EFFECTS OF DRIP IRRIGATION SCHEDULE AND MULCH ON GROWTH, YIELD AND QUALITY OF TOMATO (*Lycopersicon esculentum* Mill.) CULTIVAR MONEY MAKER GROWN IN A GREENHOUSE

BY

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DEDICATION

This thesis is dedicated to my late grandfather Hezekiah Mbira.

DECLARATION

This thesis is my original work and has not been submitted for the award of a degree in any other University.

Kere George Mbira

Signature________________ Date 8/11/2003

APPROVAL

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

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ABSTRACT

An experiment was conducted twice in a greenhouse at Egerton University, Njoro, Kenya (altitude 2200 m a.s.l.) to investigate the effects of drip irrigation, mulch and their interactions on: (a) growth, yield and quality of tomato (Cultivar Money Maker), (b) soil water tension and (c) weed growth. The experimental design was split-plot in randomized complete block design replicated three times. The main plot factor was irrigation schedule, consisting of irrigation on daily basis, every two and three days. The sub-plot factor was mulch, which included clear plastic, dry grass and no mulch (control). The data were subjected to analysis of variance (ANOVA) using MSTATC computer programme and means separated using Duncan Multiple Range Test ($P \leq 0.05$). Drip irrigation schedule or mulch type did not significantly affect plant height, stem diameter, fresh and dry weights of leaves and stems. Dry grass mulch significantly delayed days to first 50% flowering and fruiting by 9 and 7 days, respectively in Trial 1. In Trial 2, dry grass mulch significantly delayed days to 50% flowering and fruiting by 6 and 8 days, respectively. Neither drip irrigation schedule nor mulch type significantly affected marketable tomato yield. Clear plastic mulch significantly increased number of marketable tomato fruits but not individual fruit weight. Clear plastic mulch combined with daily irrigation schedule resulted in highest fruit yield in Trial 2 only. Mean fruit weight was significantly highest in dry grass mulched plots. Dry grass mulch significantly produced the lowest total soluble solids concentration. Tomato fruit firmness was not affected by drip irrigation schedule, mulch type or their interactions at four days after harvesting. Clear plastic and dry grass mulches significantly reduced weed density by 89% and 75%, respectively. Soil water tension at 40 cm depth was not significantly affected by drip irrigation schedule, mulch type or their interactions.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The commercial tomato originated from the Andean region of South America and was first domesticated in Mexico and Central America (Cooper, 1972). It became increasingly popular from the beginning of the twentieth century and in recent decades has become one of the most important vegetables produced worldwide (Nonnecke, 1989). It is an important source of vitamins A, C and B_2 and minerals such as potassium, iron and phosphorus (Nonnecke, 1989).

In Kenya, tomato is also increasingly becoming popular both in the fresh market and processing industry. The total area tomato production is approximately 2000 ha with a mean yield of 12.69 t/ha (FAO, 1999), which is low compared to those of temperate regions that range from 40 to 200 t/ha (Villarreal, 1979). Improvement of tomato yield and quality may help in the alleviation of the vicious cycle of poverty and malnutrition that are common in Kenya.

Tomato growing in Kenya is mainly under field conditions where climatic factors greatly decrease yields and quality of fruit. Seasonal variations in climate cause an irregular supply of fresh tomatoes. This is characterized by a glut during periods of moderate rainfall (mainly June to March) season and deficit during off-season (long rains). Greenhouse production of tomatoes was introduced into Kenya in the recent years to modify local climate to meet the plant growth requirement at any time of the year thereby ensuring regular supply of fresh market tomatoes.

It has been shown to increase yields and improve quality (FAO, 1990). However, its potential has not been well explored and exploited in Kenya due to inadequate management technology

1.2 Statement of the Problem

The yield and quality of tomato in Kenya is quite low due to adverse tropical climate. Tomato water management technology under greenhouse conditions has not been well documented for this region.

1.3 Research Justification

The unfavourable field conditions reduce yield and quality of tomato. This result in irregular supply of tomatoes and hence price fluctuations, which impacts negatively on both consumers and growers in Kenya. Greenhouse production of tomatoes has been proved to be successful in temperate regions and is showing good results in Kenya. However, its utilization is fairly limited due to various factors such as lack of management technology for the region. The management of greenhouse-grown tomato include efficient use of various inputs. Water is a crucial input under greenhouse conditions because rainfall is excluded. Moreover, it is a scarce resource in Kenya.

Plant water use efficiency is affected by water distribution in the soil, which may be in turn affected by irrigation schedule. Mulching has been shown to conserve soil water, regulate soil temperature and control weeds (Shrivastava et al., 1994). Mulching therefore can influence irrigation schedule. The effects of irrigation schedule and mulch on plant vegetative growth have been observed in some studies under field conditions.

However, their effects and those of their interactions on tomatoes under greenhouse conditions have not been studied. This research therefore will provide information to greenhouse tomato growers in Kenya on the response of tomatoes to drip irrigation schedule and mulching.

1.4 Hypotheses

The following hypotheses were tested for the greenhouse-grown tomato, cultivar Money Maker:

i). Daily drip irrigation increases growth, yield and quality of tomato.

ii). Clear plastic mulch increases yield, growth and quality of tomato.

iii). Daily drip irrigation and clear mulch increases yield, growth and quality of tomato.

iv). Low soil moisture content reduces growth, yield and quality of tomato.

vi). Daily drip irrigation and no mulch promote weed density.

vi). Daily drip irrigation and clear mulch maintains lower soil water tension.

1.5 Objectives

1.5.1 General objective

The overall objective of this study was to investigate the influence of drip irrigation schedule and mulching on growth, yield and quality of greenhouse-grown fresh market tomato (cultivar, Money Maker).

1.5.2 Specific objectives

The specific objectives were to determine the influence of the following on fresh market tomato grown in a plastic covered greenhouse:

i) The effects of drip irrigation schedule on growth, yield and quality of fresh market tomato.

ii) The effect of mulch type on growth, yield and quality of fresh market tomato.

iii) The effect of drip irrigation and schedule mulch type on the growth, yield and quality of fresh market tomato.

iv). The effects of drip irrigation schedule, mulch type and their combination on soil water tension at a depth of 40 cm.

v) The effects of drip irrigation schedule, mulch type and their combination on weed growth.

vi). The effects of soil water tension on growth, yield and quality of fresh market tomato.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany

Tomato is an annual shrubby plant in the temperate regions and a short-lived perennial plant in the tropics (Nonnecke, 1989). It belongs to the family Solanaceae and sub-family Solanaidae (D'Arcy, 1979). Its growth habit varies between determinate and indeterminate depending on the cultivar.

Determinate cultivars are erect, bushy and may grow up to 2 m in height. They also have restricted flowering and fruiting period, and are suitable for outdoor conditions. For indeterminate cultivars such as Money Marker, the main stem grows indefinitely, reaching a height of up to 10 m within a year under greenhouse conditions. Since indeterminate cultivars flower and fruit continuously, they are suitable for greenhouse production as they allow achievement of economic returns.

The leaves of popular greenhouse cultivars are usually 0.5 m long with a large terminal leaflet and up to eight large leaflets (Picken et al., 1986). The flowers are perfect and regular. The lower parts of the corolla are fused together with stamens within the column to form a staminal cone. The fruit is a true berry consisting of pericarp, fleshy septa between locules, a placenta and central axis (Picken, et al., 1986). The plant has a tap root system with lateral roots. The taproot may grow up to 1.5 m deep while the lateral root-zone diameter is about 30 to 70 cm (Sanders et al., 1989). It is therefore expected that irrigation management methods that distribute water and nutrients around root zone would increase growth, yield and quality of greenhouse-grown tomato.

2.2 Effects of Soil Moisture on Tomato Plants

Plant growth and yield are affected directly by plant water deficit and indirectly by soil water deficit and soil waterlogging (Rudich et al., 1981). Tomato plant growth rate decreases with a decrease in the amount of water applied (Russo, 1983; Obreza et al., 1996). Plant leaf area is reduced by water deficit through several processes. For instance, in dicotyledonous plants, drought induces reduction in individual plant leaf area probably through restriction in cell division and tissue expansion (Dale, 1988; Randall and Sinclair, 1988).

Soil water deficit may have significant negative impacts on the growth and development of most crops. Plant processes such as leaf-gas exchange and leaf area development (that depend on cell volume and expansion) are sensitive to soil moisture deficit (Lecoeur and Sinclair, 1996). Soil moisture deficit reduces photosynthetic capacity of plant leaves, thereby causing a substantial yield reduction (Lecoeur and Sinclair, 1996). The adverse effects of water deficits on plants photosynthetic capacity include restricted cell growth and expansion, carbon dioxide exchange, leaf expansion, translocation and transpiration (Hsiao, 1973).

Cook and Sanders (1990) reported that frequent irrigation to maintain soil moisture level at -0.20 bars within a soil profile up to 40 cm deep results in an increase in yield of the more valuable large-sized tomato fruits. The growth and yield of two processing tomato cultivars (VF145-B7879 and VC-82B) also increased proportionately with an increase in irrigation schedule (Sanders et al., 1989). Russo (1983) reported that tomato yields were higher with daily irrigation than under irrigation every three days. In contrast, Meek et al. (1983) found that daily irrigation gives similar results as those achieved with three or four-day irrigation intervals. The variations may be attributed to crop management practices, irrigation method, soil fertility and soil type (Shrivastava et al., 1994). Kadam and Magar (1993) reported a significant difference in tomato yield between drip irrigation scheduled after 1, 2 and 3 days. These studies were done under field conditions thus a different tomato yield response is expected under humid greenhouse conditions with reduced evapotranspiration.

