

EFFECTS OF MULCHING ON SOIL TEMPERATURE
AND MOISTURE, YIELD AND QUALITY OF TOMATO
(*LYCOPERSICON ESCULENTUM* MILL.) UNDER
KENYAN HIGHLAND GREENHOUSE CONDITIONS

BY
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A THESIS SUBMITTED TO GRADUATE SCHOOL,
EGERTON UNIVERSITY IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN HORTICULTURE

EGERTON UNIVERSITY, NJORO

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DEDICATION

Dedicated to my husband Babere Kerata Chacha.

ACKNOWLEDGEMENT

I would like to sincerely thank my supervisors Prof. F.M. Itulya and Prof. Liu for their continued support throughout the study period. I also thank the members of staff, Horticulture Department, for the technical and moral support they accorded me during my study period. I also acknowledge the various departments of Egerton University that assisted me with tools and equipments during the research time.

Much thanks to The Tea Research Foundation of Kenya for hosting part of my research experiments. I also thank my fellow graduate students for the friendship and moral support they gave me. I would wish to deeply acknowledge the financial and moral support accorded to me by my husband, my son, parents and relatives.

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LIST OF ABBREVIATIONS

FAO	Food and Agriculture Organization.
I.U	International Units
N	Nitrogen
P	Phosphorus
K	Potassium
BER	Blossom End. Rot.
SSC	Soluble Solute Concentration
TSS	Total Soluble Concentration
TNS	Total Non-Structural Carbohydrates.
DAP	Diammonum Phosphate

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ABSTRACT

Two experiments were conducted in a greenhouse at Egerton University, Tatton Farm, in Kenya. The main objective was to determine the effects of mulching on soil temperature and moisture, and if the practice can improve tomato yield and quality under greenhouse conditions. The experimental design was a two factor Randomised Complete Block design with three replications. The mulch treatments were black (M1), clear (M2), white painted (M3) and wheat straw (M4). Two tomato cultivars 'Money Maker' and 'Cal J' were used. Data on soil moisture and temperature were collected weekly for nine weeks beginning two weeks after transplanting. Plant height data were taken on weekly basis starting two weeks from transplanting up to the tenth week after transplanting. Yield and quality data were taken after harvesting. Weed and root length data were taken after removing the plastic mulches, while samples for carbohydrate partitioning analysis were also taken at the end of each experiment.

Mulching significantly ($P \leq 0.05$) influenced soil moisture, temperature and weed weight and population density. Soil moisture was lower on bare soil compared to mulched plots, with plastic mulches being superior over the wheat straw. Significantly lower soil temperatures were recorded on wheat straw and the unmulched, while higher temperatures were recorded on the plastic mulched plots with the black mulch giving the highest temperature. Significantly lower weed population density and weights were observed on the black mulch compared to the other types of mulches and bare ground. Mulching did not significantly affect plant

height, root distribution, and carbohydrate partitioning among roots, stems, and leaves. The response of tomato plant growth to mulching depended on cultivar, 'Money Maker' giving higher plant height. Mulching did not significantly influence fruit yield and quality.

Cultivar significantly ($P \leq 0.05$) influenced soil moisture, plant height, root growth, marketable fruit numbers, weight and size. On the other hand, cultivar did not significantly ($P \leq 0.05$) influence the total non-structural carbohydrates partitioning among tomato leaves, stems, and roots, weed population density and dry weight, fruit numbers and weight per plant, fruit numbers and weight per hectare, percent marketable fruit numbers and weight and total soluble solutes.

CHAPTER ONE

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a member of the Solanaceae family, originating in the western coastal plain of South America, extending from Ecuador to Chile (Cooper, 1972).

Growth of tomato varies between indeterminate and determinate habits. Determinate cultivars, which may grow to two meters in height, are erect and "bushy" with a restricted flowering and fruiting period and are suitable for field conditions. In indeterminate cultivars, the main stem grows indefinitely, reaching more than ten meters in a year's growth under greenhouse conditions. Such cultivars are ideal for long experiment's continuous cropping in greenhouses as they flower and fruit regularly and evenly. The indeterminate growth habit is dependent on the activity of the self pruning gene (Sp) while the determinate growth habit is conferred by the recessive self pruning gene (sp) (Rick and Butler, 1956).

In indeterminate tomatoes, vegetative growth and reproductive development proceed concomitantly during the greatest part of the plants' life. A strong competition between developing leaves and apical meristem influences both the earliness of harvest and the total yields. High assimilate availability under high light conditions stimulates both meristem activity and leaf growth (Hussey, 1963a), but when plants are source-limited (under high temperature and low light), young

leaf growth is favoured at the expense of apical development. This effect is counteracted by the continuous removal of young leaves (Hussey, 1963b; Kinet, 1977b).

In determinate tomatoes, only two or three inflorescences, separated by one or more leaves, are usually produced on the stem, with one time-limited flowering period, followed by a period of fruit development. Hence, vegetative growth ceases with the on-set of reproductive phase (Hussey, 1963b; Kinet, 1977b).

Vegetative growth of tomato requires fluctuating environments. Continuous light has a number of injurious effects, inducing leaf chlorosis, hypertrophy of ultrastructure and starch grains disappearances from the leaves (Descomps and Deroche, 1973). However, if air temperature is fluctuating with sufficiently wide daily change, the detrimental influence of continuous light is suppressed (Hillman, 1956).

When identical cultural conditions are maintained throughout, the plastochronic rhythm, i.e., the time interval at which leaves are initiated is constant (Kinet, 1977a; Picken et al., 1986) despite the fact that the plant is progressing through varied developmental stages.

Zobel (1975) classified tomato roots based on their origin: a) radicle or primary roots, b) lateral roots (those branch roots arising from the root pericycle), c) adventitious roots (those originating 1cm above the hypocotyl), d) basal roots (those arising within the lower 1cm of the hypocotyl and upper one centimeter of the radicle). He noted that basal roots differ from adventitious roots due to their

anatomical region of origin and from lateral roots due to their location on the hypocotyl. The root zone extends to a diameter of more than 1.5m and to a somewhat shorter depth (Hayward, 1938). The primary seminal or tap root may grow deeper than 0.5m, but it is often damaged in culture (Picken, et al. 1986).

