## **3.4 Experimental design and treatments**

A 3 x 4 factorial experiment using a split plot arrangement involving three soil types (clayey, loamy and sandy) and four levels of vermiculite (0, 10, 20, and 40 % by volume) were used in a randomized complete block design (RCBD) with three replications. Factor A (main plot) were three soil types, and factor B (sub-plots) were four levels of vermiculite. Destruction method of plant sampling method was used, whereby whole plants were harvested in two growth periods (28, 42 DAP) and at fruit ripening stage). Therefore the whole experiment was conducted in three pairs, and each had 36 pots.

### **3.5 Planting and experiment management**

Tomato seeds were sown directly into the pots (4 to 7 seeds per pot) containing 8 kg of soil vermiculite mixture at 1-inch depth. Thinning by cutting at soil level was done at 10 days after planting (DAP), where three seedlings remained. The second thinning was done at 15 DAP at which one tomato plant was left per pot. Second application of Ammonium Sulphate fertilizer 1.40 g per pot was done at 20 DAP. The third application of Ammonium Sulphate fertilizer 1.40 g per pot was done at 42 DAP. All plants in a specific soil type were irrigated with the same amount of distilled water to field capacity when water deficiency symptoms (drooping of leaves) appeared. The glasshouse day temperature recorded ranged from 30°C to 42°C while the minimum night temperature was 23°C.

### **3.6 Data collection and analysis**

#### **3.6.1 Growth parameters**

##### **3.6.1.1 Plant height**

Plant height in centimeter was determined by measuring its height from the soil level to the terminal leaf.

##### **3.6.1.2 Shoot dry weight per plant**

Tomato plants were harvested by cutting at the ground level, placed in the paper bag and dried in oven at 70°C to constant weight. The dry matter was determined by weighing the plant material using an electronic balance.

### **3.6.1.3 Root dry weight per plant**

The pots were soaked in water for several minutes to loosen the soil, the soil was removed slowly with much care by aspirating water into the soil when the pot was at the slanting position. When all the soil was removed the roots were washed carefully placed in the paper bag and dried in oven at 70°C to constant weight then weighed using electronic balance.

### **3.6.1.4 Root-shoot ratio**

The root-shoot ratio was obtained by dividing the root dry weight over shoot dry weight,  $\text{Root/shoot} = R_w/S_w$  (Arnold and Hunt, 1978).

### **3.6.1.5 Relative growth rate (RGR)**

Relative growth rate (RGR) was calculated from the following formula as described by Gardner (1985).

$$\text{RGR} = (\ln.W_2 - \ln.W_1) / T_2 - T_1$$

Where:  $\ln$  is the natural logarithm,  $W_2$  and  $W_1$  are shoot dry weight at 42 and 28 DAP respectively and  $T_2$  and  $T_1$  are the number of days after planting (42 and 28 DAP, respectively).

## **3.6.2 Yield parameters**

### **3.6.2.1 Plant harvest**

First plant harvest was done at 28 DAP date when first flower emerged observed among the plants. The second plant harvest was done two weeks later. The plants were cut at the

soil level, washed with distilled water, and put in the paper bag, dried in the oven at 70°C to constant weight.

#### **3.6.2.2 Number of flowers per plant**

Flowers were counted at 42 DAP when the first fruit was formed.

#### **3.6.2.3 Number of tomato fruits per plant**

Ripen tomato fruits were harvested per plant and counted regardless of their size and quality. This was done each time when ripening was observed and the total number was obtained after the last harvesting.

#### **3.6.2.4 Weight of tomatoes per plant**

Tomatoes in each separate plant were weighed in grams immediately after harvesting to obtain the fresh weight.

#### **3.6.2.5 Total dry matter yield per plant**

Total dry matter was obtained as a summation of shoot dry matter and root dry matter.

### **3.6.3 Statistical analysis**

All soil and plant analysis data were analyzed by using MSTATC VERSION 40/EM software for analysis of variance. The means were separated by New Duncan Multiple Range Test (DNMRT) as described by Gomez and Gomez (1984).

The statistical model used was as follows:

$$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + E_{ijk}$$

Where:

$Y_{ijk}$  = General response

$\mu$  = general mean,

$A_i$  = error due to factor A (soil type),

$B_j$  = error due to factor B (Vermiculite levels),

$AB_{ij}$  = interaction of factor A & B and

$E_{ijk}$  = random error

### 3.7 Plant material analysis

The dried tomato plants for dry matter analysis described in 3. 6. 2. 1 were ground by using motor and pestle to the fine powder. 0.5 g of the grounded plant samples was weighed into the crucibles and ashed in the muffle furnace for eight hours at 550 °C. The ash was dissolved by 2 mls of 6N HCL then diluted with several portions of distilled water to 50 mls while filtering into volumetric flask. The filtrate was used for determination of total potassium by Atomic Absorption Spectrophotometer (AAS) as described by The Ministry of Agriculture Fisheries and Food, England (1972). Tomato plant materials was analyzed for potassium to identify how much would be released by vermiculite as reported by Maclean and Watson (1985).

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

#### 4.1 Soil and vermiculite characterization

Some of the physical and chemical properties of the soil used in this study were as presented in Table 2. Based on the percentage sand, silt and clay content of the soils, the textural class was designated as sandy loam, clay, and sandy clay loam (FAO, 1990). The sandy loam textural class of the soil has some problem in water and nutrient retention while the clayey and sandy clay loam would have good moisture and nutrient retention capacity but clayey soil is associated with poor aeration (Brady and Well, 1996). All soils were of medium to high pH, according to Landon (1994) and classified as very slightly acidic to slightly alkaline which is good pH range for most crops including tomatoes. These soils composed of weatherable minerals biotite, chlorite, feldspar and hydrous mica with lower iron oxyhydroxide and aluminium (Msanya *et al.*, 2002) these minerals contribute to the pH. The total nitrogen was low to very low. This could have been due to continuous cultivation and leaching in sandy soil which could require supplementation of fertilizer for better response of tomato. Available phosphorus in sandy and clayey soils was medium while loamy soil had an adequate amount of phosphorus. The cation exchange capacity (CEC) of clay soil was high, medium for loamy and low for sandy soil according to Landon (1994). The low CEC in sandy soil indicate that there was low organic matter, low clayey particles therefore low water and nutrient retention thus low productivity. Exchangeable magnesium for all soils was adequate while exchangeable calcium was low in sandy soil medium in loamy and high in clayey soil (Landon, 1994). All soils had low content of copper and zinc but high iron content according to Landon (1994) categorization. The farm where the soils were

collected is under production for more than ten years and a major crop cultivated is maize.

**Table 2: Physical and chemical characteristics of soils and vermiculite used for pot experiment**

Soil prop	Sandy	Clay	Loamy	Vermiculite	Method
pH	6.7	7.2	6.5	5.9	Electrode
B. density	1.44	1.65	1.38	0.46	Core
P. density	2.607	2.463	2.578		Vol. flask
Porosity	44.83	32.93	46.51		
Texture	SL	Clay	SCL		Hydrometer
Sand	83 %	19 %	58 %		
Clay	16%	70 %	34 %		
Silt	1 %	11 %	8 %		
Total N	0.03 %	0.1 %	0.08 %	0.0%	Kjeldalh
Av. P	24.64 ppm	16.57 ppm	116.89 ppm	3.04ppm	Bray 1
Ex. Bases					Am. acetate
K	0.46 me/100g	1.2 me/100g	0.96	0.41 me/100g	..
Ca	1.28 me/100g	14.23	me/100g	2.55 me/100g	..
Mg	0.51 me/100g	me/100g	6.25	2.17 me/100g	
CEC	9.6 me/100g	7.51 me/100g	me/100g	45.24	..
Cu	0.20 ppm	33.6 me/100g	3.23	me/100g	DTPA
Zn	0.24 ppm	1.30 ppm	me/100g	0.20 ppm	..
Fe	26.50 ppm	0.20 ppm	21.6	0.01 ppm	..
		14.90 ppm	me/100g	10.50 ppm	
			0.90 ppm		
			0.72 ppm		
			51.50 ppm		

Vermiculite used was moderately acidic, the total nitrogen content was zero in vermiculite, while the available phosphorus was low. The CEC of vermiculite was higher than all soils and this confirm how useful can be used for soil amendment material for improving CEC and nutrient retention of soil as described by Hudson (2002). Exchangeable potassium was medium while exchangeable magnesium and calcium was high while copper and zinc content was low but very high iron content (Landon, 1994).