Increasing irrigation above crop water requirement reduces tomato fruit yield and size (Locascio et al., 1989) besides wasting the available water (Doorenbos and Pruitt, 1977). Therefore, it is important to determine an optimal irrigation regime that promotes yield and quality of fresh market tomato fruits under greenhouse conditions. FAO (1990) also reported that growth of indeterminate greenhouse tomatoes might be restricted or interrupted at any stage of growth by excess moisture, water deficit and saline conditions. Crops receiving more frequent irrigation have better water use than those receiving less frequent irrigation under similar climatic conditions (Smittle et al., 1994). Drip irrigation coupled with an increase in pan evaporation ratio results in a decrease in tomato yield (Shrivastava et al., 1994). This is due to water deficit stress that limits tomato vegetative growth and fruit expansion (Obreza et al., 1996).

2.3 Effects of Soil Moisture on Tomato Quality

The quality of fresh market tomatoes is crucial for their successful marketing. Intensive irrigation during the period of tomato fruit development and maturation adversely affect various quality parameters (Phill and Lambeth, 1981).

In contrast, increased irrigation rate and frequency to maintain soil moisture at –0.2 bars has been shown to reduce blossom-end-rot (Sanders et al., 1989; Cook and Sanders, 1990). Blossom-end-rot in tomato fruit is associated with localized calcium deficiency in the affected plant part. Calcium moves exclusively within the xylem through transpiration stream to the point of lowest water potential (Bangerth, 1979). This indicates that non-senescing leaves with high transpiration rates and concomitant low water potentials may restrict calcium movement to slowly transpiring organs like fruits (Bangerth, 1979). Sustained high relative humidity that significantly restricts transpiration also contributes to blossom-end-rot (Peterson and Taber, 1991). Alternating excess and deficiency of water can cause tomato fruit cracking (FAO, 1990). This condition predisposes the tomato fruits to secondary infections that further reduce fruit quality and marketability thereby causing substantial production losses.

2.4 Scheduling of Drip Irrigation

Irrigation scheduling involves two primary decisions, when to irrigate and how much water to apply. These two decisions are critical for management of any irrigation system and are not independent of each other (Doorenbos and Pruitt, 1977). There are various methods that can be used in scheduling irrigation. These include evapotranspiration rate (McNiesh et al., 1985; Clough et al., 1990; Hartz 1993), allowable soil water depletion (Bogle et al., 1989) and target soil water tension (Thompson and Doerge, 1995).

The interval between drip irrigation should prevent depletion of soil-water reservoir to permanent wilting point. However, the amount of soil water depletion is not as critical as energy, which plants must work against to extract water (Smittle et al., 1992).

Drip irrigation schedule is largely dictated by soil physical properties. For instance, the frequency of up to one week for heavy soils with low infiltration rate and daily in light textured soils (Doorenbos and Pruitt, 1977). Irrigation schedule also depend on crop evapotranspiration rate (Hartz, 1993). Thus the use of mulches under greenhouse conditions may affect the irrigation schedule by altering crop evapotranspiration rate.

Soil characteristics and crop water use largely determines the duration of irrigation and the amount of water applied (Clough et al., 1990). Measurements of soil water content by a neutron probe, gypsum block, nylon, tensiometers and thermal dissipation sensor may be appropriate. However, they have some measurement limitations on convenience, accuracy, durability and cost (Doorenbos and Pruitt, 1977). Crop evapotranspiration can be used to estimate crop water requirements for a period of ten days. Pan evaporation incorporates the climatic factors influencing evapotranspiration into a single measurement (Hansen et al., 1980). The main limitation of pan evaporation is that it does not indicate soil moisture status hence it may lead to poor irrigation scheduling.

2.5 Effects of Mulching on Tomato Yield and Quality

Mulch is a layer of material applied onto the surface of soil, where it remains for weeks, months or even years mainly to prevent soil erosion and reduce the rate of moisture loss and also control weeds. Mulches include a wide range of natural (organic) and synthetic materials (Benoint et al., 1984).

Polyethylene (plastic) sheet is the most popular synthetic mulch in vegetable production probably due to its availability and ease of application.

The polyethylene mulching material may be clear (transparent), blue, yellow or black in colour depending on the purpose (Benoint et al., 1984). The benefits of polyethylene mulch have been reported in pepper where it increases the number of marketable fruits (Bhella, 1988; Brown et al., 1991). This increase in yield has been attributed to increased plant growth due to improved soil moisture and increased soil temperature (Wien and Minotti, 1988). Clear plastic mulches have been shown to enhance yield and quality of tomatoes (Rudich, 1979; Chen and Katan, 1980). In contrast, (Bonamo and Lamont (1987) reported that clear polyethylene mulch is not effective in increasing total yields of muskmelons over bare ground. Black polyethylene mulch increases early total yields of large marketable fruits (>80mm in cross-sectional diameter) of tomatoes compared to no mulch (Perry and Sanders, 1986). However, average large tomato fruit weight is not affected by mulch type (Perry and Sanders, 1986). This suggests that the use of mulches can improve growth, yield and quality of tomatoes depending on the management practice employed.

The commonly used organic mulches include sawdust, corncobs, rice husks and straws of wheat and rice. The benefits of organic mulches to plants include moisture conservation, increased levels of soil organic matter, improved soil structure and lowering of soil temperature (Garnaud, 1981). The yield of tomato was highest with sugar cane trash mulch relative to black plastic mulch and no mulch (Shrivastava et al., 1994). This study was conducted under field conditions and therefore, a different response may be found in the greenhouse.

2.6 Effects of Mulching on Soil Microclimate

Mulching may reduce salt injury resulting from salt accumulation on the soil surface due to reduced evaporation within the mulched area (Benoint et al., 1984). Mulching enhances uniform moisture distribution in the upper soil layer (Rudich et al., 1981). Clear plastic mulch increases soil temperature in the 0-25 cm soil profile, conserves soil moisture by reducing surface evaporation and inhibits weed growth (Liu and Hu, 2000). Clear polyethylene mulch reduces heat convection and water evaporation from the soil to the atmosphere thereby, resulting in increased soil temperature (Marya and Lal, 1981).

Clear plastic mulch maintains higher soil moisture than rice straw (Hwang and Tae, 2000). This may be attributed to reduction of moisture losses through evaporation by clear plastic mulch. It is expected that clear plastic much would maintain higher soil moisture than dry grass mulch under greenhouse conditions due to reduced water losses through surface evaporation. Li et al. (2000) showed that rice straw significantly reduces water evaporation, soil salinity and soil temperature. The reduction in salinity was due to uniform distribution of water in the soil thus low accumulation of salts. Mulching facilitates moisture distribution near the soil surface where a greater portion of the root system may exploit the shallowly incorporated fertilizers or drip applied fertilizers (Wien and Minotti, 1988). Clear plastic mulch increases carbon dioxide concentration (Liu and Hu, 2000) and light reflection onto the plant canopy (Mathieu and Aure, 2000). The polyethylene mulch covers the soil and carbon dioxide only escapes through the planting holes (Sanders 2000). The elevated carbon dioxide and increased light reflection can increase growth, yield and quality of tomatoes.

2.7 Effects of Irrigation Methods on Growth, Yield and Quality of Tomatoes

Drip irrigation has been shown to increase total and early yields, leaf area index of tomato than furrow sprinkler or furrow irrigations (Kadam and Magar, 1993; Liu, 2000). This may be attributed to uniform moisture and root distribution (Sanders et al., 1989), reduced weed competition for light, nutrients and moisture under drip irrigation (Bogle and Hartz, 1986). Clark et al. (2000) found that drip irrigation rate does affect yield of tomatoes under sandy soils. This may be due to low water holding capacity of sandy soils and therefore, use of mulches and different drip irrigation intervals under clay loam soils may affect yields of tomatoes grown in the greenhouse.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

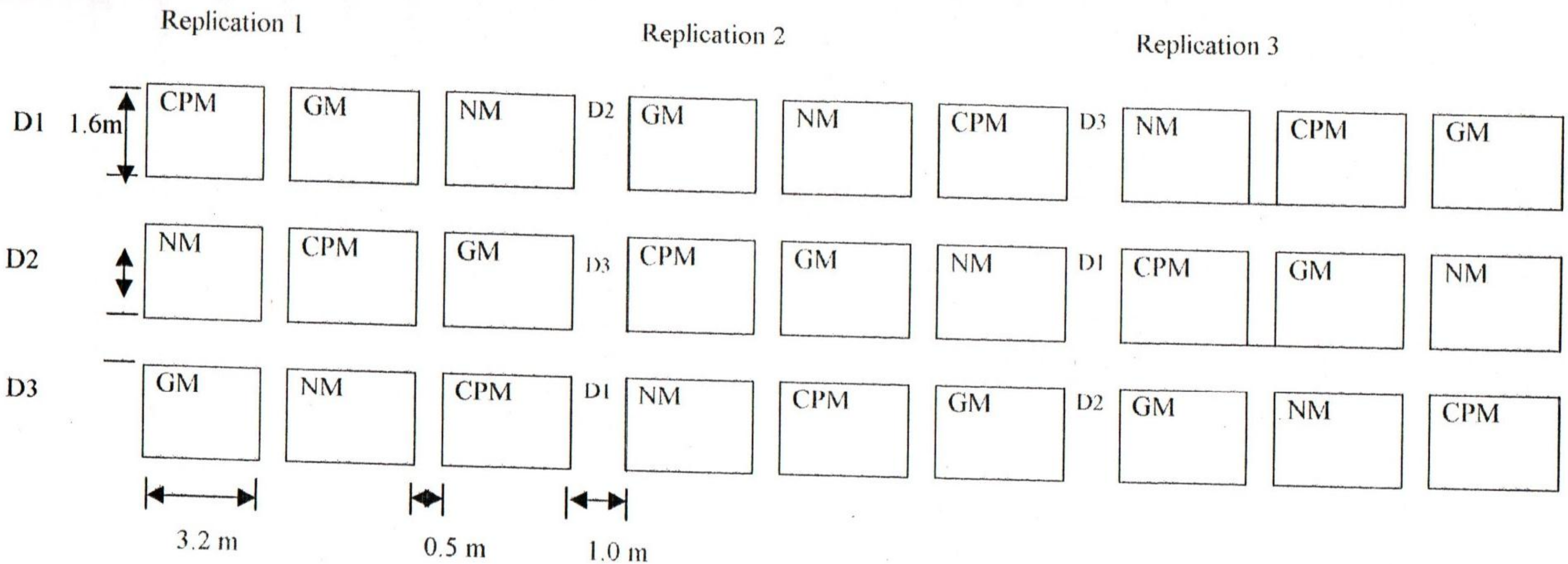
The study was conducted in a plastic covered greenhouse at Egerton University, Tatton farm, (Horticulture Demonstration Section), Kenya. The farm lies at a latitude of approximately 0° 23' S, Longitude of 35° 35' E and at an altitude of 2200 m above sea level. The mean temperature, humidity, evaporation rate and rainfall during the study period were about 19.68°C, 62.45%, 3.93 mm/day and 907 mm/year, respectively (Egerton University Meteorological Station, 2001). The minimum and maximum temperature within the greenhouse in Trial 1 was 8.7°C and 31.5°C, respectively, (Appendix 1). In Trial 2, the minimum and maximum temperature within the greenhouse was 7.4°C and 34.5°C, respectively. The mean relative humidity in the greenhouse was 69.3% and 71.5% in Trial 1 and Trial 2, respectively. The ambient temperature and relative humidity were recorded automatically by thermohdyrograph placed centrally 50 cm above the ground level. The soil pH (H_2O) and (0.01M $CaCl_2$) at 0-30 cm depth was 6.3 and 5.4, respectively. The textural class was clay loam (40% clay, 31% silt and 29% sand).