Root temperature directly affects the nutrient status of a plant by affecting nutrient absorption and translocation in the following ways:

- a) by modifying the availability of elements in the soil due to differences in microbial activity or by changing the size and the extent of the root system;
- b) by controlling active nutrient uptake through assimilate oxidation and by transpirational flow regulation; and
- c) by affecting the viscosity of water and cytoplasm, thus altering the membrane permeability to water (Kramer, 1940).

Root temperature also affects the nutrient status of a plant indirectly by its effects on the production rate of hormones in the roots (Atkin et al., 1973) and the nutrient distribution within the plant according to the strength of the various metabolic sinks.

Jones et al. (1978) showed that night air temperature could be reduced and greenhouse tomato production maintained when the root system was kept warm. Increased root zone temperature enhanced root elongation (Maletta and Jones, 1987; Mooreby and Graves, 1980).

The temperature requirement means must be above 16° C (Yamaguchi, 1983). The optimum temperature range is 21° C to 24° C. The minimum soil temperature for seed germination is 10° C, optimum is 30° C and the maximum is 35° C. Poor fruit set occurs if the maximum day temperatures exceed 38° C for 3 to 10 days before anthesis. This is due to destruction of pollen and egg cells. Poor fruit set also occurs if the maximum day temperature exceeds 38° C for 1 to 3 days following anthesis because the embryo is destroyed after pollination. Also, fruit set is poor if the minimum night temperatures are too high, > 25° C to 27° C, a few days before and a few days after anthesis.

The optimum temperature for fruit ripening is 18 to 24° C. At temperatures <13° C fruits ripen poorly and slowly, and <10° C, chilling occurs and the fruits may not ripen at all. If the temperature exceeds 32° C during the storage of harvested mature green fruits, the formation of red colour, lycopene is inhibited and the fruits are yellowish when ripe. When the mean temperatures are above 40° C, the fruits remain green because the chlorophyll degrading mechanism is inactivated.

The optimal air temperature for net assimilation in tomatoes is between 25° C and 30° C (Khavari-Nejad, 1980). It does not seem to matter greatly in young plants if day and night temperatures differ. Relative growth rates of young plants respond relatively independently to the day and night air temperature with an optimum for both at around 25° C (Picken et al., 1986).

Tomato is one of the most popular vegetables. In 1993, world tomato production was 70 million metric tonnes overtaking bananas, pome fruits, oranges and grapes (FAO, 1994). In 1998, FAO estimates for world tomato production was 89,828,000 metric tonnes, while Kenyan production was 333,000 metric tonnes (FAO, 1998). The world area under tomato production was estimated at 316,900 ha (FAO, 1998) and Kenya produced tomatoes in 3,000 ha (FAO, 1998). Due to its high yield potential and price, greater tomato production can vastly improve the annual incomes of tropical farmers, especially those operating small farms and adequate labour (idle or experimentally under-employed farm workers) required for the production of this intensive crop (Calkins, 1978a).

Tomatoes are increasingly becoming popular both in fresh markets and processing industries. They are eaten fresh as salads in combination with leafy vegetables, green onions, cucumbers, pepper and other vegetables or eaten stewed, fried, and baked or processed in various preserved forms such as tomato paste and peeled products. Tomatoes are good sources of vitamin A (900 I.U. per 100g edible portion) and B₂ (0.06 mg per 100g edible portion) besides other nutrients such as calcium (0.04mg per 100g edible portion) and iron (0.5mg per 100g edible portion) (U.S. Department of Agriculture, 1963).

Tomatoes grown under greenhouses would ripen earlier than those grown in open fields, because of the enhanced control on the temperature, and hence, early maturity. Whilst field and greenhouse tomatoes share many common characteristics, for successful production, there are specific requirements for

greenhouse cultivars, such as the ability of high yields and quality to give returns to high production cost and resistance to several diseases that are severe in greenhouses (Griensberg and Stewart, 1986).

Mulching is defined as the application of materials inorganic as well as organic which are allowed to lie on the soil surface. A mulch is any material applied to the soil surface primarily to prevent loss of water by evaporation, to suppress weeds, to reduce temperature fluctuations, or to promote productivity (Jacks, et al., 1955). These materials include organic substances, such as peat, wood chips, pine needles (Gartner, 1978); mineral material, such as sand, gravel stones and granite chip (Wright, 1985); and manufactured material, such as plastic, paper, glasswool, metal foil, cellophane urethane foam (Creagur and Katchur, 1975), and rockwool (Paterson et al., 1979). Organic and synthetic mulches are used in the production of tomatoes for water conservation, provision of a more favourable soil temperature regime, and reduction of nutrient loss by leaching (Loy and Wells, 1975). Organic mulches such as straw act to buffer soil temperature (Unger, 1978), whereas synthetic mulches such as clear polyethylene permit more divergent temperature fluctuations-warm in the daytime and cooler at night (Anderson and Guttridge, 1978). Organic mulches generally reduce loss of nitrate, sulphate, calcium, magnesium and potassium (Jones et al., 1977; Jones and Jones, 1978), but organic mulches can temporarily tie up soil nitrogen levels as they decay. As a result of changing the soil hydrothermal regime, straw mulch can increase the density and spread of roots (Allmaras and Nelson, 1971). Mulches

might also mitigate the harmful effect of soil fungi and nematodes (Chalfant et al., 1977).

Benefits of plastic mulches include water and fertilizer management, weed control with less herbicide application and regulation of soil temperature. Black mulches are used to warm the soil in spring, and white mulches can be used to keep soil cooler during hot days (Decoteau et al., 1986).

Crops grown in the open field or in greenhouses could benefit from covering the soil with polyethylene film mulch. The mulch might be either transparent, black or yellow according to the purpose for which the mulch is needed (Rudich, 1979; Garnaoud, 1981; Benoint et al., 1984).