#### **4.2 General response of tomato on soil types and vermiculite levels**

##### **4.2.1 Soil type effects**

Results indicating tomato growth performance due to soil types are presented in Appendix 2. Tomato growth due to soil types did not indicate significant differences ( $P \leq 0.05$ ) between tomato grown on clay and loamy soil, except for tomato height at 28 DAP and weight of fruits. Tomatoes grown on loamy soil were taller than tomatoes grown on clay soil suggesting that the low bulk density of loamy soil 1.35g/cc that classified as uncompacted contributed to higher tomato growth, while the bulk density of clay was 1.65g/cc close to the 1.75g/cc which is classified as compacted soil and can restrict root penetration and growth of shoot (Passioura, 1991; Sharp *et al.*, 1988). Weight of harvested tomato fruits was higher on clay than on sandy soils probably because the nutrient status of clay soil was higher than in loamy soil, this could have contributed to high nutrients in tomato fruits thus large in size and weight. Tomatoes grown on sandy soil differed significantly from those grown on loamy and clay soils on most variables such as tomato height at 28 and 42 DAP, shoot DM at 28 and 42 DAP, total DM at 28 and 42 DAP, weight of fruits, and RGR. The variables were lower in sandy soil than clay

and loamy soil suggesting that it was caused by the low fertility status of sandy soil including low CEC, poor water retention, and low nutrient contents.

#### **4.2.2 Vermiculite effects**

Results indicating tomato response to vermiculite levels are presented in Appendix 3. The results indicated significant differences ( $P \leq 0.05$ ) on most variables except for R-S ratio at 42 DAP and height of tomato at 42 DAP. Results indicated that tomato response was increasing as vermiculite level increased in the soil. This verifies the usefulness of vermiculite as soil amendment material that can improve physical and chemical properties of soil and enhance tomato growth and yield as was reported by Moetler (2002). Tomato height and R-S ratio at 42 DAP did not differ significantly ( $P \leq 0.05$ ). This suggest that from 28 DAP tomato growth rate started decreasing until it reached maximum height and R-S ratio at which most of assimilates were directed towards the reproductive organs for fruit formation. This is in agreement with Arnold and Hunt (1978) who had similar observations. Results indicated that potassium in tomato plant material was decreasing significantly as vermiculite level increased in soil. This suggest that there was fixation of potassium by vermiculite which was increasing as the level of vermiculite increased in soil, this phenomenon was also observed by Bergmann (1992).

#### **4.3 Seed germination and growth**

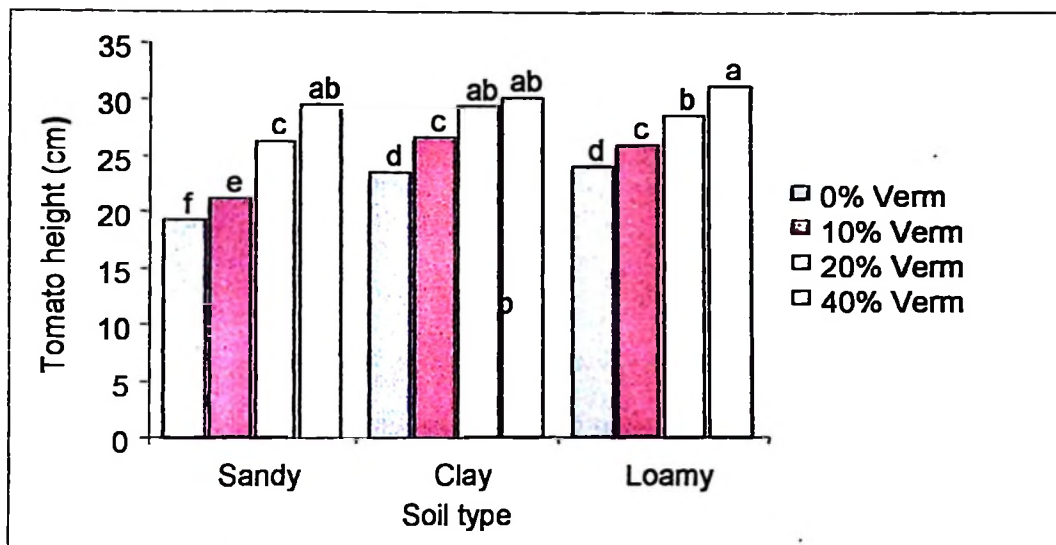
Seed germination ranged between 4 to 6 DAP and lasted for three days. Soil type and treatment effects were not significant on seed germination, although seedling emergence in soils with high level of vermiculite started earlier than soils without vermiculite. High temperature affected tomato growth and yield such that some flowers died and few fruits

aborted before maturity. The lowest temperature recorded during the day was 30°C and the highest was 42°C. High temperature could be the cause of inconsistency yield.

#### **4.4 Tomato growth parameters**

##### **4.4.1 Tomato height**

Difference in tomato height was highly significant ( $P \leq 0.05$ ) among soil types at 28 DAP but not at 42 DAP. Tomato grown on loamy soil had the highest height at 28 DAP although not significantly different from clay soil, and the lowest height was observed in sandy soil (Fig.1). The effect of vermiculite levels on tomato height at 28 DAP was highly significant, tomato height were increasing as the vermiculite level increased. Tomato height increased from 19.27 cm in control treatment to 29.60 cm when 40% vermiculite level was applied in sandy soil. This is equivalent to 53.6% increase while tomato height in loamy and clay increased by 29.7 and 28.4 percent respectively Appendix 4. The increased tomato height on sandy and loamy soils with high level of vermiculite could be attributed to the increased CEC from vermiculite and constant supply of water due to the increased water retention in soils amended with vermiculite. Suganya and Sivasamy (2006) observed an increase of CEC when vermiculite was added in the soil. Also Ece and Derakei (2007) observed the increase in water and nutrient retention in sandy soil when vermiculite was applied which resulted into an increase in plant height.



**Figure 1: Tomato height at 28 DAP in different soils amended with different levels of vermiculite**

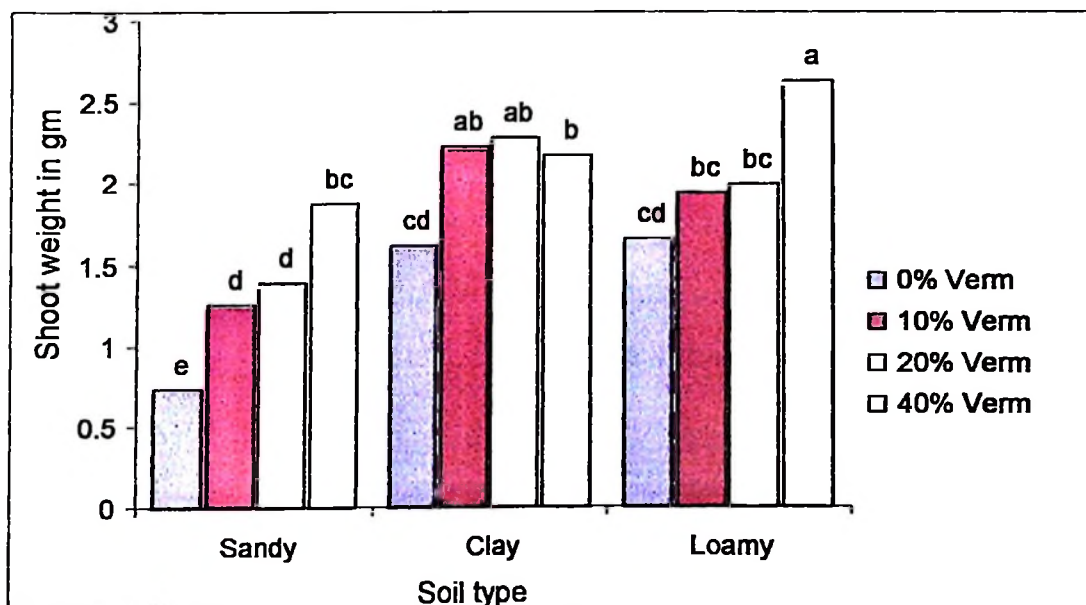
(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

Tomato height at 42 DAP did not differ significantly ( $P \leq 0.05$ ). At this age all plants in different soil vermiculite levels reached almost the same height. This suggests that from flowering period the growth rate of tomato started decreasing until each plant reached its maximum height. This is in agreement with Arnold and Hunt (1978) who had similar observation.