3.2 Experimental Design and Treatments

The experimental design was split-plot in randomized complete block replicated three times (Figure 1). The main plot factor was irrigation schedule, which consisted of irrigation frequency on daily (D1), every two days (D2) and every three days basis (D3), respectively. Sub-plots were made of mulch types, which consisted of no mulch

(NM), clear plastic mulch, (CPM) (0.014 mm thick), and dry grass (GM). The main grass was *Hyperrhenia Species*. Main plot measured 1.6 m wide and 10.6 m long. A path measuring 1.0 m wide separated two main plots. To prevent water flow from different treatments, a polythene sheet 1 m wide was buried at a depth of 60 cm. Individual sub-plots measuring 1.6 m wide and 3.2 m long were planted with 'Money Maker' tomato seedlings spaced 50 cm between rows and 40 cm within rows. There were four rows per sub-plot and each row had nine plants (36 plants per plot). Two outer rows formed guard rows while the two inner rows were used for data collection.

The plants were irrigated uniformly in the first 21 days after transplanting to ensure proper take-off of the transplants. Irrigation treatments then followed. The water application rate ranged between 1 litre for young (non-flowering) plants to 2 litres for older (flowering and fruiting) plants per day (Liu and Nyalala, 2000 personal comm.). The water discharge rate from each emitter was 4 litres per hour. The irrigation-time to supply two litres of water per plant for daily, two and three days schedule was 56 minutes, 1 hour and 52 minutes and 2 hours 48 minutes, respectively. Clear plastic mulch was stretched tightly in the respective subplots and each edge firmly covered with 20 cm layer of soil before transplanting. Dry grass mulch was applied 8 cm thick to cover 100% of the subplots immediately after transplanting.



D1-Irrigation once daily, D2- irrigation every two days and D3-Irrigation every three days.
CPM-clear plastic mulch, GM-dry grass mulch and NM-no mulch.

Figure 1: Experimental Layout.

3.3 Cultural Practices

3.3.1 Land preparation and fertilizer application

Greenhouse soil was dug using a forked-hoe, pulverized to a fine tilth and levelled. Well-decomposed pig manure was uniformly applied on the soil surface at the rate of 10 tonnes per hectare (1 kg/m^2) and worked into the soil to a depth of 15 cm to allow exploitation by shallow roots of tomato seedlings at transplanting (Oikeh and Asiegbu, 1992). Pig manure was used because it has been shown to have adequate nitrogen content and was more available than poultry manure (Oikeh and Asiegbu, 1992). Phosphorus in the form of diammonium phosphate (DAP 18:46:0) was evenly broadcasted on soil surface at 123 kg phosphorus per hectare and incorporated into the soil to a depth of 15 cm to improve phosphorus uptake (Thompson and Doerge, 1995). The beds were levelled using a rake. Inflatable plastic drip tubes with emitters spaced 0.33 m apart were placed at the centre of each two rows so that each tube irrigated two rows of tomato plants.

3.3.2 Nursery establishment and operations

The potting media was prepared by mixing topsoil obtained near the greenhouse (experimental site) with well rotten pig manure in the ratio of 2:1 (v/v). Plastic pots measuring 9 cm, 9 cm, 5 cm in height, top and bottom diameters, respectively with a hole at the bottom were filled with soil-manure mixture. Tomato seeds (Cultivar. Money Maker) were directly sown in the pots at a depth of about 2 cm within the greenhouse. The seedlings were later thinned to one at fourteen days after transplanting. About 300 ml of water were applied to the pots using a watering can with a fine rose. Watering continued daily immediately after sunset for three weeks.

Watering frequency was gradually reduced to once every two days to harden the seedlings in readiness for transplanting. The pots were kept weed free by regular hand pulling of emerging weeds.

3.3.3 Transplanting

Transplanting was done on the fourth week after sowing when the seedlings had attained 4 to 5 true leaves (Liu and Nyalala, 2001 personal comm.). Transplanting was carried out on 29th September 2001 and 25th March 2002 for trials 1 and 2, respectively. Only healthy, vigorous and normal seedlings were selected and transplanted.

3.3.4 Plant training and pruning

Tomato plants were trained to single stems. The stems were twisted on sisal twines connected to two parallel horizontal wires stretched at 0.3 m and 2.2 m above the ground level, respectively. The upper horizontal wires were supported on wooden poles of about 18 cm in diameter installed 2.4 m and 4 m apart. Lateral shoots and senescing or diseased leaves were removed regularly by hand snapping.

3.3.5 Pest and disease control

Tomato pests such as white flies (*Bemisia tabaci*), thrips (*Franinella spp., Thrips spp.*), leaf miner (*Linomyza spp.*), aphids (*Aphis spp.*), red spider (*Tetranychus spp.*) and rusette mites (*Aculops spp.*) that are common in greenhouses were regularly controlled by application of broad spectrum pesticide, Brigade (Bifenthrin 25 g/l). The pesticide was applied once every two weeks at the rate of 2 ml per litre of water.

Tomato early blight (*Alternaria solani*) and late blight (*Phytophthora infestans*) were controlled by application of Ridomil (40 g/kg metaxyl-M + 640 g/kg mancozeb) at 40 g per litre of water every two weeks. Tomato plants that were severely attacked by early blight (*Alternaria solani*) and late blight (*Phytophthora infestans*) were carefully uprooted and destroyed.

3.4 Parameter Assessments

To assess the effects of treatments on the tomato crop, the following parameters were measured:

3.4.1 Growth and development rate

The heights and stem diameters of eight randomly selected tomato plants from the middle two rows were measured weekly using a metre rule. The number of leaves of six randomly selected plants was counted weekly. The rate of maturity was assessed by counting the number of days taken from transplanting to first 50% flowering and fruiting.

3.4.2 Yield and yield components

The number of flowers and fruits of 11 plants selected for harvesting in each sub-plot were counted through the crop growth period. The percentage fruit set per truss of the first two trusses were calculated by dividing the number of fruits by that of flowers then multiplied with 100. Tomato fruits with any externally detectable colour change ('star breakers') were considered mature and harvested. Fruits that were at least 30 g, with regular shape and no signs of pest or disease attack were considered marketable. Marketable fruits were counted and weighed using analytical balance (accuracy 0.5g).

Harvesting was carried out from 12th December 2001 to 3rd February 2002 and 6th June 2002 to 10th July 2002 for trials 1 and 2, respectively. Harvesting was carried out seven and five times at weekly intervals in trials 1 and 2, respectively. In Trial 2, harvesting was terminated earlier due to severe attack by tomato late blight disease.

3.4.3 Dry matter partitioning

Three plants from the two middle rows were randomly selected and assessed for dry matter partitioning at 68 days after transplanting when most trusses had formed fruits. The plant parts were separated into stem, leaves, and fruits, and their fresh weight measured using a balance (accuracy ± 0.5 g). The stem and leaf samples were put in turkey paper bags and oven dried for four day at 70°C. The fruit samples were cut into small pieces spread out in single layers and oven dried at 70°C for one week (Nyabundi and Hsiao, 1989). Oven dried samples were then weighed. Harvest index was calculated by dividing the fruit dry weight by total shoot (leaves, stems fruits and pruned plant parts) dry weight.

3.4.4 Fruit firmness

Ten tomato fruits per plant from four selected plants in each sub-plot were randomly sampled at the turning stage. The fruits were washed with calcium hypochlorite 20% (v/v) to eliminate surface pathogens and rinsed with distilled water for three minutes. Excess water was blotted-off using blotting paper. The fruits were placed in ventilated cartons at room temperature and tested for firmness using a hand pressure tester at an interval of 0, 2, 3 and 4 days through out the ripening period (Falluji et al., 1982). Fruit ripening lasted for four to five days.

3.4.5 Total soluble solids

The juice from 50 randomly selected table ripe tomato fruits per treatment was analysed for total soluble solids using a hand refractometer (0-30° brix).

3.4.6 Weed growth

The unmulched and dry grass mulched plots were weeded clean two weeks after planting. Weeds were sampled using a 0.09 m^2 quadrant at the end of the tomato production season. Weeds were hand pulled and washed in running tap water to remove soil debris. Four quadrants were taken from each sub-plot. The weeds were put in turkey paper bags and oven dried at 70°C for 48 hours and their dry weight measured using analytical balance (accuracy $\pm$ 0.05 g).

3.4.7 Soil moisture measurement

Tensiometers were placed 24 cm from the drip line at 40 cm depth at the centre of each sub-plot 21 days after transplanting to measure soil water tension. The tensiometers were installed at 40 cm depth where root density is high (sanders et al., 1989).