Black polyethylene mulch may increase early and total yields of tomatoes by modifying soil temperature, moisture retention, nutrient availability and by suppressing weeds (Knave and Mohr, 1967; Perry and Sanders, 1986; Vandenberg and Tiessen, 1972). Loy and Wells (1975; 1982 and 1983) found that row covers combined with black polyethylene mulch increased early and total tomato yields over those from unmulched, uncovered plots, because of the interaction between polyethylene mulch and row covers.

Mulching with clear plastic increased concentration of phosphorous, potassium, calcium and nitrate-nitrogen and decreased the concentration of sodium in tomato leaves (Wien and Minotti, 1987). An increase in phosphorus concentration has been consistently obtained using clear plastic mulch.

Statement of the Problem

Tomato production in Kenya is characterized by extreme seasonality under field production as influenced by the weather patterns. Greenhouse tomato production ensures year-round production of tomatoes under optimal production conditions, given that tomato renders itself a useful vegetable for greenhouse production.

The use of greenhouses for tomato production has been limited, because of added costs of production associated with the initial high costs of greenhouse installation. The use of different types of mulches has also been limited because of their high costs (polyethylene mulches).

Production of tomatoes in Kenyan highlands under field conditions has been difficult due to low temperatures that can be as low as 10.22°C (Egerton minimum temperature average for 10 years from 1992-2001) compared to the 21 to 24°C that is the optimal range for tomato production. Therefore, there is an interest in greenhouse production, because it offers warmer conditions that promote faster plant growth. Consequently, there is a limit as to how greenhouses can improve the soil temperature. The problem of soil temperature and soil moisture regulation under Kenyan highland greenhouse conditions has not been addressed and documented in any scientific publication.

Justification of the Study

Although research on mulching tomato has been conducted, very little, if any, has been done under Kenyan conditions and in greenhouses. Yet, mulching is a cultural practice with integrated advantages that could increase yields and quality of greenhouse tomatoes. This study was therefore, to determine the type of mulch material that will have broader advantages to the plants under Kenyan highland greenhouse conditions. The need to provide information on soil temperature and moisture regulation by mulching to those growers who would wish to use greenhouse to produce tomatoes under Kenyan highland conditions cannot be overemphasized.

Hypotheses

The hypotheses established for this study were:

1. Mulch materials induce large differences in soil temperature under greenhouse micro-environments.
2. In greenhouses, mulch types impact differently on soil moisture.
3. Mulches control weeds in greenhouses.
4. Black plastic mulches increase tomato yields more than clear plastic mulches and organic mulches.
5. Black mulch facilitates higher tomato quality than clear plastic mulches and organic mulches.

Objectives of the Study

The main objective of this study was to determine if mulching could be used to regulate soil temperature and moisture, and thus improve the yields of tomato grown under greenhouse conditions under highland conditions in Kenya.

The specific objectives were to determine the effects of black, clear, white-painted plastic mulches and wheat straw on: (a) Soil temperature, (b) Soil moisture, (c) Tomato plant growth, (d) Tomato total and marketable yields, (e) Tomato fruit quality expressed as fruit firmness and size, and (f) Weed population density and dry weight.

CHAPTER TWO

LITERATURE REVIEW

Effects of Mulching on Soil and Water Conservation

For plants to grow well, they require adequate supply of water in the growth medium. The role of mulching in erosion control is that it reduces splash erosion, surface sealing and gives water a chance to soak into the soil. The dead residues of organic mulches are absorptive and help hold considerable water at the soil surface. Furthermore, the mulch permits more time for water to infiltrate the soil (FAO, 1996).

By providing a protective barrier at the soil surface, a mulch reduces water evaporation (Scholl and Schwemmer, 1982) and increases moisture levels (Kolb et al., 1983). Suppression of weed growth also reduces moisture loss through transpiration, enabling the important surface soil layer to remain moist for a longer period than unmulched soil surface.

Certain mulches such as straw may improve water penetration in the soil. This improvement is due to a number of factors, including the protection provided by the mulch against rain impact at the soil surface, reduced soil compaction (Ingle, 1981), and increased biotic activity (Jacks, et al., 1955). However, not all organic mulches will allow water to penetrate easily. Peat mulches tend to absorb and hold rain and release it to the air again by evaporation (Rowe-Dutton, 1976). Further, if peat mulch dries out, it will shed water and become difficult to rewet

(Gartner, 1978). Fresh grass clippings, may prevent water penetration and immobilise soil nitrogen.

Where moisture conservation is a major consideration, organic mulches such as bark, straw or wood chips are preferred to plastic as they tend to maintain higher soil moisture levels (Litzow and Pellet, 1983; Ashworth and Harrison, 1983). However, there are large differences among organic materials in their moisture conservation properties, straw being more effective than manure, with hay grass and wood shavings intermediate (Harris and Yao, 1923).

Plastic and other solid synthetic mulches may prevent water penetration and cannot be laid over large areas without some means of water ingress. In addition, the high temperatures that develop under clear plastic also tend to reduce soil moisture levels (Ashworth and Harrison, 1983).

A mulched soil contains moisture at higher levels than bare soil (Hoyt and Hargrove, 1986; Bristow, 1989). Soil moisture and soil temperature are interrelated, because the radiation received by the soil will not begin heating substantially until the evaporative demand is satisfied (Bristow, 1988).

Higher soil moisture under cover crop residue could have variable effects on weed seed germination. During droughty periods, residue could maintain soil moisture at levels more favorable for germination than bare soil (Mohler and Teasdale, 1993). However, in saturated soils, residue could limit soil drying and inhibit emergence of weed species intolerant of saturated conditions.

Mulching has various effects on the soil and the plant. Moisture distribution in the upper layer is more uniform, compared to unmulched soil. More roots develop in the upper soil layer that is usually richer in nutrients and useful microorganisms (Lippert et al., 1964; Knavel and Morh, 1967).