#### 4.4.2 Shoot dry matter production

Shoot dry matter production at 28 DAP differed significantly ( $P \leq 0.05$ ) between vermiculite levels but the difference was not significant at 42 DAP (Fig. 2). The shoot dry matter production at 28 DAP show that 40 % vermiculite level increased shoot dry matter production than any other level. Shoot dry matter in sandy soils increased from 1.33 g/p in

control treatment to 2.23 g/p when 40% vermiculite level used equivalent to 156% increase in dry matter, while the increase in loamy soil was 59% and 35% in clay soil. The increased dry matter production in sandy soil with the highest level of vermiculite could be attributed to the increased CEC and constant supply of water due to the increased water retention in soils amended with vermiculite compared to other treatments without vermiculite. These findings are in line with Suganya and Sivasamy (2006) who observed the increase in porosity, CEC and minimum moisture depletion on sandy soil amended by vermiculite. Also Nakano (2007) observed an increase on tomato growth when oxygen concentration increased in the root zone. This suggests that the increased root respiration enhanced water and nutrient uptake by plant which in turn increased photosynthesis thus high shoot dry matter.

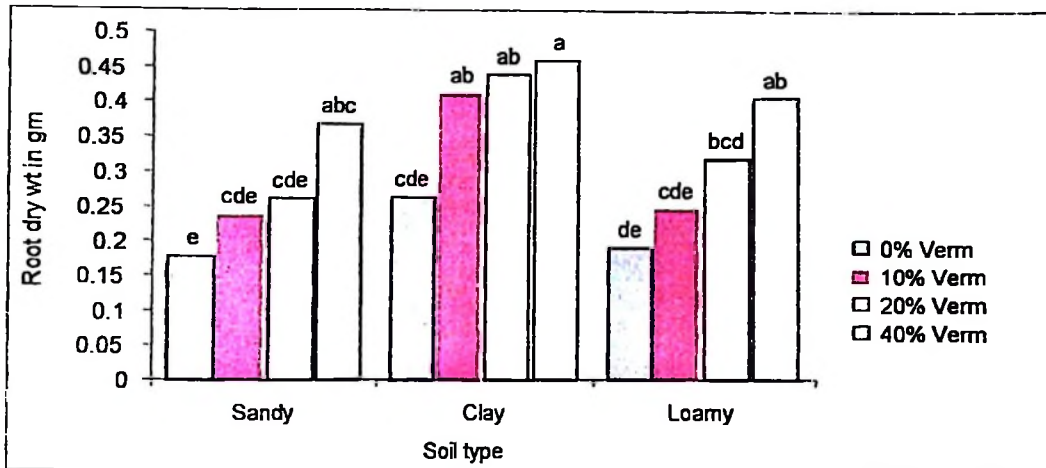


**Figure 2: Shoot dry weight at 28 DAP in different soils amended with different levels of vermiculite**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.4.3 Root dry weight

Tomato root dry weight was not significantly different between clay and loamy soils, but differed significantly ( $P \leq 0.05$ ) with sandy soil. Results indicate that root dry weight differed significantly only at 28 DAP ( $P \leq 0.05$ ) between vermiculite levels (Fig. 3). Root dry weights at 28 DAP was higher in soils with high levels of vermiculite compared to the soils with less or without vermiculite. But the case was different at 42 DAP where the highest root weight was observed in 20% vermiculite level in sandy soil, followed by 10%, 40% and least was sandy without vermiculite. The root dry matter increased from 0.177g/p in sandy soil without vermiculite to 0.367g/p in sandy soil with 40% vermiculite level which is equivalent to 107.3% increase (Appendix 5). Suggesting that there was reduction in bulk density of the soil hence allowing easy root growth and development. The incorporation of organic matter and other soil amendments into soil help to improve soil physical properties, thereby positively influencing root development (Rose *et al.*, 1995). Smalley and Wood (1995) also found increased root density in sandy and clay soil when amended with organic or inorganic soil amendment. Marschner (1995) observed an increase in root growth of corn when grown in vermiculite substrate. Another reason for the increase in root growth was due to improvement of soil physical properties such as porosity which increased air supply to the roots hence improved root respiration and growth. These results are in agreement with Jayabalakrishnan (2007) who observed the increase of root respiration and growth of sunflower grown in soil vermiculite mixture.

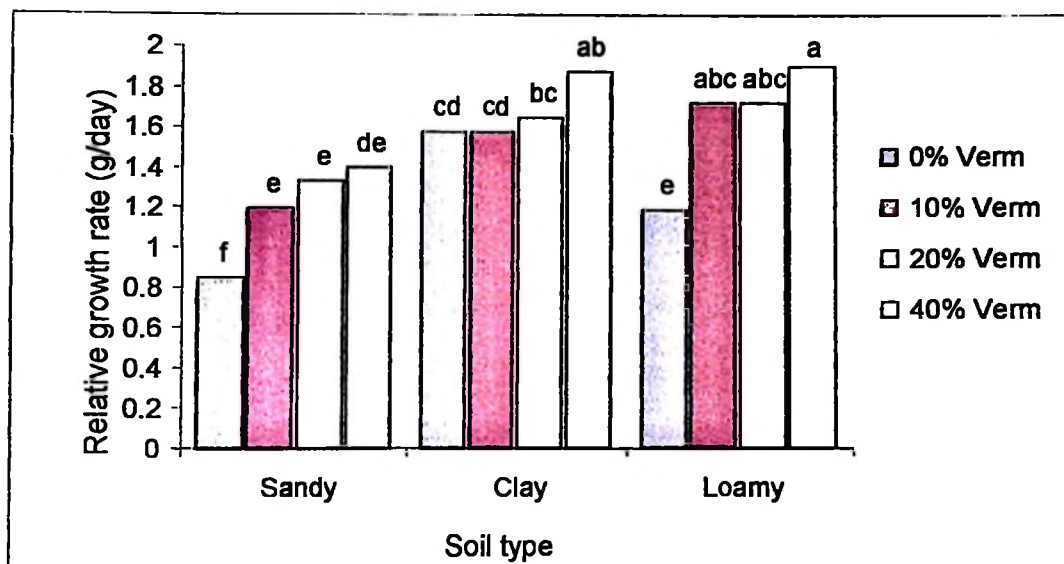


**Figure 3: Tomato root dry weight at 28 DAP in different soils amended with different levels of vermiculite.**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.4.4 Relative growth rate (RGR)

The tomato growth rate was increasing as the vermiculite level increased in all soil type (Fig. 4). A 40% vermiculite level resulted in the highest overall growth rate 5.17 g/day compared to 3.61 g/day in soils without vermiculite. The growth rate of tomato grown in sandy soil without vermiculite was 0.85 g/day compared to growth rate of 1.40 g/day for the tomato grown in sandy soil with 40% vermiculite level (Appendix 6). This is equivalent to 65% increase in growth rate compared to 59% and 19% growth rate in loamy and clay respectively. Suganya and Sivasamy (2006) found that application of 1% vermiculite increased the growth rate of finger millet grown in sandy soil by 63.9% over control treatment and it was associated with increased CEC, water retention, and nutrient absorption. Hudson (2002) also reported the increased tomato growth rate in high vermiculite levels due to good soil environment for nutrient supply, aeration, reduced soil compaction, and water retention, which are important factors for plant growth.



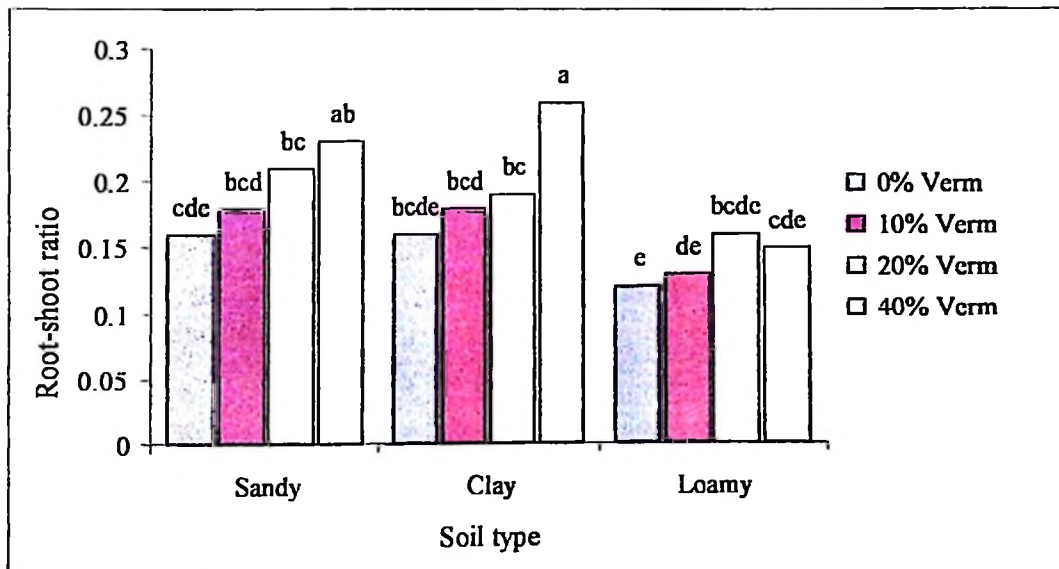
**Figure 4: Relative growth rate of tomatoes grown in different soils amended with different levels of vermiculite**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.4.5 Root-shoot ratio