Tensiometer readings were taken once daily during the week days between 12.30-1.00 pm when greenhouse temperature and relative humidity was maximum and minimum, respectively thereby, promoting high evapotranspiration rate.

3.5 Data Analysis

The data obtained was subjected to analysis of variance (ANOVA) and the treatment means separated by Duncan's Multiple Range Test (DMRT) at ($P < 0.05$) using MSTATC statistical package (Michigan State University, 1993).

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of Drip Irrigation and Mulching on Plant Growth

Plant height and stem diameter were not significantly affected by drip irrigation intervals, mulching or their interactions (Table 1). Drip irrigation schedule or mulching did not significantly influence fresh tomato fruit weight in both trials (Tables 2a and 2b). Neither drip irrigation schedule nor mulch type affected fresh leaf weight (Tables 2a and 2b). There was no significant interaction between drip irrigation and mulch type on leaf fresh and dry weight and stem fresh and dry weight. Fruit fresh weight tended to be higher with daily irrigation and clear plastic mulch (Tables 2a and 2b). Harvest indices were not significantly affected by drip irrigation schedule. There was significant interaction between irrigation schedule and mulch type on harvest index (Tables 2a and 2b).

Table 1. Effect of drip irrigation schedule and mulch type on stem height and stem diameter at 70 days after transplanting

Main effects	Trial 1		Trial 2	
	Stem height (m)	Stem diameter (cm)	Stem height (m)	Stem diameter (cm)
Irrigation schedule				
Daily	1.5	1.3	1.3	1.3
Every two days	1.5	1.3	1.4	1.3
Every three days	1.4	1.4	1.4	1.4
S.E.M[y]	0.06	0.03	0.03	0.03
F-test	ns[z]	ns	ns	ns
Mulch types				
No mulch	1.5	1.3	1.4	1.3
Dry grass	1.5	1.3	1.3	1.3
S.E.M	0.06	0.01	0.03	0.03
F-test	ns	ns	ns	ns

Means within columns are not significant at $P \leq 0.05$, n =9. [z] ns =Not significant
[y]S.E.M.is the standard error of the mean.

Table 2a. Effects of drip irrigation schedule and mulch type on leaf fresh and dry weight, stem fresh and dry weight, fruit fresh and dry weight per plant (g/plant) and harvest index (Trial 1)

	Growth parameters^{Z}						
	Leaf fresh weight	Leaf dry weight	Stem fresh weight	Stem dry weight	Fresh fruit weight	Fruit dry weight	Harvest index
Irrigation schedule							
Daily	782.1	127.4	653.2	97.5	1904.0	295.9	0.6 ^{a}
Every two days	682.4	121.0	573.8	77.6	1813.9	355.0	0.6 ^{a}
Every three days	685.9	119.1	623.5	81.0	1771.3	290.6	0.6 ^{a}
S.E.M.^{Y}	5.78	1.28	8.76	2.45	2.3	13.26	0.08
F-test	ns	ns	ns	ns	ns	ns	ns
Mulch types							
No mulch	658.6	103.2	648.7	70.6	1015.0	243.2 ^{ab}	0.6 ^{a}
Dry grass	682.4	115.6	611.9	100.4	1662.0	226.1 ^{b}	0.5 ^{b}
Clear plastic	582.3	111.3	590.0	88.5	1893.4	357.1 ^{a}	0.6 ^{a}
S.E.M.	4.86	3.32	10.12	19.23	14.54	26.07	0.06
F-test	^{Z}ns	ns	ns	ns	ns	*	*
Interaction effects							
Daily + no mulch	803.7 ab	107.7	724.7	113.8	1809.0 ^{b}	262.8 ^{b}	0.5 ^{c}
Daily + dry grass	804.6 ab	133.2	643.4	83.0	1829.7 ^{b}	216.0 ^{c}	0.6 ^{b}
Daily + clear plastic	466.7 ^{bc}	89.8	591.5	95.8	2543.3 ^{a}	340.2 ^{ab}	0.7 ^{a}
Every two days + no mulch	601.8 ^{bc}	112.9	617.6	74.9	1299.7 ^{bc}	242.3 ^{bc}	0.6 ^{b}
Every two days + dry grass	829.3 ^{a}	130.4	546.2	68.2	2037.7 ^{ab}	261.5 ^{bc}	0.5 ^{c}
Every two days + clear plastic	542.0 ^{bc}	104.0	557.6	89.8	2086.7 ^{ab}	379.9 ^{a}	0.7 ^{a}
Every three days + no mulch	699.7 ^{b}	106.6	603.9	76.7	1894.3 ^{ab}	366.2 ^{ab}	0.7 ^{a}
Every three days + dry grass	469.4 ^{bc}	90.6	646.2	79.2	1369.7 ^{bc}	265.9 ^{bc}	0.6 ^{b}
Every three days + clear plastic	645.3 ^{b}	119.9	620.8	82.3	1344.7 ^{bc}	245.1 ^{bc}	0.6 ^{b}
S.E.M.	23.86	25.68	14.68	10.54	28.13	7.48	0.03
F-test	ns	ns	ns	ns	ns	*	*

^{Z}Means within the column followed by the same letters or not followed by letters are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. ns denotes not significant at $P \leq 0.05$, * Significant at $P \leq 0.05$. n= 9. ^{Y}S.E.M. is the standard error of the mean

Table 2b. Effects of drip irrigation schedule and mulch type on leaf fresh and dry weight, stem fresh and dry weight, fruit fresh and dry weight per plant (g/plant) and harvest index (Trial 2)

	Growth parameters[Z]						
	Leaf fresh weight	Leaf dry weight	Stem fresh weight	Stem dry weight	Fresh fruit weight	Fruit dry weight	Harvest index
Irrigation schedule							
Daily	542.8	88.4	579.3	86.5	1504.0	233.5 [b]	0.6
Every two days	581.4	103.0	508.9	68.8	2013.9	319.0 [a]	0.6
Every three days	584.3	101.4	552.9	70.4	1267.3	207.9 [b]	0.6
S.E.M.[y]	2.36	6.30	3.35	5.89	24.50	17.63	0.04
F-test	ns	ns	ns	ns	ns	*	ns
Mulch types							
No mulch	678.8	104.8	575.3	79.2	1782.6	302.7 [a]	0.6 [a]
Dry grass	682.4	114.9	542.6	68.9	1428.0	194.4 [b]	0.5 [b]
Clear plastic	481.0	98.6	523.2	78.4	1493.4	280.0 [ab]	0.5 [b]
S.E.M.[y]	23.46	4.45	3.27	2.19	8.82	16.13	0.08
F-test	ns	ns	ns	ns	ns	*	*
Interaction effects							
Daily + no mulch	603.7	80.9	642.7	100.9	1559.0	226.5 [b]	0.8 [a]
Daily + dry grass	689.4	114.1	570.6	73.6	1914.3	226.0 [b]	0.5 [c]
Daily + clear plastic	616.7	121.4	524.5	84.9	2365.3	316.4 [a]	0.5 [c]
Every two days + no mulch	581:6	109.1	547.7	66.4	1103.7	205.7 [b]	0.7 [b]
Every two days + dry grass	629.3	98.9	484.4	60.5	1235.7	169.2 [bc]	0.5 [c]
Every two days + clear plastic	608.0	116.7	494.4	79.6	1034.3	175.5 [bc]	0.5 [c]
Every three days + no mulch	721.7	110.0	535.5	68.0	1604.3	230.9 [b]	0.5 [c]
Every three days + dry grass	649.2	125.3	572.5	70.18	1128.99	192.8 [b]	0.4 [d]
Every three days + clear plastic	625.3	116.1	550.5	73.01	900.67	164.2 [bc]	0.5 [c]
S.E.M.	7.83	8.85	14.6	14.31	32.43	6.66	0.03
F-test	ns	ns	ns	ns	ns	*	*

[Z]Means within the column followed by the same letters or not followed by letters are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. ns denotes not significant at $P \leq 0.05$, * Significant at $P \leq 0.05$. n=9. [y]S.E.M. is the standard error of the mean

Irrigation schedule did not significantly influence the number of leaves per plant (Table 3). The number of leaves was significantly higher with clear plastic than grass mulch in Trial 1 (Table 3). There was no significant interaction between drip irrigation schedule and mulch on leaf numbers (Table 3). Drip irrigation schedule did not significantly influence days to first 50% flowering and fruiting (Table 3). In Trial 1, dry grass mulch significantly delayed days to first 50% flowering and fruiting by 9 and 7 days, respectively (Table 3). However, in Trial 2, dry grass mulch delayed days to 50% flowering and fruiting by 6 and 8 days, respectively (Table 3). There was no significant interaction between drip irrigation schedule on days to first 50% flowering and fruiting (Table 3).

4.2 Effects of Drip Irrigation Schedule and Mulch Type on Yield of Tomato

Drip irrigation schedule did not significantly influence tomato fruit number in both trials (Table 4). Clear plastic mulch significantly produced the highest fruit number (Table 4). There was no significant interaction between drip irrigation schedule and mulch type on tomato fruit number in Trial 1 (Table 4). However, daily irrigation combined with clear plastic mulch significantly produced the highest number of fruits Trial 2 (Table 4). The lowest number of fruits was obtained from irrigation every three days combined with dry grass mulch in Trial 2.