Bonfil et al. (1999) found that during growth of wheat, uncultivated soil with straw mulch increased water content in the upper soil layer and also encouraged the development of a longer root system capable of utilizing deeper water efficiently. Bhattacharyya and Rao (1985) showed that soil covers such as black polyethylene, 10 t/ha of banana trash or 15 t/ha of sugarcane leaf trash considerably reduced consumptive use of water and number of irrigations needed throughout the period of crop growth. Consumptive use ranged from 1024mm under-polyethylene cover at 60% depletion of available soil moisture to 1560mm under no cover treatment at 20% depletion. There was a perceptible increase in water use efficiency under soil covers at low available soil moisture depletion levels. Soil covers reduced the periodic crop coefficient values (the effect of crop characteristics on crop water requirements) compared with bare soil, indicating a reduced (23 to 33%) water requirement of plants under soil covers. High crop coefficient values and crop evapo-transpiration values for the corresponding period, periodic water requirement for profitable production could be estimated.

Effects of Mulching on Soil Temperature

It has been reported (Pan, 1999) that the higher soil temperature and air temperature of the mulch treatment early in the experiment and the improved water and nutrient availability provided by fertigation are important factors in the tomato yield improvement in a mulched and fertigated plot compared to untreated plot.

Baeten et al. (1984), found that the best early yields were obtained with minimum (16.3°C) temperatures and the highest total yields with low maximum (25.4°C) temperature in greenhouses covered with modified polyethylene covers. In their studies, Gonzalez and Vives (1986) found that black, blue and red polyethylene mulches increased tomato yields and quality more than rice husks or sawdust mulches.

Noto (1994) found that temperature in soil covered with polyvinyl chloride mulch was only slightly higher than with polyethylene mulch. He also reported that nematode attacks were reduced by solarization to a varying extent and that plants grown on solarized soil gave higher yields than those achieved in untreated soils.

Organic mulches have been shown to reduce afternoon soil temperatures and to maintain higher soil moisture levels than unmulched treatments. Black plastic mulches increased soil temperature by 1 to 2°C , but sometimes resulted in lower soil moisture levels in early summer, probably by hindering penetration of rainfall. Both undyed Kraft paper and black paper mulches reduced afternoon soil temperatures by 4°C , but this effect diminished over time (Schonbeck and Evanylo, 1998).

Tu et al. (1991) showed that mulching with a transparent plastic sheet increased the soil temperature at a depth of 5cm by 12°C and the soil temperature reached 40°C or more for 119 hours during the 15-day test period, while in the unmulched plot, this temperature was never reached. The highest and lowest temperatures of the mulched plot were 51°C and 27°C, respectively, compared with 39°C and 23°C for the unmulched plot.

Mashngaidze et al. (1996) studied the effects of clear and black plastic mulch against the uncovered control on soil temperature, weed seed viability and weed seedling emergence and height and yield of tomato 'Money Maker'. Mean weekly soil temperatures at 2cm depth at 14.00h were highest under the black plastic covers.

Amador-Berrocal and Vives (1976) found that mean soil temperature was lowest (20.4°C) under sawdust and highest (22.4°C) under black plastic. Each mulch type creates its own unique soil temperature regime and large differences have been recorded between organic and plastic mulches. Soil temperatures are lower under organic mulches during the day and slightly higher at night than those on bare soil (Paterson, 1979). Temperature fluctuations are therefore reduced (Ashworth and Harrison, 1983), but organic mulches have less effect on experimental temperature variation (Bredell and Bernard, 1974).

Dark coloured mulches, such as black polyethylene, absorbs the sun's rays and may increase soil temperature considerably, especially during sunny periods. In a trial in Wisconsin, U.S.A., plastic mulches significantly increased soil temperature

at 10 cm depth compared with organic mulches (Ashworth and Harrison, 1983). Higher soil temperatures also were recorded under black plastic than under bark or hay and these differences were greatest early in the experiment (Litzow and Pellet, 1983).

The benefits of compost addition are usually attributed to nutrient release (Hornick, 1988; Lee, 1997) or increased water retention (Uson and Cook, 1995). Gajri et al. (1994) and Mbagwu (1991) showed that a compost mulch both decreased maximum soil temperature and kept surface layers wetter. Raised soil temperature had been found to affect root and leaf development adversely in maize (Brouwer et al., 1973; Lal, 1974). Maize germination and root development starts at 9 or 10°C (Aldarby and Lowery 1987), growth reaching an optimum at 28°C (Walker 1970; Barber et al., 1988).

Reduction in soil temperature due to mulching was in the range of 0.5 to 1.0°C with all temperatures being below the optimum for maize growth. Reductions were probably due to a lower thermal conductivity and higher air content in the mulch than in the underlying soil. By analogy, a hay mulch has been found to reduce the total radiation balance at the surface and more than halve the flux of heat into a top soil compared with a bare soil (Oke, 1987). Soil temperature fluctuations were therefore reduced by the presence of compost mulch.

Low air temperature reduces the number of nodes preceeding the first inflorescences, but does not reduce the number of flowers (Phatak et al., 1966). Calvert (1957) found that the effects of night air temperature on tomato flower

number depends on the stage of development. Low root temperature was shown to increase flower number of tomato plants (Phatak et al., 1966).

As for vegetative growth, Abdelhafeez et al. (1971) found that roots of tomatoes were thicker, whiter, and less branched at low soil temperature (14°C). Shoot dry weight is increased when root and air temperatures are high. On the other hand high root temperature reduced root fresh weight of tomato plants. Gosselin and Trudel (1982) showed that root temperature above 24°C reduced root growth of tomato plants. Abdelhafeez et al. (1971) and Cooper (1973) indicated that root systems are generally longer and more branched, but thinner at high root temperature.

Cooper (1973) reported that root temperature reduces photosynthesis only under extreme temperature conditions. However, an increase in root temperature from 14 -20°C increased total leaf area of tomato plants (Abdelhafeez et al., 1971), while low air temperature reduced it.