Root-shoot ratio differed significantly ( $P \leq 0.05$ ) both with respect to soil type and vermiculite levels especially at 42 DAP. Generally root-shoot ratio was increasing as the vermiculite level increased as shown on Fig. 5. This could be caused by the increased root weight which was increasing as the vermiculite level increased. Singh and Sainju (1998) reported that root growth is influenced by soil physical properties such as structure, temperature, aeration, and water content. High R-S ratio in clayey soil with 40% vermiculite level indicate that root biomass was higher in clay soil with 40% vermiculite level than other vermiculite levels. This suggests that 40% vermiculite level in clayey soil increased air in the tomato root zone than other vermiculite levels, this enhanced root respiration thus higher root growth and biomass. The increase in root biomass caused the

increase in root-shoot ratio. Haase and Rose (1993) observed that plants with high root-shoot ratio are tolerant to draught compared to plants of the same species with lower root-shoot ratio. The increased root biomass increases the ability of plant to explore water and nutrients in the soil. It is therefore obvious that the plant grown in soil amended with vermiculite increases its water stress avoidance potential. A high root-shoot ratio means that the roots are abundant, and that the seedling is more likely to avoid water stress after planting, particularly in droughty sites or under conditions of high evaporative demand.



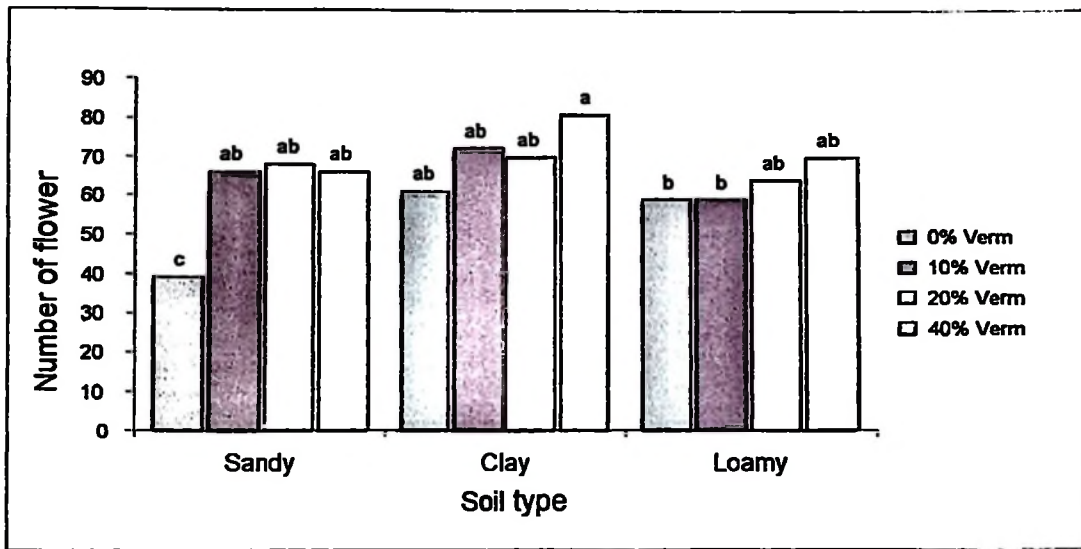
**Figure 5: Root-shoot ratio at 28 DAP in soils amended with different vermiculite levels**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

## **4.5 Tomato yield parameters**

### **4.5.1 Number of flowers**

Tomato grown in sandy soil produced the lowest number of flowers and differed significantly ( $P \leq 0.05$ ) with clay and loamy soils. Results indicated the increase of the number of flowers from 39 in sandy without vermiculite to 68 flowers in sandy with 20% vermiculite level equivalent to 74% compared to clay soil where the number of flowers increased by 38% and 20% in loamy soil. Although the overall results show that tomato grown in soils with 40 % vermiculite level produced the highest number of flowers (Fig. 6), the case was not the same on sandy with 40% vermiculite. A sandy soil with 20% vermiculite level showed the highest number of flowers, suggesting that severe deficiency of potassium observed in sandy soil with 40% vermiculite level could be the cause of reduced number of flowers. This comply with Bergmann (1992) who noted that the more optimal the potassium uptake, the better the yield as long as all other growth factors are favourable and that lack of potassium when the plant is young cannot be compensated for later and depressed yields. Usually flower number in tomatoes has direct relation with the number of tomato fruits which have direct relation with tomato yield (Reuben *at el.*, 1999).



**Figure 6: Number of flowers per tomato plant grown in soils amended with different vermiculite levels**

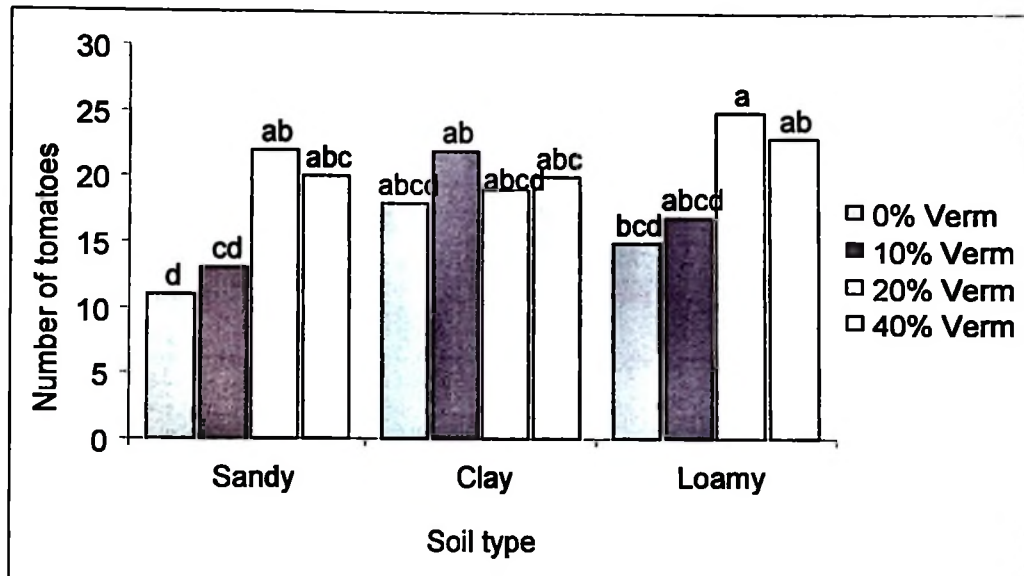
(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.5.2 Number of tomato fruits

The number of tomatoes produced in sandy, clay and loamy soils did not differ significantly ( $P \leq 0.05$ ) although the sandy soil produced the lowest absolute number of tomato. The number of tomatoes produced in different soils with vermiculite level differed significantly ( $P \leq 0.05$ ). Vermiculite level showing the highest number of tomato fruits was 20% which produced 22 tomato fruits followed by 40%, 10% and soil without vermiculite was the last, these produced 21, 17, and 15 fruits per plant respectively (Fig. 7). The number of tomato fruits is very small compared to the number of flowers, and this is because many flowers were dying due to high temperature in the glass house which was ranging from 31 °C to 41 °C during the day, and the minimum night temperature was 23 °C while the day soil temperature was 37°C. Villareal (1980) reported that high temperature

in tomato cause low fruit setting ability. Frimpong *et al.* (2006) and Blancard (1994) also reported that high soil temperature in tomato cause high flower abortion and poor fruit setting as well as deformed fruits. Accumulation of proline in tomato leaves during high temperature causes depletion of proline in the reproductive tissues thereby seriously reducing pollen formation and viability (Abdelmageed *et al.*, 2003) hence causing flower abortion. Moreover a number of explanations have been offered for the poor reproductive performance in tomatoes at high temperature. These include reduced or abnormal pollen production, abnormal development of the female reproductive tissues, hormonal imbalances, low levels of carbohydrates, and lack of pollination (Peet *et al.*, 1997).