Table 3. Effects of drip irrigation schedule and mulch types on number of leaves, days to first 50% flowering and fruiting

Main effects	Trial 1			Trial 2		
	No. of leaves	Days to 50% flowering	Days to 50% fruiting	No. of leaves	Days to 50% flowering	Days to 50% fruiting
Irrigation schedule						
Daily	17.0	28.2	38.3	16.8	24.0	34.1
Every two days	18.7	25.1	34.3	17.7	21.1	34.3
Every three days	16.8	27.3	35.9	17.6	25.3	36.4
S.E.M.^{y}	0.82	1.27	0.64	0.78	1.23	0.62
F-test	ns^{z}	ns	ns	ns	ns	ns
Mulch types						
No mulch	18.0^{ab}	21.94^{b}	34.2^{b}	16.9	23.4	34.2^{b}
Grass	16.7^{b}	31.11^{a}	41.1^{a}	16.7	29.3	42.0^{a}
Clear plastic	21.0^{a}	24.4^{b}	32.4^{b}	17.4	24.3	31.0^{b}
S.E.M	0.45	2.37	1.79	0.48	2.40	2.48
F-test	*	*	*	ns	ns	*

Means within the column followed by the same letters or not followed by a letter series are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. n = 9. ^{Z}ns denotes not significant at $P \leq 0.05$, * Significant at $P \leq 0.05$. ^{Y}S.E.M. is the standard error of the mean

Table 4. Effects of drip irrigation schedule and mulch types on tomato fruit number ($\times 10^5$)

	Drip irrigation schedule			
Mulch type	Daily	Every two days	Every three days	Mulch effects
Trial 1				
No mulch	211	246	203	212 ^{b}
Dry grass	217	223	210	225 ^{ab}
Clear plastic	248	240	268	253 ^{a}
Irrigation effects	226	236	227	
S.E.M.^{Y}	23.54	18.62	15.13	
F-test	ns^{Z}	ns	ns	
Trial 2				
No mulch	73 ^{bc}	86 ^{bc}	58 ^{c}	72 ^{b}
Dry grass	47 ^{c}	70 ^{bc}	105 ^{b}	74 ^{b}
Clear plastic	155 ^{a}	88 ^{bc}	96 ^{bc}	113 ^{a}
Irrigation effects	92	81	89	
S.E.M.	6.37	10.50	16.43	
F-test	ns	ns	ns	

Mulch and irrigation effects were separated in columns and rows, respectively using Duncan's Multiple Range Test, n=9. Means followed by the same letter or not followed by a letter series are not significantly different at $P \leq 0.05$. ^{Z}ns denotes not significant. ^{Y}S.E.M. is the standard error of the mean

Irrigation schedule did not influence individual tomato fruit weight (mean fruit weight) (Tables 5). Clear plastic mulch had significantly lower mean fruit compared with either grass or no mulch (Tables 5). There was no significant interaction between drip irrigation and mulch type on tomato mean tomato fruit yield (Tables 5).

Neither drip irrigation schedule nor mulch significantly affected marketable tomato yield in both trials (Table 6). There was no interaction between drip irrigation interval and mulch type on yield in Trial 1 (Table 6). However, in Trial 2, daily irrigation combined with clear plastic mulch significantly produced the higher marketable yield than daily irrigation and no mulch yield (Table 6).

Table 5. Effects of drip irrigation schedule and mulch types on individual fruit weight

Main effects	Mean fruit weight (g)
Trial 1	
Irrigation schedule	
Daily	65.6
Every two days	65.1
Every three days	71.8
S.E.M. [y]	2.6
F-test	ns [Z]
Mulch effects	
No mulch	66.3 [ab]
Dry grass	73.6 [a]
Clear plastic	62.6 [b]
S.E.M.	4.32
F-test	*
Trial 2	
Irrigation schedule	
Daily	71.6
Every two days	75.3
Every three days	74.8
S.E.M.	1.24
F-test	ns
Mulch effects	
No mulch	77.5 [a]
Dry grass	75.9 [a]
Clear plastic	68.2 [b]
S.E.M.	7.63
F-test	*

Means within the column followed by the same letter or not followed by a letter series are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. n=9. [Z]ns denotes not significant, * denotes significant. [y]S.E.M. is the standard error of the mean

Table 6. Effects of drip irrigation schedule and mulch types on marketable tomato yield (tons/ha)

	Irrigation schedule			
Mulch Types	Daily	Every two days	Every three days	Mulch effects
Trial 1				
No mulch	139.8	157.7	142.4	146.7
Dry Grass	148.1	175.6	151.5	158.4
Clear Plastic	157.1	155.0	186.4	166.2
Irrigation effects	148.3	162.3	160.1	
S.E.M.^{y}	8.62	9.13	18.97	
F-test	ns^{Z}	ns	ns	
Trial 2				
No mulch	67.3 ^{bc}	75.1 ^{bc}	87.4 ^{abc}	69.3
Dry grass	55.7 ^{c}	70.7 ^{bc}	100.3 ^{ab}	75.5
Clear plastic	115.2 ^{a}	82.1 ^{abc}	57.7 ^{c}	92.6
Irrigation effects	79.4	76.2	81.8	
S.E.M.	12.63	8.73	12.40	
F-test	ns	ns	ns	

Means within the column followed by the same letter or not followed by letter series are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. n=9. Irrigation and mulch effects were separated in rows and columns, respectively. ^{Z}ns denotes not significant. ^{Y}S.E.M. is the standard error of the mean

4.3 Effects of Drip Irrigation and Mulch Type on Yield Components

Drip irrigation schedule or mulches did not significantly influence the number of flowers in the first two trusses (Table 7). There was no significant interaction between irrigation schedule and mulch types on number of flowers and fruits in the first two trusses (Table 7).

4.4. Effects of Drip Irrigation schedule and Mulch Type on Tomato Quality

Drip irrigation schedule did not significantly influence the concentration of total soluble solids in both trials (Table 8). Total soluble solids concentration was significantly higher in tomatoes mulched with clear plastic mulch compared with those under dry grass mulch in both trials (Table 8). There was no significant interaction between drip irrigation schedule and mulch type on concentration of total soluble solids in the two trials (Table 8).

Table 7. Effects of drip irrigation schedule and mulch type on yield components

Main effects	Number of flowers/truss		Number of fruits/truss		% fruit set	
	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2
Irrigation schedule						
Daily	11.4	10.3	7.0	6.4	62.2	62.0
Two days	10.6	10.8	7.0	6.4	65.2	60.2
Three days	10.3	10.7	6.5	6.5	65.3	60.9
S.E.M.^{y}	0.84	0.73	0.32	0.03	3.38	2.50
F-test	ns^{Z}	ns	ns	ns	ns	ns
Mulch effects						
No mulch	10.7	10.3	7.0	6.2	62.8	59.8
Grass	11.2	10.2	6.6	6.4	62.7	62.6
Clear plastic	10.8	12.3	6.9	7.0	66.7	61.47
S.E.M.	0.72	1.19	0.33	0.57	3.38	3.08
F-test	ns	ns	ns	ns	ns	ns

Means within columns are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test, n =9. ^{Z}ns denotes not significant. ^{y}S.E.M. is the standard error of the mean

Table 8. Effects of drip irrigation schedule and mulch type on tomato total soluble solids (° Brix).

Main effects	Trial 1	Trial 2
Irrigation schedule		
Daily	4.4	4.3
Every two days	4.8	4.4
Every three days	4.4	4.5
S.E.M. ^{y}	0.03	0.02
F-test	ns^{Z}	ns
Mulch types		
No mulch	4.6 ^{ab}	4.4 ^{ab}
Dry grass	4.3 ^{b}	4.3 ^{b}
Clear plastic	4.7 ^{a}	4.6 ^{a}
S.E.M.	0.02	0.02
F-test	*	*

Means within columns are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test, n =9. , ^{Z}ns denotes not significant. * Denotes significant. ^{y}S.E.M. is the standard error of the mean

Drip irrigation schedule did not significantly influence tomato fruit firmness in both trials. Daily irrigation and dry grass mulch had significantly higher fruit firmness at day two after harvesting in Trial 1 (Table 9b). Fruit firmness was not significantly influenced by mulch type at day two after harvesting in Trial 1 (Table 9b). The fruit firmness was significantly lower with dry grass mulch in Trial 2 (Table 9c). Fruit firmness was generally highest and lowest at 0 and 4 days, respectively after harvesting (Table 9e).

Table 9a. Effects of drip irrigation schedule and mulch type on tomato fruit firmness (newtons) at day zero after harvesting

	Irrigation schedule			
Mulch Types	Daily	Every two days	Every three days	Mulch effects
No mulch	11.2	10.3	11.1	10.9
Dry Grass	11.2	9.5	11.4	10.3
Clear Plastic	10.9	8.4	10.6	10.4
Irrigation effects	11.0	9.4	11.1	
F-test	ns^{Z}	ns	ns	

Means are not significant at P < 0.05.n= 9. ^{Z}ns denotes not significant

Table 9 b. Effects of drip irrigation schedule and mulch type on tomato fruit firmness (newtons) at day 2 after harvesting (Trial 1)

	Irrigation schedule			
Mulch Types	Daily	Every two days	Every three days	Mulch effects
No mulch	6.4 ^{ab}	5.2 ^{bcde}	6.1 ^{abc}	5.9
Dry Grass	7.0 ^{a}	4.1 ^{e}	4.8 ^{de}	5.3
Clear Plastic	5.0 ^{cde}	5.5 ^{bcde}	5.5 ^{bcde}	5.3
Irrigation effects	6.2	4.9	5.4	
F-test	ns^{Z}	ns	ns	

Mulch and irrigation effects were separated in columns and rows, respectively n=9. Interaction effects were separated in columns and rows. Means followed by the same letter or not followed by a letter within column and rows are not significantly different according to Duncan's Multiple Range Test at P ≤ 0.05. ^{Z}ns denotes not significant.

Table 9c. Effects of drip irrigation schedule and mulch type on tomato fruit firmness (newtons) at day 2 after harvesting (Trial 2)

Mulch Types	Irrigation schedule			
	Daily	Every two days	Every three days	Mulch effects
No mulch	9.0	8.9	8.9	8.9 [a]
Dry Grass	7.7	7.5	7.9	7.7 [b]
Clear Plastic	8.8	9.3	8.3	8.8 [a]
Irrigation effects	8.3	8.6	8.4	
F-test	ns[z]	ns	ns	

Mulch and irrigation effects were separated in columns and rows, respectively, n=9. Means followed by the same letter or not followed by a letter are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. [z]ns denotes not significant L.S.D. for interaction effect is 0.09.