Excessive vegetative growth related to warm temperature of the substrate causes deleterious effects upon flowering and fruiting of greenhouse tomato (Morgan and O'Hitare, 1978).

Effects of Mulching on Pest and Disease Control

With reference to a tomato crop, yield losses do correlate with leaf pest population densities. The leaves close to the trusses are of primary importance. The number and weights of fruits are reduced markedly with increasing severity of

leaf removal (Stacey, 1983). De-leafing has a cumulative effect in delaying flower production, but encourages early fruit ripening. Yield loss is greater in trusses, which ripen later in the experiment. The rate of photosynthesis in tissue damaged by the vegetable leaf minor was significantly reduced. The effect was not restricted solely to the mined area. Fruit was most sensitive to leaf minor attack when the fruits were still small. They decreased yield by inhibiting the development of more fruits.

Brown spot of lupins, initiated by rain splash of soil-borne spores of *Pithium setosa* was controlled by cereal stubble which provided more persistent protection during the experiment than fungicidal seed dressing. Disease severity decreased with increasing quantity of stubble (Sweetingham et al., 1993).

Yellow leaf curl virus transmitted by the whitefly (*Bemisia tabaci*) can be reduced significantly and infection of tomato plant can be largely prevented if the soil is mulched by yellow plastic film. As long as the plants are young and the plastic film is not covered by the plants, the flies will be attracted more by the yellow plastic than by the plants. The heat of the yellow plastic exposed to the sun will kill the flies. This effect can last for ten to twenty days after transplanting and about thirty days after direct seeding. Suitable insecticides still have to be applied but their efficiency will be much higher when yellow plastic is used.

Azam et al. (1997), showed that plants covered with Agril (a polyester material) had a lower incident of egg and nymphal populations and of tomato leaf

curl virus and that there was a significant increase in the yield of plants under Agril cover treatment.

Csizinszky et al. (1995), showed that aphids were least numerous on the aluminum yellow mulches and most numerous on the blue mulch. They also found that the fewest thrips were captured on aluminum mulch and the fewest whiteflies were captured on the yellow, aluminum and orange mulches. They reported that although the differences were not always significant, the fewest adult whiteflies also were observed on foliage of tomato plants grown on the yellow, white, and black mulches. Later in the experiment as plant foliage covered the mulch, differences in the number of insects captured were similar for all mulch colours. Low numbers of whiteflies on the orange and aluminum mulches delayed virus symptom development and increased yields.

In 1997 they evaluated the yellow mulch with and without a soybean oil emulsion spray on the mulch. Under low *Bemisia argentifolii* stress in the spring, yields were similar on all mulch treatments. Under high stress from the pest-transmitted tomato mottle virus (Tmov), yield was based on orange mulch. Virus symptom development in the autumn was delayed and marketable yields were best on aluminum, orange and yellow with soybean oil treatments. The numbers of *Bemisia argentifolii* generally were highest on the conventionally used white or black mulches.

Mulching and staking significantly reduced the incidence of early and late blights by five to twenty percent and increased fruit yield more than twofold.

compared to unmulched and unstaked controls. The apparent rate of infection of the two pathogens was significantly lower in mulched and staked tomato than in the controls. Mulching was more effective than staking in suppressing early and late blight diseases in tomato. Combination of the two reduced incidences by 20 % than two separate practices used.

Influx of winged aphids and the incidence of aphid-borne virus (tabacco etch, potato Y or cucumber mosaic virus) were greatly reduced on plots of capsicums. On mulched plots, capsicum yields were almost double those of the control plots (Black, 1980)

Warren and Cartwright (1999), found that aphids on tomato leaves were highest on bare soil for the first three weeks. After three weeks, aphid counts were negligible with all treatments.

Das (1999), studied the effects of organic mulching on root knot nematode population, rhizome rot incidence and yield of ginger and found a significant positive response of mulching irrespective of the type of mulch material. Maximum germination percentage and maximum tiller numbers per individual clump were observed with paddy straw mulching, but these plots had a lower rhizome yield and a greater number of root galls, than the plots treated with mango, karan, and mahaneem leaves, indicating the possible nematicidal properties of these leaves. Plots mulched with mahaneem leaves had final nematode populations below the initial level and were completely free from rhizome rot.

Studies by Costello and Altieri (1995), showed low aphid populations in broccoli undercropped with leguminous cover crops (white clover, strawberry clover and a mixture of birds foot trefoil and red clover) compared with aphid population on broccoli without a cover crop. Broccoli with living mulches had lower aphid population over all, although the differences with clean cultivation were greatest early in the experiment for *Myzus persicae* and diminished over time. According to this study, consistently lower aphid populations were observed early during the experiment on broccoli in all living mulches compared with clean cultivation, which was as a result of late aphid colonization. Living mulches also significantly reduced *Brevicoryne brassicae* abundance compared with clean cultivation.

Effects of Mulching on Weed Control

There are many reports of satisfactory weed control with a wide variety of mulching materials. Good results have been obtained with plastic film (Davison, 1982) and organic materials (Kolb, 1983), with bark being more effective than straw. The thickness of a mulch necessary to control weeds depends on the type of material used. A depth of approximately 100 mm when settled is required for straw (Bushnell and Weaver, 1930) and about 50 to 70 mm for sawdust (Rowe-Dutton, 1957). A deep mulch (100 mm) of hardwood bark chips, sawdust, or crushed corn cobs gave more effective control than a shallow mulch (50 mm) of the same material (Gartner, 1978). Provided a 75 mm layer of bark mulch is properly

applied, 85% weed control should be achieved during a 3-year period (Campbell-Loyd, 1986).

Apart from smothering effect of mulches, chemicals in the materials also can affect weeds. Phenols and tannins in coniferous bark or sawdust improved the degree of weed control and reduced cultivation costs compared with chopped bark, straw, or a limestone gravel (Kolb et al., 1985).