Tomato grown in the sandy soil with 20% vermiculite level produced an average of 22 tomato fruits per plant which was the highest number of tomato fruits in sandy soil compared to the number of tomato fruits harvested in sandy without vermiculite which produced 11 tomato fruits per plant. This increase is equivalent to 82% compared to 33% increase in loamy and 14% in clay soils. These findings comply with those obtained by Sabrah *et al.* (1993) who recommended 4% vermiculite level based on weight bases which are nearly 20% on volume bases. The increased water retention, and reduction of the number of macro-pores in sandy soil after mixing with vermiculite, allowed good root soil contact this enhanced nutrient absorption by roots. Silberbush *et al.* (1983) pointed out that contact between roots and soil increases delivery rate for mineral nutrients to the plant.



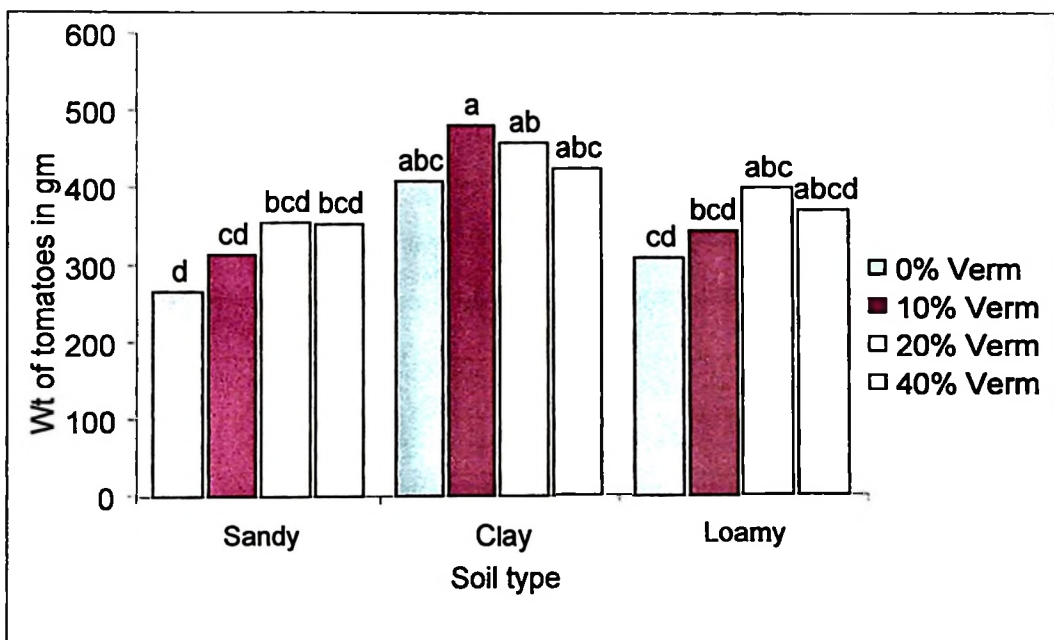
**Figure 7: Number of tomato fruits per plant grown in soils amended with different vermiculite levels**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.5.3 Tomato fresh weight

Weight of tomatoes produced per plant in sandy, clay and loamy soils differed significantly ( $P \leq 0.05$ ). Clay soil produced the highest weight of tomato per plant because it was more fertile than other soils used for pot experiment. The effect of vermiculite levels to the tomato weight was highly significant ( $P \leq 0.05$ ) as shown in Fig. 8. A 20% vermiculite level produced the highest weight of tomatoes followed by 10% and 40% which did not differ significantly and the least was 0% vermiculite level. This agrees with the findings observed by Sabrah *et al.* (1993) who recommended 20% vermiculite ratio to be used for amending sandy soil. Tomato grown in sandy soil without vermiculite produced 265.7g of tomatoes per plant compared to 356g of tomatoes per plant produced in sandy soil with 20% vermiculite level; this is equivalent

to 33.9% increase of tomatoes weight per plant. These results indicate that vermiculite gives best response when used for amending sandy soil than other soil types. The reason is that sandy soil lack most favourable properties of growth media compared to clay and loamy soils like low cation exchange capacity (CEC), low nutrient content and low water retention which are compensated by vermiculite application as was pointed out by Hudson (2002)



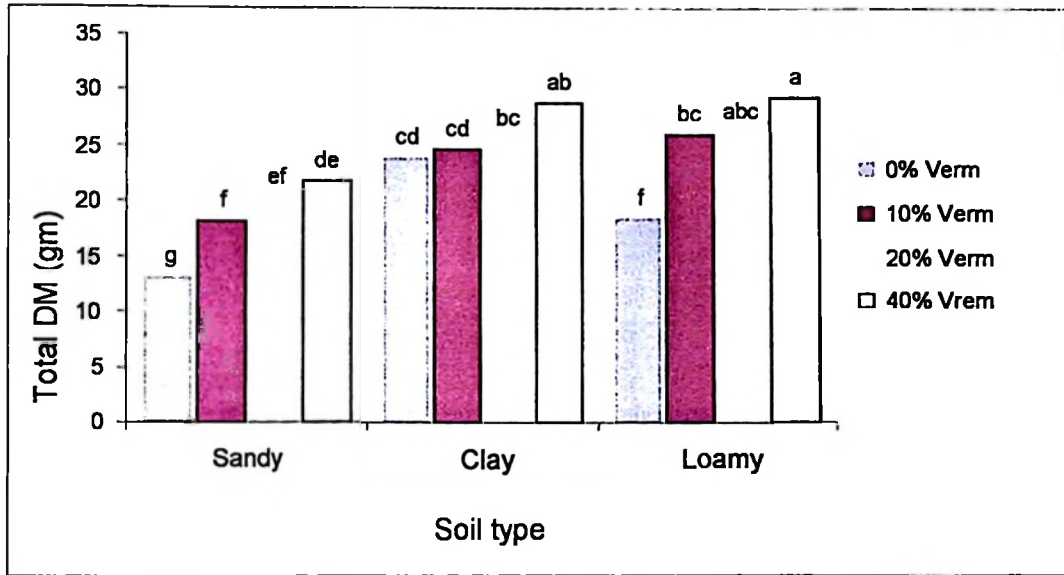
**Figure 8: Weight of tomato in soils amended with different vermiculite levels**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.5.4 Total dry matter yield

Sandy soil produced the lowest dry matter during the course of experiment compared to clay and loamy. The low nutrient contents in sandy soil before mixing with vermiculite could be attributed to low DM production. The total dry matter (shoot and root) harvested at 28 DAP show significant difference ( $P \leq 0.05$ ) among vermiculite levels.

There was an increase in total dry matter as the vermiculite level increased in all soil types (Fig. 9). The total dry matter in sandy soil without vermiculite was 1.24 g/p compared to 2.24 g/p in sandy with 40% vermiculite level which is equivalent to 67% increase in dry matter (Appendix 7). The increased air space by vermiculite amendment increased oxygen supply to the root zone, this increased root respiration which enhanced root growth, water and nutrient absorption resulting into higher production of dry matter. This is in line with observation by Nakano (2007) who observed the increase in shoot and root dry weight of tomato when the air space in the root-zone was enlarged up to 50%. A highest dry matter at 28 DAP was observed in Loamy soil with 40% vermiculite followed by clay soil with 20% vermiculite, and the least was sandy without vermiculite. At 42 DAP the highest DM observed in loamy soil with 40% vermiculite, followed by clay with 40% vermiculite, 20% vermiculite and the least was sandy without vermiculite. Although the total DM harvested in sandy soil was lower than those harvested in clay and loamy soils, results indicate higher response in sandy soil than other soil types. The DM increased from 1.24 g/p to 2.24 g/p equivalent to 83% increase when 40% vermiculite level was applied in sandy soil compared to an increase of 40% in clay soil and 55% in loamy soil at 28 DAP. Results show that vermiculite enhanced growth of tomato in sandy soil than in clay and loamy soils. Amending sandy soil with vermiculite improved soil moisture retention, CEC, porosity, water and nutrient supply resulting into increased root and shoot growth as observed by Potter (2001) and Suganya and Sivasamy (2006).