Table 9d. Effects of drip irrigation schedule and mulch type on tomato fruit firmness (newtons) at day 4 after harvesting

Mulch Types	Irrigation schedule			
	Daily	Every two days	Every three days	Mulch effects
No mulch	4.6	4.6	4.1	4.0
Dry Grass	4.8	4.8	4.1	4.1
Clear Plastic	4.4	4.1	4.8	3.9
Irrigation effects	4.6	4.5	4.3	
F-test	ns[z]	ns	ns	ns

Means are not significant at $P \leq 0.05$. [z]ns denotes not significant. n=9

Table 9e. Effects of days after harvesting on tomato fruit firmness (Newtons)[w]

Days after harvesting	Trial 1	Trial 2
0	1.1 [a]	1.2 [a]
2	0.6 [b]	0.9 [b]
4	0.5 [bc]	0.5 [c]
S.E.M.[y]	0.03	0.04
F-test	ns[z]	ns

[w]Means within columns followed by the same letter are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. [z]ns denotes not significant. [y]S.E.M. is the standard error of the mean.

4.6 Effects of Drip Irrigation and Mulch Type on Weed Growth

There was no significant effect of irrigation schedule on weed biomass in Trial 1 (Table 10). However, in Trial 2, drip irrigation once every three days significantly increased weed biomass compared to daily or two days irrigation schedules (Table 10). At the same irrigation schedule, weed biomass was significantly highest under no mulch compared to grass or plastic mulches (Table 10).

Table 10. Effects of drip irrigation schedule and mulch types on weed biomass (g/m^2)

Main effects	Trial 1	Trial 2
Irrigation schedule		
Daily	45.4	72.1^{b}
Every two days	55.6	77.5^{b}
Every three days	51.9	104.3^{a}
S.E.M.^{y}		
F-test	^{z}ns	*
Mulch types	101.1^{a}	208.6^{a}
No mulch	32.5^{b}	36.2^{b}
Dry grass	19.2^{b}	9.1^{b}
Clear plastic		
S.E.M.	60.1	89.56
F-test	*	*

Means within columns followed by same letters or not followed by a letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test. ^{z}ns denotes not significant. * Denotes significant. ^{y}S.E.M. is the standard error of the mean.

4.7 Effects of Drip Irrigation and Mulching on Soil Water Tension

Irrigation once every three resulted in the highest soil water tension at 28 days after transplanting (Table 11). However, it was observed that soil water content was relatively lowest with three-day irrigation schedule during the entire tomato growth period (Figure 2). Mulch types did not significantly influence soil water tension during the first 28 days after transplanting (Table 11). Mulch did not significantly affect soil moisture content. However, soil water tension tended to be low with daily irrigation and dry grass (Figure 3). There was no significant interaction between drip irrigation schedule and mulch on soil water tension at 28 days after transplanting (Table 11).

Table 11. Effect of drip irrigation and mulch types on soil water tension (bars) at 40 cm depth on day 28 after transplanting[w]

Mulch type	Drip irrigation schedule			
	Daily	Every two days	Every three days	Mulch effects
No mulch	0.1	0.1	0.1	0.1
Dry grass	0.1	0.1	0.1	0.1
Clear plastic	0.1	0.1	0.1	0.1
Irrigation effect	0.1	0.1	0.1	

[w]Means are not significantly different at $P \leq 0.05$. n=9

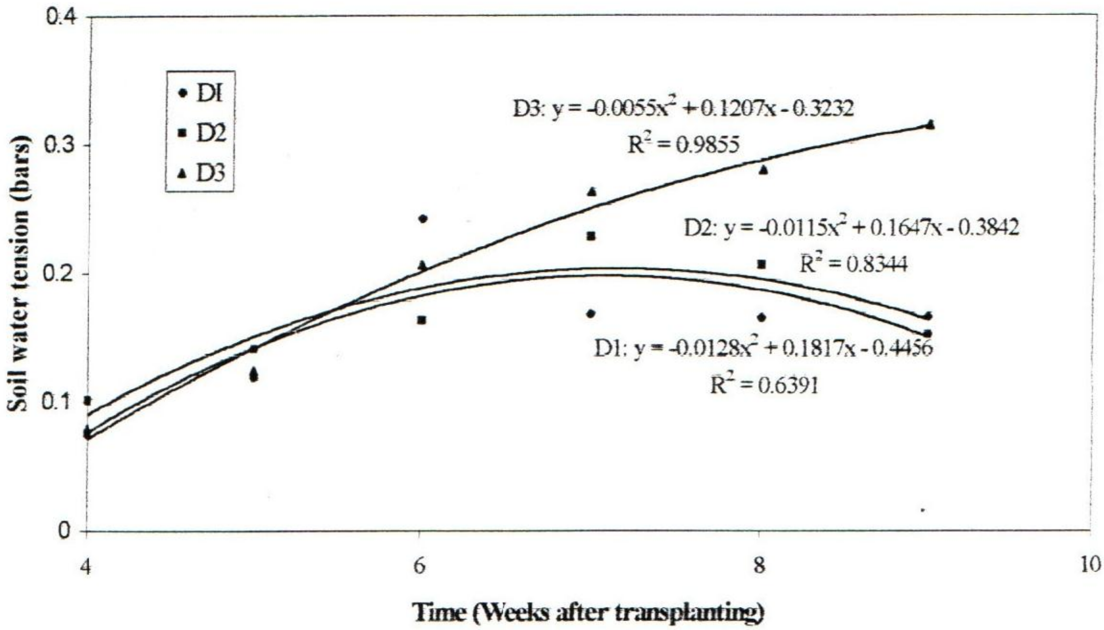


Figure 2. Effects of drip irrigation schedule on soil water tension. D1, D2 and D3 denote daily, every two and every three days irrigation schedule, respectively.

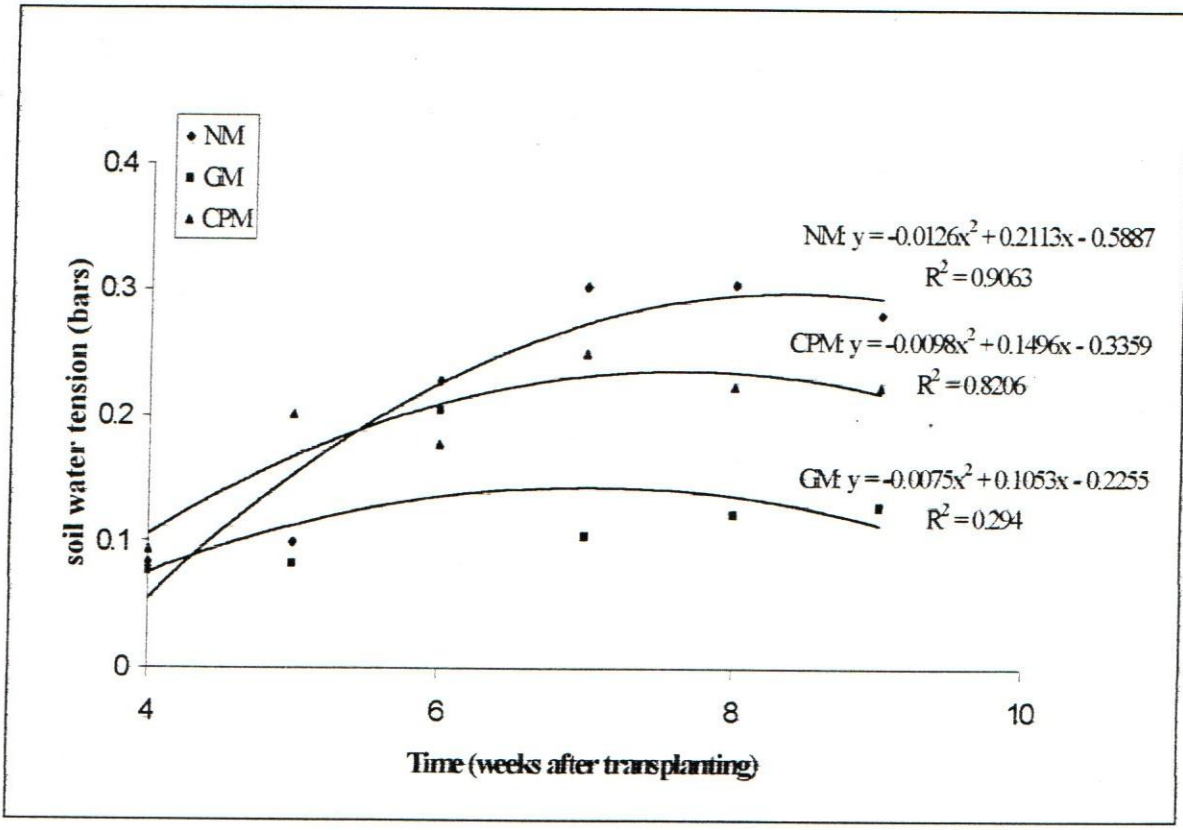


Figure 3. Effects of mulch type on soil water tension. CPM, GM and NM denotes daily irrigation and clear plastic mulch, respectively.