Although organic mulches can be effective against annual weeds, Davison (1983), observed that they usually have little effect on established perennials. Perennial weeds can emerge through deep layers of organic mulch, and if present when the mulch is applied, they are likely to thrive, because of the absence of competition from annual weeds. He also observed that opaque plastic material give excellent control of annual weeds and more effective than organic mulches against perennials.

Despite the general efficacy of mulches against weeds, Rowe-Dutton (1976), noted problems that can arise with both opaque synthetic and organic mulches. If plastic mulches are torn, accidentally or to assist water penetration, weed growth through the holes will be vigorous. Even with undamaged plastic, vigorous weed growth can occur at the gap around the stem or stake. Transparent plastic film results in high soil temperature than opaque plastic film and crop growth may be enhanced initially (Agulhon, 1975), but the vigorous weed growth that occurs beneath clear plastic is a severe limitation. Some organic mulches, (bark and sewage sludge) can brake down rapidly and be reinvaded quickly by

weeds (Insley, 1981). Finely, pulverised grades of bark, in particular, tend to be colonised rapidly (Campbell-Lloyd, 1986), and moreover, the weed problem may be increased by weed seeds introduced in certain mulches, such as fresh manure, and hay cut when seeding.

The use of mulch alone does not provide adequate weed control (Talbert et al., 1975). Herbicides recommended for application to the mulched surface of the bed includes diuron, terbacil, and simazine, which generally provide adequate control of most annual and some perennial weeds (Baldwin and Boyd, 1989).

Soil solarization for 98 days effectively controlled, purple nutsedge (*Cyperus rotundus* L.), Southern Crabgrass (*Digitaria ciliaris* L.), Florida Parsley (*Richardia scabra*) and Pigweed (*Amaranthus retroflexus* L.), the predominant weeds present in plots ten months after removing the plastic mulch (Clauzell, et al., 1990). However, studies conducted in Israel (Horowitz, et al., 1983; Rubin and Benjamin, 1983), showed that many weeds can be controlled in shorter solarization periods (30 days). Soil solarization for 30 days was not as effective as 98 days for weed control. With longer periods, the incidence of nutsedge for example was significantly reduced in solarized soil almost one year after removal of mulch.

Bell (1984), observed that plastic reduced the need for weed control. When herbicides were used, bensulide gave as good or better results under a plastic as when used without plastic; Naptalam under black plastic had practically no herbicidal activity. Twenty five to fifty gallons of methamlac, applied through drip

irrigation gave good control in vegetables with an improvement in activity when applied under plastic mulch. Soil solarization killed existing weeds and prevented further weed germination (if the soil remained undisturbed).

Whithan (1982) observed best results with black polyethylene and a strong correlation between weed control and growth with the exception of with grass hay, Glyphosate and Simatrole D (strong growth but only moderate weed control) and sawdust (good weed control and poor growth).

Living mulches can provide many beneficial functions in an agroecosystem, including weed control, improved soil fertility and insect control. Weed suppression by cover crop, physical obstruction to weed emergence, allelopathic potential (Barnes and Putnam, 1982; Else and Ilnicki, 1989) and more recently, increased seed predation in the presence of ground cover (Reader, 1991). Mulches may alter the emergence pattern of weeds by moderating the microclimate of weed seed germination zone (van Wiljk et al., 1959) and altering the light stimulus that reaches the weed seeds (Facelli and Pickett, 1991).

In Nigeria, living mulches decreased weed biomass eight fold compared to conventionally tilled maize (Akobundu, 1980). The presence of crownvetch as a living mulch reduced numbers of weed dandelions in a maize crop by 74% compared to maize without a cover crop (Hartwig, 1989). Enache and Ilnick (1987), found that in maize crop, living mulches reduced weed cover more than did dead mulch or no cover. It is evident that cover crop mulch system can reduce weed emergence and growth. They alter the light stimulus needed for emergence

of certain weeds (Moore et al., 1994) and can release allelochemicals that inhibit weed growth, (Barnes and Putman, 1983; Mwaja et al., 1995).

Abu-Irmaileh, (1991), showed that solarization for 6 weeks reduced or eliminated broomrape infestation and improved crop yields. Crops grew best in plots after solarization with black polyethylene if they were planted through the same mulch after it was perforated.

Akobundu (1993), was able to show that perennial weeds such as *Centrosema pubescens* Benth. and *Psophocarpus palustris* can be used as living mulches to reduce the weed biomass in a maize crop. Herbaceous legumes are useful as live mulches or as intercrops. Pueraria and mucuna are the most commonly used species to maintain or improve soil fertility and control erosion (Wilson and Lal, 1986). Mucuna cover cropping has been adopted in the recent years by farmers in South Benin Republic (Manyong et al., 1996), not because of soil fertility management considerations, but because of reduced labour for weed control.

Weed seed bank size and composition were analyzed in maize fields mulched with prunings from *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* by Kamara et al. (1999). They found that in the first year of the trials , there were 87%, 78% and 79% more weed seeds in the unmulched plots than in the *G. sepium* , *L. leucosephala* and *S. siamea* mulched plots, respectively. In the second year of cropping, the weed seed bank at 0 to 5cm soil depth was higher

than in the first year in the *G. sepium*, *L. leucocephala* mulch treatments by 41% and 65%, respectively. *S. siamea* had a lower seed bank at all times of sampling.

The influence of light, soil moisture and temperature on establishment of selected species of hairy vetch residue on soil surface was investigated under controlled conditions in the greenhouse by Mohler and Teasdale, (1993). They found that hairy vetch residue at rates ranging from 616 /gm-2 had no effect on corn, slightly reduced velvet leaf and green foxtail establishment, and severely inhibited common lambsquarters establishment, under full sunlight conditions. The same rates of hairy vetch residue reduced velvet leaf, green foxtail and common lambsquarters establishment more under a shade cloth with 9% light transmittance than under full sunlight.

Mashingaidze et al. (1996), observed that clear plastic mulch did not affect the viability of weed seeds in soil samples collected for 0 to 3cm and 0 to 5cm depths, 6 and 10 weeks after transplanting, respectively. When the plastic mulch was removed at the end of the trial, more weeds had emerged under the clear plastic (324 weeds per square meter) than in the uncovered control (99 weeds per square meter) and under the black plastic (6 weeds per square meter).