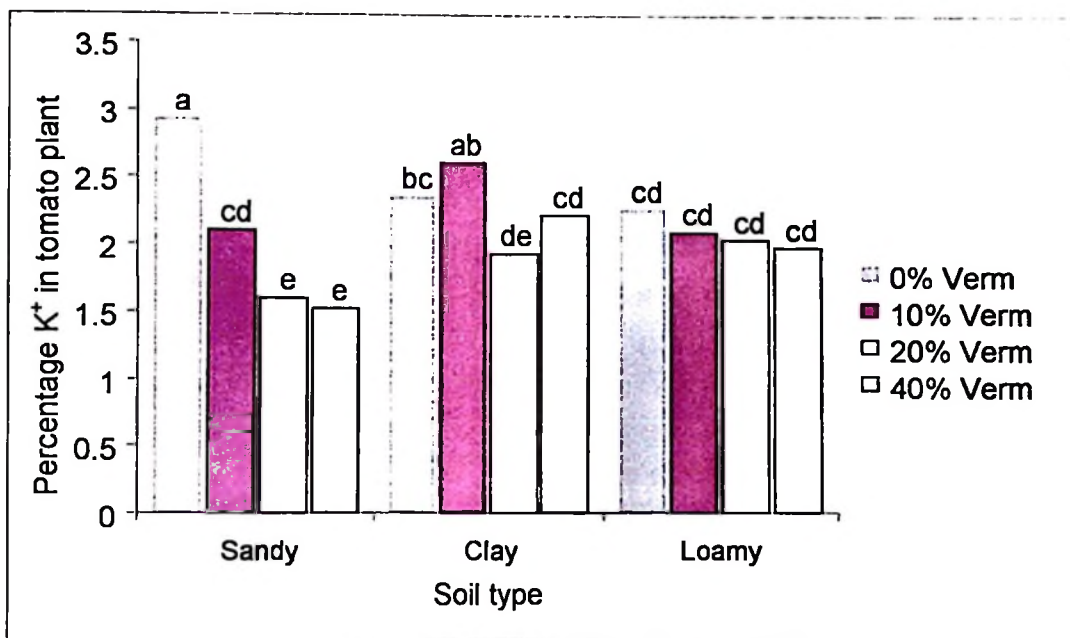


**Figure 9: Total dry matter yield of tomato at 28 DAP in different soil type which received different levels of vermiculite**

(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

#### 4.6 Potassium content in tomato plant material

Potassium content in young mature leaves of tomato grown in different soils did not indicate significant difference ( $P \leq 0.05$ ). Potassium content in tomato plant material tended to decrease as vermiculite level increased in soils (Fig. 10). Tomato leaves harvested from sandy soil without vermiculite contained highly significant amount of potassium compared to those harvested from 20% and 40% vermiculite levels. As vermiculite level increased, potassium content in sandy soil was decreasing much more than in clay and loamy soils.



**Figure 10: Potassium in tomato plant material grown in soils with different vermiculite levels**

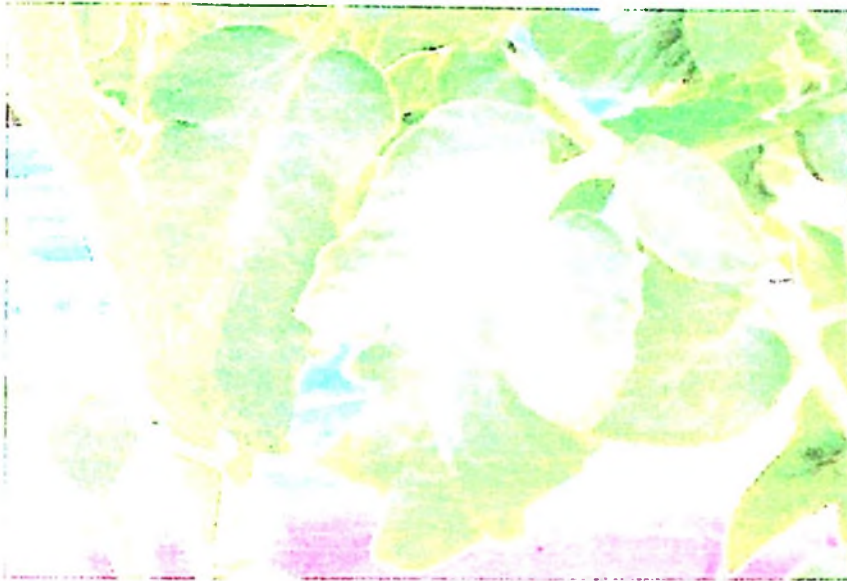
(Bars followed by the same letter do not differ significantly at  $P \leq 0.05$ ).

Potassium deficiency symptoms (leaf scorch or necrotic lesions on the margins of old leaves) was clearly observed on tomato grown in sandy with 40% vermiculite level, followed with mild symptoms in sandy with 20% vermiculite level as shown on Plate 1 - 3, while the other sandy treatments and the rest clay and loamy treatment did not indicate potassium deficiency symptoms. Death of leaf margins suggests the effect of potassium deficiency which causes shrinkage of collapsed cells and tissues due to reduced starch synthesis (Bergmann, 1992). This starts from the leaf tip progressing along the margins spreading towards the middle of the leaf. Potassium contents in tomato grown in sandy soil with 40% vermiculite level, decreased by 27%, compared to 12% in clay and 6% in loamy soils. The critical concentration of potassium in tomatoes is reported to be 2.5% (Widders and Lorenz, 1982). Potassium content in tomatoes ranged from 1.62% in sandy

with 40% vermiculite to 2.92% in sandy without vermiculite while in clay was from 2.22% to 2.36% and loamy soil was from 1.98% to 2.17% (Appendix. 8). Potassium deficiency was severe in tomato grown in sandy soil because usually soils with heavy textures are higher in potassium bearing minerals and therefore generally contain higher reserves of available K and coarse texture contain low available K (Mengel and Kirkby, 1978). The difference in potassium content in tomato leaves was significant among vermiculite levels as shown on Fig. 10. Maclean and Watson (1985) reported that exchangeable  $K^+$  can be released from clay interlayer of mica-like layers of illite and interstratified 2:1 layer silicates like vermiculite, but results suggest that, K in the 2:1 mineral silicates are not readily available to the plant but the release is correlated with a stage of weathering.



**Plate 1: Potassium deficiency symptoms (necrosis on the leaf margins) in tomato grown in sandy soil with the highest level of vermiculite (40%)**



**Plate 2: Mild potassium deficiency symptoms (necrosis on the leaf margins) in tomato grown in sandy soil with 20% vermiculite level**



**Plate 3: Tomato leaves grown in sandy soil with 10% vermiculite levels showing no potassium deficiency symptoms**

The decrease in potassium content for tomato leaves grown in high level of vermiculite could be caused by too high vermiculite content in soil which is known to cause  $K^+$  fixation. Minerals with 2:1 interlayer structure fix potassium through exchange process with water in the interlayer space during dehydration process and collapse of vermiculitic interlayers (Sparks and Huang, 1985). Potassium fixation which is driven by diffusion (Sparks, 1987) is particularly profound in soils abundant in vermiculite (Olk 1995). Stone and Wild (1978) reported that cation with low hydration energies such as potassium causes dehydration and therefore are fixed in interlayer space / position. Sawhney (1970) found that ion selectivity in many soil clay minerals is concentration dependent. At low concentration of  $K^+$ , wedge sites are more selective for  $K^+$  from a  $K^+/Ca^{2+}$  solution than interlayer sites. However at higher concentrations interlayer sites are more efficient in fixing  $K^+$ . Fixation of vermiculite is primarily due to interlayer surfaces not wedge of zones of selectivity because the zones are relatively small volume in most vermiculite.

Bergmann (1992) also reported that potassium deficiency occurs primarily in soils containing beidellite and vermiculite in their clay fraction and normal potassium fertilization of such soils has little effect.

#### **4.7 Physical analysis of amended soils**

Laboratory analysis results carried out on physical characteristics of the soil vermiculite mixture are as presented on Table 3. Results indicated that there was an increase of water retention as vermiculite level increased in both soil while the bulk density was decreasing as vermiculite level increased.