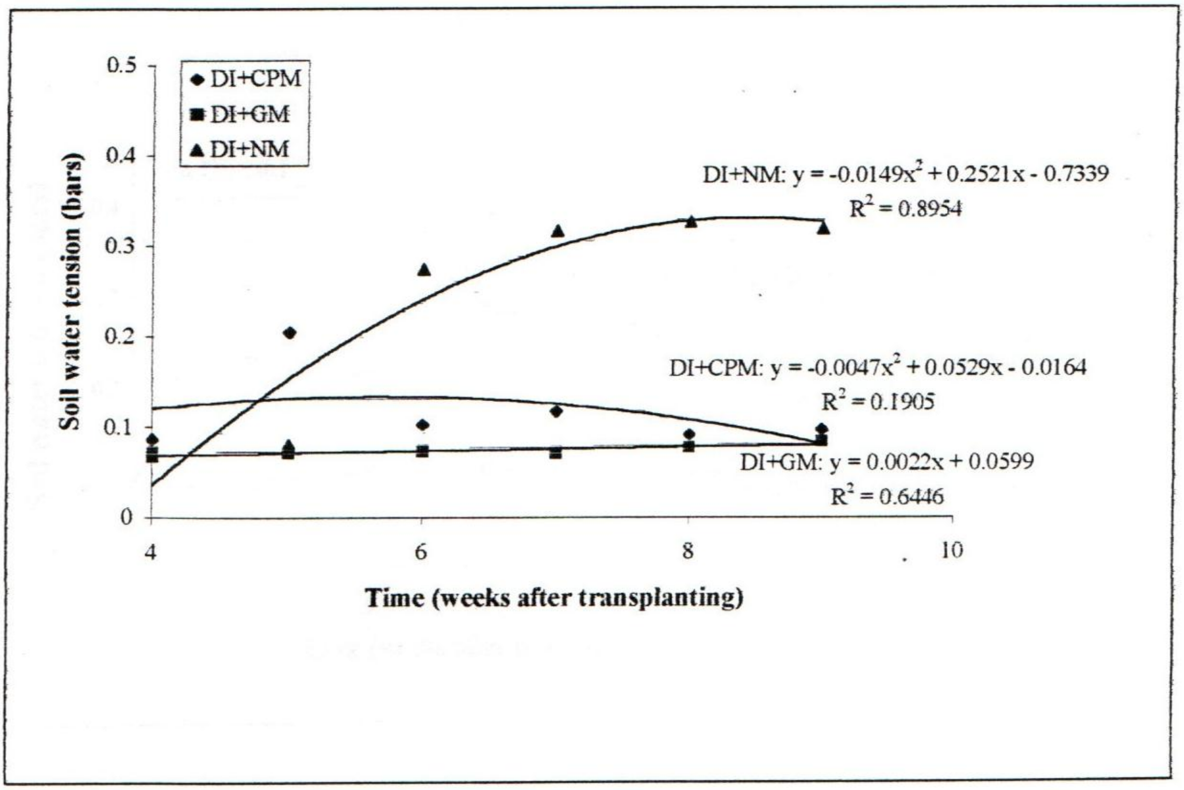


Figure 4 a. Effects of daily drip irrigation schedule and mulch type on soil water tension. D1+CPM, D1+GM and D1+NM denotes two-day drip irrigation and clear plastic mulch,two-day drip irrigation and grass mulch and two-day drip irrigation and no mulch,respectively.

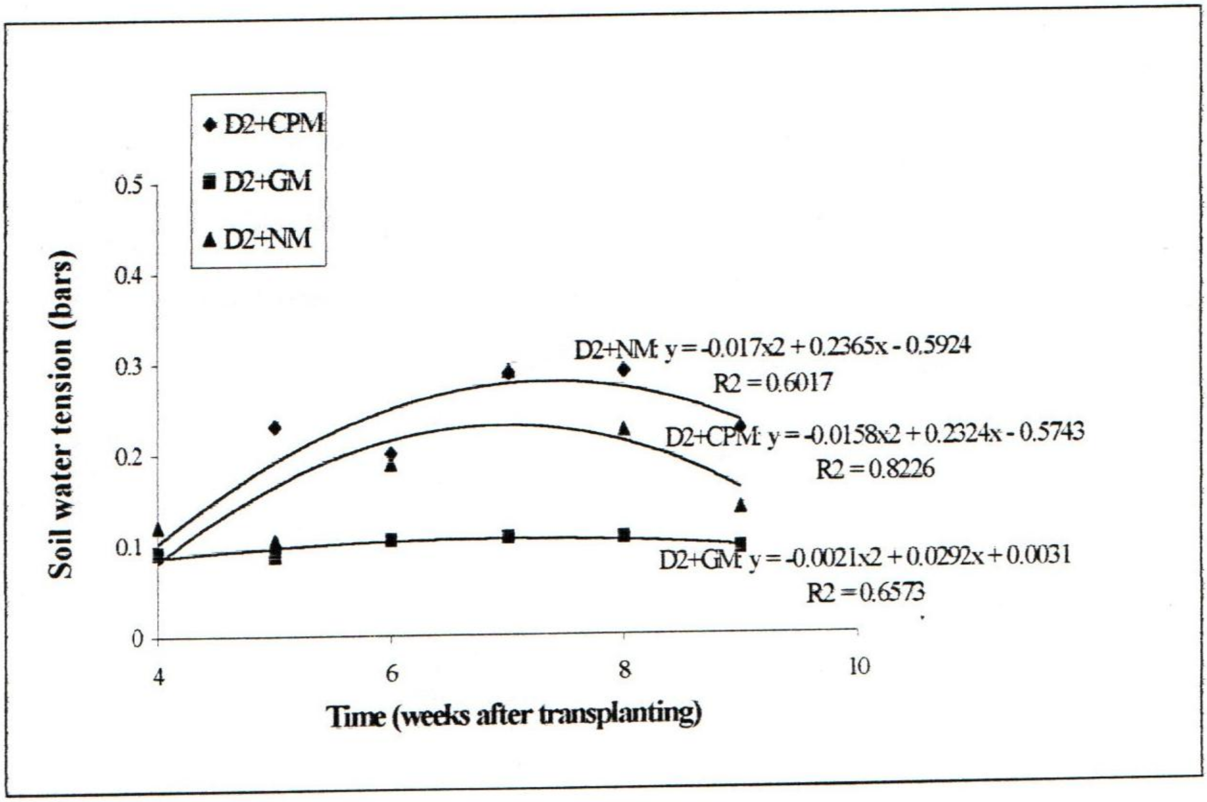


Figure 4b. Effects of two-day drip irrigation schedule and mulch type on soil water tension. D2+CPM, D2+GM and D2+NM denotes two-day drip irrigation and clear plastic mulch,two-day drip irrigation and grass mulch and two-day drip irrigation and no mulch,respectively.

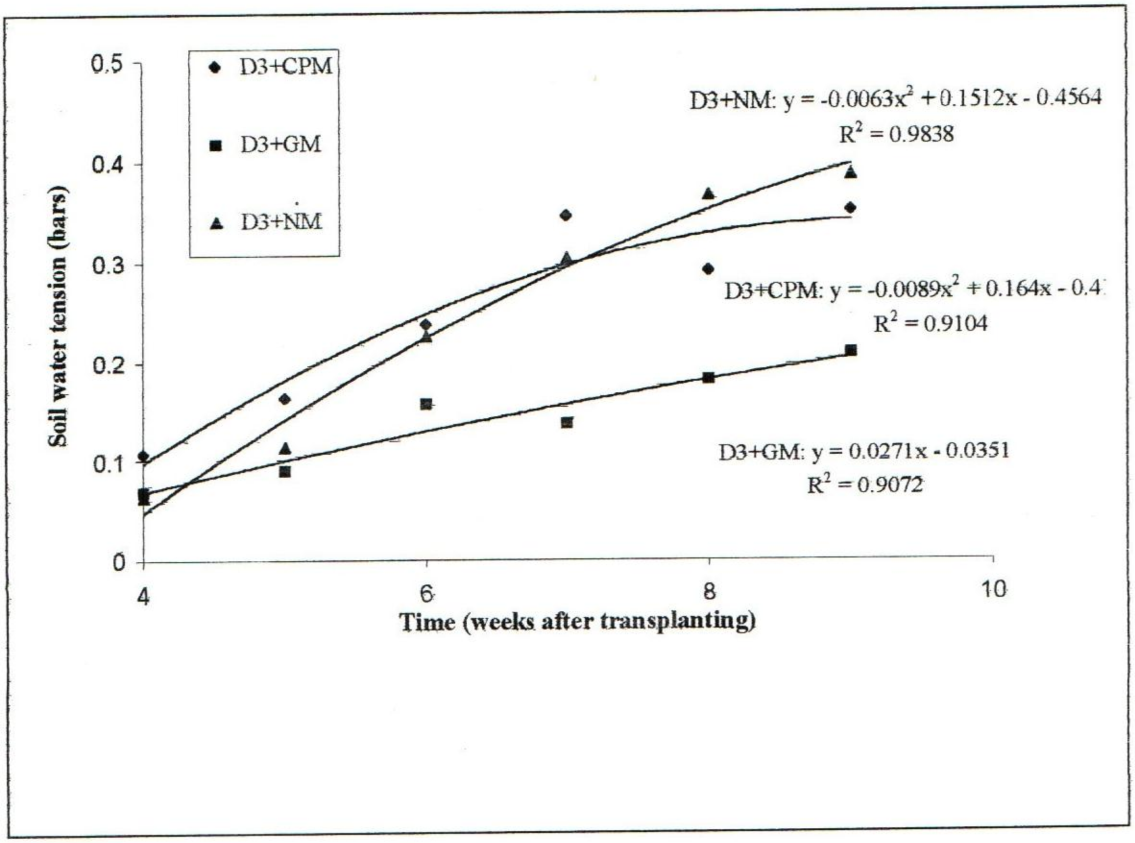


Figure 4c. Effects of three-day drip irrigation schedule and mulch type on soil water tension. D3+CPM, D3+GM and D3+NM denotes three-day drip irrigation and clear plastic mulch, three-day drip irrigation and grass mulch and three-day drip irrigation and no mulch,respectively

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of Drip Irrigation Schedule and Mulch Type on Growth and Development of Tomatoes

The high relative humidity in the greenhouse might have reduced water losses through surface evaporation. This may explain lack of response of tomato growth to irrigation schedule. These findings contrast those of Meek et al (1983) that showed that drip irrigation scheduled at every three days reduces tomato height under field conditions sandy soils. The effect of mulching on plant growth was not observed since under conditions of the study, the water conservation of the various mulches used was similar according to tensiometer readings. This contrast the findings of Gupta and Achrya (1993) that showed that tomato plant height, stem diameter and leaf number were the higher under transparent polyfilm mulch compared to those under no mulch. In this study, it was observed that that transparent polyfilm mulch increases tomato leaf number. This variation might be due to differences in soil type and growth conditions during the experimental period.