Asiegbu (1991), studied the response of tomato and eggplant to mulching and N-fertilization under tropical conditions. He found that black plastic mulch was the most effective for weed control and resulted in more crop growth and higher fruit yield.

Braun et al. (1984), showed that solar heat sterilization followed by mulching with polyethylene sheeting showed promise for the control of *Orobanche ramosa*.

The Effects of Mulching on Tomato Yield and Quality

Csizinszky, et al. (1995) in their study on the influence of colour mulches on yield and insect pest population on tomatoes, showed that plant growth and yields were inconsistent with mulch colours during the three experiments. In fall 1988, in a once over harvest, extra large (≥ 70 mm diameter) and marketable fruit yields were higher ($P \leq 0.05$) on blue than on the conventional white mulch. In Spring, 1988, early marketable yields on the red mulch were higher than on black mulch, and in fall 1989, under high stress from tomato mottle virus transmitted by silver-leaf whitefly (*Bemisia argentifolii*). Experimental yields of extra large fruits were better on orange than on white mulch. In fall 1988 and 1989, fruit size and marketable yields were reduced on yellow mulch.

Kaniszewski (1994), studied the response of tomato to drip irrigation and mulching with polyethylene and non-woven polypropylene and found that mulching generally increased the total and marketable yields. The highest increase in total yields (36%) and in marketable yield (53%) was obtained with combined treatment of irrigation plus mulching with black polyethylene.

In their study Abdul-Baki et al. (1994), evaluated ten cultivars of processing tomatoes grown in bare soil or on black polyethylene, and on hairy

vetch (*Vicia villosa*) for fruit processing quality, and leaf necrosis. Yields were higher, fruits were heavier and leaf necrosis less in hairy vetch than in bare soil or black polyethylene mulch. With the exception of pH, yield and fruit quality component responses to mulch treatment were not cultivar dependent. Fruit pH, TSS concentration and colour equaled values obtained using bare soil production practices. Per cent solids were highest with black polyethylene and lowest with hairy vetch. The hairy vetch mulch delayed fruit maturity compared to the bare soil and black polyethylene.

Famosa and Bautista (1983) evaluated sugarcane mulch and nitrogen fertilizer for tomato production. They found that mulching tomatoes with sugarcane bagasse left to decompose eight months increased the number of flowers per plant, chlorophyll content of the leaves, dry matter and total yield per plant and P and K content, organic matter content and the bulk density of the soil. Mulching with 5, 7.5 and 10 cm bagasse mulch required 90, 150 and 210 Kgs N/ hectare, respectively to obtain the highest net income plus return.

Mashingaidze et al. (1996) showed that cumulative yield over the seven week harvesting period differed among the three treatments, being 18.6, 14.8 and 7.82 tons per hectare for the clear plastics, black plastics and uncovered control, respectively. The plastic mulching treatment enhances plant growth and yield by changing the temperature and light microenvironment of the plants.

The influence of various mulch types (rice husks, saw dust, black, white and transparent) was investigated by Amador-Berrocal and Vives (1976) who

found that saw dust and rice husks mulch gave the highest yield, followed by black plastic. Transparent plastic was inferior as a consequence of abundant weed growth. Ankara and Arin (1998), observed that greenhouse and mulching had positive effects on improving plant development. The highest early yields were obtained from plants pruned from the fourth truss and mulched with any mulch under the greenhouse. Total yield was highest (5,725 g/plant) in plants pruned from eighth truss and mulched with wheat straw mulch.

Mohapatra et al. (1999), reported that plastic mulched plots were better than unmulched plots with respect to plant growth, yield and conservation of soil moisture. The highest yield was obtained with planting on ridges with 50% N applied basal, and mulching at 20 days after planting. Pan et al. (1998), showed that plastic mulch with fertigation gave greater total and factory grade yields compared with no mulch. The yields of factory grade tomatoes at the optimum harvest date were 79 tons/ha with black plastic mulch and 51 tons /ha with no mulch. It is suggested that the higher soil and air temperatures of the mulch treatments early in the experiment and the improved water and nutrient availability provided by fertigation were important factors in this yield improvement.

Chiesa et al. (1997), reported that black and orange polyethylene mulching increases early yields compared with controls by means of greater fruit numbers. Gudoy et al. (1996), showed that tomatoes planted with mulch significantly had bigger fruit size (41.40g), more number of fruits per plant (24.73) and marketable fruits harvested (21.96) than without mulch. Data showed that marketable yields

of unmulched (8.49 ton/ ha.) and mulched (21.96 ton / ha.) tomatoes were highly significant. No significant differences were observed on non-marketable yield.

Use of black mulch resulted in greater increase in growth and yield of tomato than rice straw or water hyacinth (*Eichhornia crassipes*) mulch. Black and red polyethylene mulches were the most effective in increasing yield (Chakraborty and Sadhu, 1995). Firake et al. (1994), showed that earliest flowering and fruiting were observed with sugarcane trash mulch. The average plant heights in treated plots were >14.8% greater than those with no mulch. Maximum cumulative yield was observed in transparent mulch, followed by sugarcane trash mulch. Transparent plastic tunnels, sugarcane trash mulch, black plastic mulch and transparent plastic mulch increased the tomato yield by 91, 80 16 and 13%, respectively compared with no mulch.

Blossom-end rot (BER) of tomato is a calcium disorder in early fruit development (Geraldson, 1957). Mulching is commonly used to help conserve and maintain soil moisture, but impermeable plastic mulches have actually been associated with an increase in BER (Rutgers Univ., 1990). Because large fluctuations in soil water deficits are conducive to development of BER (Pill and Lambeth, 1980; Shaykewich et al., 1971), mulching should decrease BER by reducing soil moisture losses.