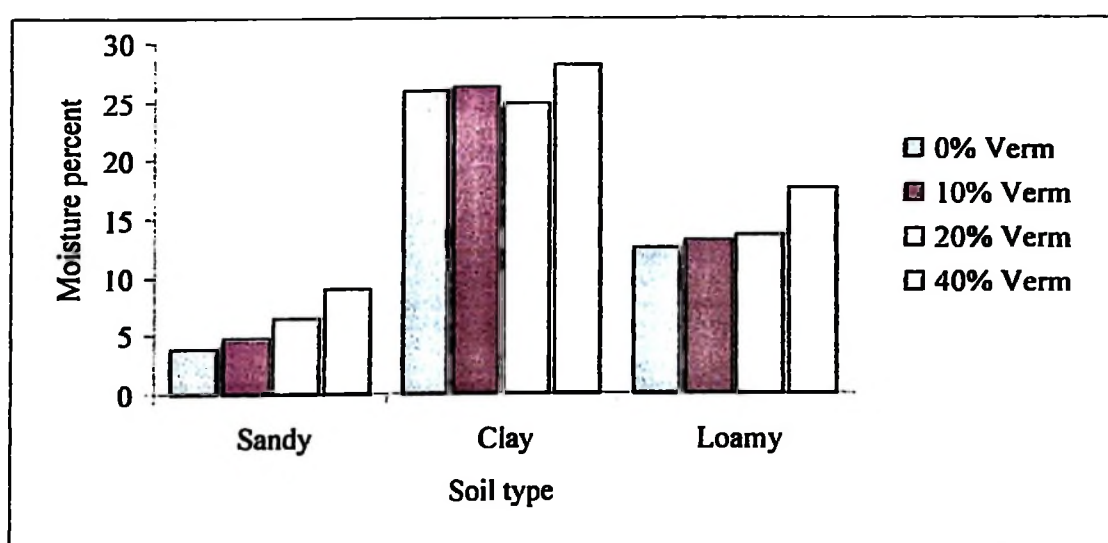
**Table 3: Laboratory results on physical characteristics of soils amended with different vermiculite levels**

Treatment	Moisture		
	percent		
	0.0 bar/ pF2.0	0.3 bar/ pF 2.45	Bulk density g/cc
Sandy 0%	4.66	3.82	1.55
Sandy 10%	5.95	4.78	1.46
Sandy 20%	7.40	6.48	1.31
Sandy 40%	9.94	8.96	1.23
Clay 0%	27.77	24.19	1.28
Clay 10%	29.06	25.24	1.13
Clay 20%	29.20	26.96	1.09
Clay 40%	29.90	28.09	1.01
Loamy 0%	14.75	12.43	1.34
Loamy 10%	15.12	13.04	1.30
Loamy 20%	17.20	13.54	1.29
Loamy 40%	20.76	17.53	1.02

#### 4.7.1 Water holding capacity

Laboratory analysis results indicated the highest increase in moisture content of sandy soil than other soils as the vermiculite level increased to 40% (Fig. 11), followed by loamy soil while the lowest increase was observed in clay soil. The water content (maximum retention) pF 2.0 in sandy soil increased from 4.66% in sandy without vermiculite to 9.94% when 40% vermiculite level was applied equivalent to an increase

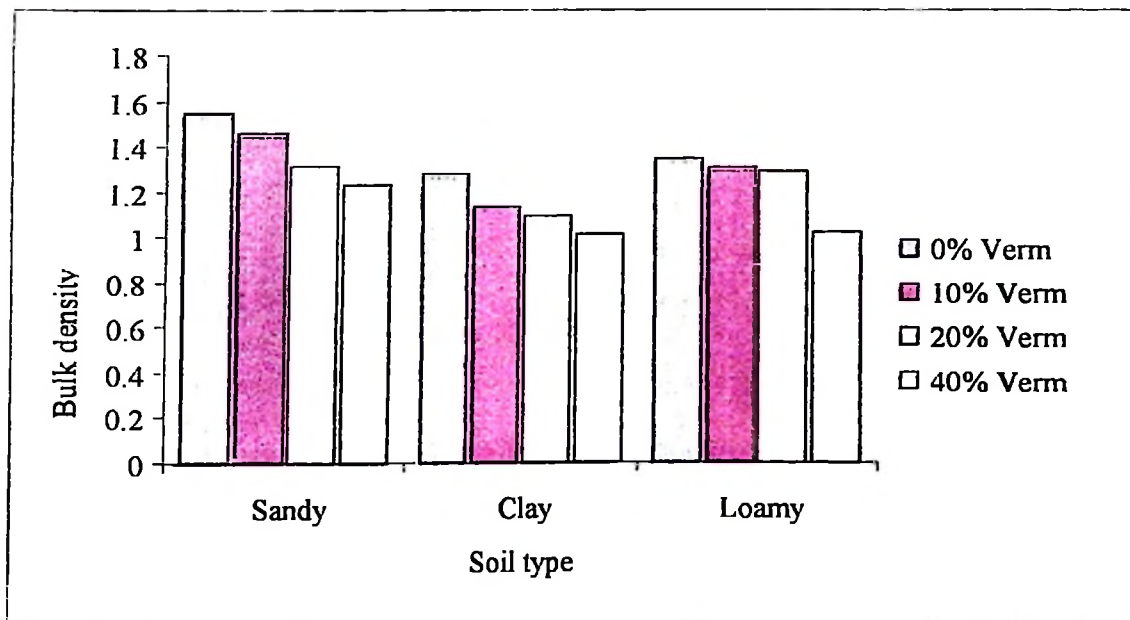
of 113% compared to the control treatment (Table 3). Water content at field capacity (0.3 bar or pF 2.4) increased from 3.82% in sandy soil without vermiculite to 8.96% when 40% vermiculite level was applied equivalent to 134% increase in water retention, while water retention in loamy and clay soils increased by 40% and 6% respectively. Suganya and Sivasamy (2006) observed the increase in moisture retention to the soils amended with vermiculite from 7.5 to 80.1 percent. Warneke and Richards (1974) reported that the capacity to store water in soil can be improved by the incorporation of amendments such as organic matter and vermiculite. The increase in water holding capacity of soils mixed with vermiculite suggests that formation of the interlayer air space in exfoliated vermiculite when heated, creates a large chemically active surface area which acts as water absorbent thus increased water holding capacity of soil. Hudson (2002) and Hombostel (1991) pointed out that exfoliated vermiculite has large chemical surface that makes it useful as an absorbent of water and some chemical processes.



**Figure 11: Water content at 0.3 bar (field capacity) in soils amended with different vermiculite levels**

#### 4.7.2 Bulk density

Laboratory analysis showed that bulk density of all soils was decreasing as vermiculite level increased (Fig. 12). The bulk density of sandy without vermiculite decreased from 1.55 g/cc to 1.23 g/cc, clay from 1.28 g/cc to 1.01 g/cc and loamy decreased from 1.34 g/cc to 1.02 g/cc when 40% vermiculite applied equivalent to 21% decrease for sandy, 21.1% decrease for clay and 24% decrease for loamy soil (Table 3). The low bulk density in soils amended with vermiculite suggest that vermiculite which is a very porous material (because of the presence of interlayer air space in its structure and its light weight) contributed to the decreased bulk density. Hombostel (1991) pointed out that exfoliated vermiculite is a lightweight material with a low bulk density, the properties makes it attractive for use as a soil amendment material.



**Figure 12: Bulk density of soils amended with different vermiculite levels**

## CHAPTER FIVE

### 5.0 CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

The findings clearly indicated the usefulness of vermiculite as a soil amendment material in improving physical and chemical properties of soil such as moisture retention and nutrient supply potentials on sandy soils compared to clay and loamy soils. Growth of tomato measured in terms of shoot dry weight, total dry weight, plant height, relative growth rate and root dry weight was increasing as vermiculite levels increased up to 40%. Contrary to growth parameter, yield of tomatoes measured in terms of weight and number of tomato fruits harvested per plant was highest in 20% vermiculite level. However, as the level of vermiculite in sandy soil increased to 40%, potassium content in plant material decreased by 27% thus reduced tomato yield. This study revealed that soil amendment with vermiculite in sandy and loamy soil increased water retention as the vermiculite level increased but not in clay soil. It was an expected phenomenon because clay soil already had high water retention such that vermiculite effect was masked. It is therefore concluded that vermiculite ratio of 20% is the optimum level for improving moisture retention and fertility in sandy soils ensuring better yield of tomatoes. Actual yield of tomato was not obtained in glasshouse pot experiment, therefore economic analysis was not done to find if this technology could have economic value.

## **5.2 Recommendations**

Based on the above findings, vermiculite application on sandy soil gives better response than in clay and loamy soils.

**5.2.1** The best soil: vermiculite ratio to be used for sandy soil in glass house for tomato production is 20% while 40% vermiculite level would be best for clay and loamy soils.

**5.2.2** There is a need for establishment of effects of vermiculite on the supply of other cations and micro- nutrients.