The delay in attainment of first 50% flowering and fruiting caused by dry grass mulch may be attributed to low soil temperature under the dry grass mulch (Gupta and Achrya, 1993). The low temperature coupled with high soil moisture probably reduced absorption of nutrients and consequently delayed maturity, which is in agreement with findings of Wien and Minnoti (1988) and Ramalan and Nwokeocha (2000). Low soil temperatures and high soil moisture content have been shown to encourage vegetative growth at the expense of reproductive development (Schonbeck and Evanylo, 1998).

In contrast, Firake et al. (1994) found that sugarcane trash promotes early flowering compared to no mulch and clear plastic mulch under rain-fed field conditions where plastic mulch might have increased rate of runoff thereby reducing water infiltration.

5.2 Effects of Drip Irrigation Schedule and Mulch Type on Tomato Yield and Yield Components

Non-significant difference in yield of tomato between clear plastic mulch and no mulching observed in this study is partly due to same irrigation rate and increased tomato plant competition against weeds. Transplanting and trellising of tomato gave tomatoes height advantage over weeds. Thus yield reduction due to weed effects were minimized. These results are in agreement with findings of (Mitchell et al., 1991). In contrast, clear plastic mulch has been shown to significantly increase the marketable yield of tomatoes (Rudich, 1979; Chen and Katan, 1980).

The high fruit number under clear plastic mulch led to increased fruit competition for assimilates and probably moisture, which reduced fruit expansion hence, reduced individual fruit weight. This shows that clear plastic mulch only increases tomato yield by increasing tomato fruit number but not individual tomato fruit weight. However, Sweeney et al. (1987) reported higher tomato yield with black plastic mulch under field conditions. The variation of the findings can be associated with plant protection system used, the colour of polyethylene mulch and soil type. The high relative humidity within the greenhouse reduces consumptive water use as evaporation demand is decreased (FAO, 1990). The plastic covering material of the greenhouse probably reduced the mulch effect by reducing evaporation and heat losses (Perry and Sanders, 1986).

Non-significant influence by irrigation schedules on tomato yield parameters found in both trials is in agreement with findings of Meek et al. (1983) and Kadam and Magar (1993). This suggests that drip irrigation once after every three days does not reduce yield of tomatoes grown in soils with good water retention under greenhouse conditions. These findings are at variance with that of Dalvi et al. (1995) who reported that drip irrigation after every two days significantly increased tomato yield. In addition, Russo (1983) and Sanders et al. (1989) found that daily drip irrigation schedule increases tomato yield compared to longer drip irrigation schedule. In other studies, Pasternak and De-Malach (1995) reported that drip irrigation after every two or three days significantly lowered yields of tomatoes in comparison to daily irrigation. These conflicting results may be due to variations in soil type and climatic factors (Shrivastava et al., 1994), tomato growth rate (Sanders, 2000), water quality and plant protection system (Perry and Sanders, 1986). Thus, the influence of drip irrigation schedules should be reported under prescribed set of tomato production conditions.

5.3 Effects of Drip Irrigation Schedule and Mulch Type on Quality of Tomatoes

Lowest soluble solids obtained with dry grass mulch can be attributed to low soil water tension maintained by dry grass mulch, which led to higher water uptake by fruits and hence dilution of the concentration of the total soluble solids. The results are in line with findings of Muller (1993) and Tan (1995). This contrasts findings of Mathieu and Aure (2000) and Dorais et al (2001), who showed that clear plastic mulch increases total soluble solids. Delayed first 50% flowering by dry grass mulch made fruiting to coincide with increased competition between vegetative and fruit growth for photosynthates. This might have lowered amount of photosynthates partitioned to the fruit hence reduced concentration of total soluble solids in the ripe fruits (Mitchell et al., 1991). Also the high rate of transpiration and high temperature below plastic mulch Liu (2000) might have caused localized soil salinity build-up (Dorais et al., 2001). This stimulated starch accumulation in the mature tomato fruits leading to sucrose unloading into the developing fruits, which were hydrolyzed on maturation into soluble hexoses thereby increasing total soluble solids contents (Dorais et al., 2001).

Plastic mulches concentrate carbon dioxide around the plant canopy as the planting holes acts as vents for carbon dioxide escaping from beneath the mulch (Sanders, 2000). This relatively elevated carbon dioxide concentration might have accounted for the increased total soluble solids. Behoboudian and Tod (1995) also reported higher total soluble solids in tomato fruits exposed to pre-harvest carbon dioxide enrichment. It can also be suggested that increased carbon dioxide levels in clear polyethylene mulch reduced loss of the simple sugars due to respiration that account for larger proportion of total soluble sugars (Behoboudian and Tod, 1995).

Since there was no treatment effect on fruit firmness at four days after harvesting it can be concluded that there are other factors that in fruit firmness such as variety and storage temperature. Higher fruit firmness observed under clear plastic mulch may be due to thicker flesh of the fruits as reflected by high dry matter content. Falluji et al. (1982) reported that fruit firmness is strongly influenced by tomato fruit flesh tissues. Also, it can be suggested that the high firmness of tomato fruit immediately after harvesting is due to skin strength, which weakens up on ripening and senescence.

5.4 Effects of Drip Irrigation Schedule and Mulching on Weed Growth

Clear plastic mulch formed a barrier on weed growth and may have scorched the tender emerging weeds. This explains the lower weed biomass under clear plastic mulch than no mulch treatment. This agrees with findings of (Al Masoum et al., 1998; Sago et al., 1999). Grass mulch effectively smothered the weeds and excluded light from reaching the seeds or emerging seedling thus lowering the weed biomass compared with unmulched plots. However, the weed seeds that managed to germinate and emerge above the grass mulch grew vigorously due to adequate availability of moisture in the soil Shrivastava et al. (1994) and Smeda and Weller (1996) hence the higher amount of biomass compared with no mulch. It is evident that mulching with either grass or clear plastic mulches can reduce production cost and minimize root damage during weeding. However, dry grass mulch has the potential of introducing weed seeds into the greenhouse. This may be avoided by harvesting grass for mulching before seeding stage.

5.5 Effects of Drip Irrigation Schedule and Mulch Type on Soil Water Tension

The lack of significant effect of drip irrigation might have been due to the irrigation rate selected. High soil water tension obtained under clear plastic mulch may be due to increased soil temperature, which promoted conversion of water into water vapour, which later condensed beneath the polyethylene sheeting and thus not recorded at 40 cm depth. Conversely, Gupta and Achrya (1993) noted that water content was highest with clear plastic mulch at 30-60 cm depth. The variation was due to the fact that their study was conducted in sandy soil with low water holding capacity under field conditions. Thus water loss through surface evaporation was reduced by plastic mulch greatly. Also sandy soil with large pore spaces could not hold water within the higher soil profile hence deeper percolation was expected. Organic mulches grasses reduce afternoon soil temperature (Kosmas et al., 1998) and evapotranspiration thereby maintaining higher soil moisture than plastic mulches (Schonbeck and Evanylo, 1998).

Lower soil water tension under dry grass mulch at 40 cm probably maintained cool temperatures, which promoted adsorption of water vapour during the low night temperatures. This is in line with findings of Kosmas et al (1998). Although clear plastic mulch restricted water vapour adsorption, reduction in evaporation was more important. The unmulched plots had higher soil water tension than dry grass mulch due to evaporative soil surface water losses.

The soil water tension increased rapidly up to 42 days after transplanting due to increased fruiting which in turn increased consumptive tomato water use. This agrees with findings of Doorenbos, and Pruitt (1977). The reduction of soil water tension from the 49 days after transplanting may be due to removal of lower leaves or diseased leaves and, which reduced transpiration water losses.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

Daily drip irrigation schedule does not increase tomato plant height, stem diameter, number of leaves, fresh and dry weights of leaves and stems. Drip irrigation schedule does not influence fruit harvest index. Grass mulch delays days to 50% flowering and fruiting.

Daily drip irrigation does not increase yield of tomatoes under greenhouse conditions. Clear plastic mulch increases number of marketable fruits while it reduces mean fruit weight. There is no interaction between drip irrigation schedule and grass on yield of greenhouse-grown tomatoes.

There is no effect of daily drip irrigation schedule on total soluble solids concentration of fruits at the same irrigation rate under greenhouse conditions. Dry grass mulch lowers concentration of fruits due to increase in fruit water content. Irrigation schedule and mulch do not affect fruit firmness. This shows that fruit firmness is influenced by other factors such as variety, storage conditions and duration.

Both grass and clear plastic mulches effectively reduce weed biomass under greenhouse conditions. Weed biomass tends to be higher with irrigation with three-day drip irrigation schedule because of higher water application rate.

The following recommendations can be made:

1. Grass mulch should be recommended to greenhouse tomato growers in Kenya since it is easily biodegradable, improves soil structure and organic matter, and is locally available. Moreover, it has no adverse effects on yield of fresh market tomatoes.
2. Three-day drip irrigation schedule should be adopted under greenhouse tomato production. This will reduce labour required for irrigation and allows use for other farm operations and domestic consumption.
3. Daily drip irrigation schedule should be combined with clear plastic mulch while three-day drip irrigation should be combined with grass mulch for improved yield of greenhouse-grown tomatoes.

Future Research

1. A further study should be done to incorporate irrigation rate and frequency to indicate their relative effects on growth, yield and quality of fresh market greenhouse tomatoes.
2. This study did not indicate soil nutrient status as affected by irrigation schedule and mulch types thus a research should be carried out to determine the effects of irrigation schedule and mulch types on soil nutrient status.
3. A further study should be done to evaluate the elemental nutrient composition of greenhouse-grown fresh market tomato as affected by irrigation schedule and mulch type.

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APPENDIX 1

Table A1. Mean temperature within the greenhouse (Trial 1)

Maximum temperature, °C		Minimum temperature, °C	
Day	Night	Day	Night
31.5	13.0	10.6	8.7

Table A2. Mean temperature within the greenhouse (Trial 2)

Maximum temperature, °C		Minimum temperature, °C	
Day	Night	Day	Night
34.5	15.6	12.2	7.4

Table A3. Mean relative humidity within the greenhouse

Relative humidity, %	
Trial 1	Trial 2
69.3	71.5