**5.2.3** Field experiment studies should be conducted to identify if this technology will economically pay.

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## APPENDICES

Appendix 1: Characteristics of vermiculite from Mikese

K %	Na%	Ca%	Mg%	P %	S %	Al%	Fe%	Cu ppm	Zn ppm	Mn ppm	As ppm	Cr	Pb
												ppm	ppm
2.25	0.05	1.84	8.00	0.33	0.02	6.43	7.88	9.00	220	912	3.6	1935	25.3

Source: Omac Laboratory, (2007)

Appendix 2: Mean effects of soil types (main plots) on different variables

Soil type	Height 1* cm	Height 2* cm	Shoot 1* DM (g)	Shoot 2* DM (g)	Root DM 1* (g)	Root DM 2* (g)	Root-sh 1*	Root-sh 2*	Total DM 1* (g)	Total DM 2* (g)	No Flower	No Fruits	Wt Fruits (g)	RGR (g/day)	%
Sandy	24.08c	71.08b	1.310b	15.55b	0.26b	15.13b	0.19a	0.17a	1.650b	18.35b	60.0b	16.0a	322.2c	1.19b	2.06a
Clay	27.43b	77.33a	2.07a	22.37a	0.39a	22.36a	0.19a	0.15ab	2.46a	25.78a	71.0a	20.0a	443.6a	1.67a	2.28a
Loamy	28.57a	76.33a	2.06a	21.63a	0.29ab	21.63a	0.13b	0.13b	2.30a	25.07a	63.0b	20.0a	356.7b	1.63a	2.07a
X	29.11	74.92	1.81	19.85	0.32	19.71	0.17	0.15	2.14	23.07	65.0	19.0	374.1	1.49	2.14
SE	0.213	0.727	0.13	0.449	0.03	0.921	0.007	0.004	0.14	0.227	1.82	1.22	7.873	0.02	0.14
CV%	4.27	6.29	13.6	10.71	21.3	11.36	12.76	9.81	10.3	7.72	16.1	22.1	17.12	8.63	9.15
LSD <sub>0.05</sub>	0.8375	2.852	0.50	1.764	0.12	3.618	0.035	0.036	0.53	0.89	7.16	4.79	30.91	0.08	0.56

Means followed by the same letter(s) within the column are not significantly different at  $P \leq 0.05$  level based on DMRT

1\* = 28 DAP, 2\* = 42 DAP

Appendix 3: Mean effects of vermiculite levels (sub plots) on different growth variables

Verm %	Height 1*(cm)	Height 2*(cm)	Shoot DM 1*(g)	Shoot DM 2*(g)	Root DM 1*(g)	Root DM 2*(g)	Root-sho 1*	Root-sho 2*	Total DM 1*(g)	Total DM 2*(g)	No Flower	No Fruits	Wt Fruits (g)	RGR (g/day)	K %
0	22.27d	73.22a	1.330c	16.84b	0.210c	16.57b	0.15b	0.13a	1.650c	18.48c	53.0b	15.33c	328.2b	1.20c	2.48a
10	24.62c	76.78a	1.81b	20.49a	0.299b	20.48a	0.16ab	0.14a	2.09b	22.97b	65.6a	17.11bc	380.4ab	1.50b	2.27b
20	28.10b	75.11a	1.89b	20.72a	0.340b	20.70a	0.19a	0.14a	2.22b	24.09b	67.2a	21.56a	404.9a	1.56b	1.86c
40	30.31a	74.56a	2.23a	21.35a	0.411a	21.08a	0.19a	0.16a	2.58a	26.72a	72.4a	20.56ab	383.0ab	1.72a	1.94c
X	29.11	74.92	1.81	19.85	0.315	19.71	0.17	0.15	2.14	23.07	64.6	18.64	374.1	1.50	2.14
SE	0.559	1.57	0.08	0.708	0.022	0.746	0.007	0.005	0.07	0.594	3.47	1.374	21.35	0.04	0.07
CV%	4.27	6.29	13.59	10.71	21.32	11.36	12.76	9.81	10.3	7.72	16.1	22.12	17.12	8.63	9.15
1.SD	1.113	4.67	0.245	2.105	0.070	2.217	0.031	0.03	0.22	1.765	10.3	4.083	63.44	0.13	0.19

Means followed by the same letter(s) within the column are not significantly different at  $P \leq 0.05$  level based on DMRT

1\* = 28 DAP, 2\* = 42 DAP

**Appendix 4: Effects of combination of soils and vermiculite on tomato height at 28 DAP**

Vermiculite levels %	Soil type			SE $\pm$ 0.3747
	Sandy	Clay	Loamy	
0	19.27f	23.50d	24.04d	66.81
10	21.20e	26.63c	26.03c	73.86
20	26.27c	29.41ab	28.63b	84.31
40	29.60ab	30.17ab	31.17a	90.94
SE $\pm$ 0.2134	96.34	109.71	109.87	315.92

Values followed by the same letter within a column are not significant difference at  $P \leq 0.05$  level based on DMRT

**Appendix 5: Effects of combination of soils and vermiculite on root dry weight at 28 DAP**

Vermiculite levels %	Soil type			SE $\pm$ 0.0236
	Sandy	Clay	Loamy	
0	0.177e	0.263cde	0.190de	0.630
10	0.237cde	0.413ab	0.247cde	0.897
20	0.260cde	0.44ab	0.320bcd	1.020
40	0.367abc	0.460a	0.407ab	1.234
SE $\pm$ 0.0315	1.041	1.576	1.164	3.781

Values followed by the same letter within a column are not significant difference at  $P \leq 0.05$  level based on DMRT

**Appendix 6: Effects of combination of soils and vermiculite on the relative growth rate of tomatoes (g/day)**

Vermiculite levels (%)	Soil type			S.E. $\pm$ 0.21
	Sandy	Clay	Loamy	
0	0.845f	1.573cd	1.187e	3.605
10	1.193e	1.577cd	1.717abc	4.487
20	1.333e	1.640bc	1.720abc	4.693
40	1.397de	1.877ab	1.897a	5.171
S.E. $\pm$ 0.18	4.768	6.667	6.521	17.956

Values followed by the same letter within a column are not significant difference at  $P \leq 0.05$  level based on DMRT

**Appendix 7: Effects of combination of soil and vermiculite on total dry matter at 42 DAP**

Vermiculite levels %	Soil type			SE $\pm$ 0.0734
	Sandy	Clay	Loamy	
0	13.073g	23.883cd	18.477f	55.433
10	18.163f	24.730cd	26.023bc	68.916
20	20.320ef	25.610bc	26.360abc	72.290
40	21.830de	28.903ab	29.437a	80.170
SE $\pm$ 0.135	73.386	103.126	9.200100.297	276.809

Values followed by the same letter within a column are not significant difference at  $P \leq 0.5$  level based on DMRT

**Appendix 8: Effects of combination of soil and vermiculite on potassium content in plant material**

Vermiculite levels %	Soil type			SE $\pm$ 0.0652
	Sandy	Clay	Loamy	
0	2.923a	2.360bc	2.170cd	7.453
10	2.103cd	2.607ab	2.093cd	6.803
20	1.707e	1.937de	2.037cd	5.581
40	1.617e	2.223cd	1.983cd	5.823
SE $\pm$ 0.135	8.250	9.127	8.993	25.660

Values followed by the same letter within a column are not significant difference at  $P \leq$

0.05 level based on DMRT

Appendix 9: Anova summary for the studied variables (mean Squares)

	df	Height 1 cm	Height 2 cm	Shoo DM 1 g	Shoo DM 2 g	Root DM 1 g	Root DM 2g	Root-sh 1	Root-sh 2	Total DM 1 g	Total DM 2 g	No Flower	No Fruits	Wt of Fruits g	RGR (g/day)	K %
Rep	2	1.766	18.08	0.01	4.81	0.016	1.39	0.002	0.001	0.24	2.03	10.08	26.36	7131.19	0.015	0.02
FacA	2	45.28***	135.25**	2.26*	168.14***	0.059	189.9**	0.013	0.005	2.24*	202.1***	385.1*	48.03	46973.5	0.84***	0.19***
Err(a)	4	0.546	6.333	0.19	2.48	0.012	10.19	0.001	0.001	0.22	0.62	39.92	17.82	743.78	0.005	0.24
FacB	3	115.2***	19.51	1.23***	37.49**	0.06***	40.05**	0.003	0.001	1.31***	106.5***	612.3**	76.32*	9516.5	0.43***	0.76***
AxB	6	3.92*	32.89	0.12	7.85	0.003**	8.39	0.001*	0.001**	0.13	8.49*	124.71	36.55	1760.7	0.049*	0.32***
Err(b)	18	1.264	22.21	0.06	4.52	0.005	5.01	0.001	0.001	0.05	3.18	108.08	17.00	4103.2	0.017	0.04
Total	35	488.13	233.79	3.87	225.29	0.158	254.99	0.021	0.01	4.15	322.9	1282.2	222.08	70228.9	1.352	1.57

X = Significant ( $P \leq 0.05$ ), xx = highly significant ( $P \leq 0.01$ ) and xxx = highly significant ( $P \leq 0.001$ )