In their studies on increasing yield of tomatoes with plastic mulches and apex removal, Wien and Minotti (1988), found that apex removal (topping)

delayed anthesis of the first flowers by six days, but then the faster branch growth increased flower cluster numbers more rapidly on topped plants than on untopped plants. Apex removal and clear plastic mulch stimulated basal branching and led to a 25% increase in yields of the first four harvests, with the combination of treatments having additive effects. Mulching increased leaf concentrations of phosphorus, potassium, calcium and nitrate-nitrogen and decreased sodium concentrations whereas topping increased calcium, magnesium and sodium concentrations in leaves. Mulching resulted in a 50% increase in early yields but topping decreased marketable early yields by 20% because of fasciation (catfacing).

Olasantan (1985), observed that mulching and staking significantly increased vegetative growth, yield and yield component of the tomato plants. Mulched plants grew taller and had more branches and a greater number and weight of fruits than staked plants. Improved cultivars responded better to mulching and staking than local ones. Wezel and Boaker (1999) found that mulching millet with (*Guiera senegalensis*) increased yield by 68% to 94% compared to the control.

Effects of Water on Tomato Yield and Quality

Water stress during fruiting affects fruit quality and yield. Adequate soil moisture during flowering, fruit set and fruit development is critical for maximum tomato yield (Rudich et al., 1977; Wudiri and Henderson, 1985).

Tomato fruit quality is improved with moderate water stress, because the total and soluble solid concentration (SSC) are increased (Geisenberg and Stewart, 1986; Mitchell et al., 1991; Vittum *et al.*, 1961). The increased soluble solute concentration results from lower water accumulation by the fruits.

Excessive moisture during fruit development increases foliar diseases and fruit rots (Greisenberg and Stewart, 1986; Rudich et al., 1977). Water deficit can cause serious losses in most crop plants including tomatoes. Water stress has been shown to affect many plant's processes such as cell elongation and growth (Acevedo et al., 1970), ABA synthesis (Henson et al., 1989), carbon dioxide assimilation (Robinson et al., 1988) and sugar accumulation (Handa et al., 1983).

Many plants develop morphological and physiological adaptations to water stress. Some examples of adaptations to water stress are rapid completion of ontogony, leaf rolling, reduced leaf size, low stomatal conductance and high root: shoot ratios (Landsberg and Jones, 1981; Morgan, 1984). Through osmotic adjustment, some species actively accumulate solutes during water stress and decrease osmotic potential so that turgor potential remains above levels critical for cellular expansion (Hsiao, 1973; Hsiao et al., 1976; Turner, 1979).

Long-term osmotic adjustments to periodic stresses and short-term diurnal adjustments both provide an effective mechanism to maintain sufficient turgor for stomatal opening and photosynthetic productivity (Lakso, 1983).

Indeterminate glasshouse tomatoes which usually possess a surplus of photosynthetic area in relation to fruit production can withstand water stress and a

reduction in leaf area without any adverse effect on yield (Tanaka, et al., 1974 a,b). In processing tomatoes, however, photosynthetic area is normally limiting for fruit production. Water stress limits photosynthesis in tomato mainly by increasing resistance to the movement of gases through the stomata (Duniway, 1971; Duniway and Slatyer, 1971; Hinkley, 1973; Thorne and Kollr, 1974). Water stress also impairs the translocation of assimilates and the resulting accumulation of these yields (Stevens, 1981).

Kamimura et al. (1972), studied the effect of soil moisture levels on fruit skin and showed that high soil moisture lowered the tensile strength of tomato fruit skin. Because of this low tensile strength, the fruit developed many minute cracks when it enlarged rapidly. These minute cracks later developed into visible cracks. Under low soil moisture, they found that the tensile strength of the skin was greater as a result fruit grew more slowly and had fewer minute cracks. Tomato vegetative and fruit growth is very sensitive to water stress (Sanders et al., 1989; Wudiri and Hernderson, 1985). Its quality is improved with moderate water stress, because the total soluble solutes are increased due to lower water accumulation by the fruit (Mitchell et al., 1991; Vittum et al., 1961).

Fruit weight decreased with soil water potential decreases, emphasizing the sensitivity of cell size to hydrostatic turgor pressure (Brix, 1962). He found that low plant water potential (-12 to -15 bars) induced by low soil water content completely inhibited photosynthesis in tomato while respiration was less sensitive, remaining at 70% of the maximum rate. Hence, reduced photosynthetically derived

structural material and osmotica may also have reduced fruit weight and low soil water potentials.

Effects of Temperature on Tomato Yield and Quality

Baeten et al. (1984) found that the best early yields were obtained with high minimum (16.3°C) temperatures and the highest total yields with low maximum (25.4°C) temperatures in greenhouses covered with modified polyethylene covers. Ingratta (1980) showed that warming the soil increased tomato yield by 15 to 20% under normal growing conditions. It caused an increase in shoot growth as measured by plant height and shoot dry weight and a reduction in the development of the root. The higher water content of the shoot and the greater mineral content of the plants maintained at higher root temperatures were attributed to more efficient root systems.

Yakir et al. (1984), showed that there was a significant reduction in fruit quality of tomato where the temperature was greater than 30°C for an average of 9 hours per day, on the basis of traits, including color total soluble solid content and acidity. There was no significant change in the major carotenoid pigments concentration in the fruit compared with fruits ripened at optimal temperatures. Diurnal processes in the plant are suggested as the major factors accounting for the cited differences. "White tissue", a color disorder of tomatoes was a major factor affecting fruit quality at high temperatures.

Soil warming increases plant growth (Cooper, 1973; Gosselin and Trudel, 1982; Nothman et al., 1978) and crop productivity (Rykbost, et al., 1975; Trudel and Gosselin, 1982).

Fruit color and firmness are affected by temperature (Davies and Hobson, 1981). Low temperatures tend to reduce lycopene synthesis (Koskitalo and Ormrod, 1972) and temperatures above 30°C can inhibit lycopene production altogether (Goodwin and Jamikorn, 1952).

In their studies on the effects of mulches on soil temperature and solar radiation on the production of tomatoes, Gonzalez and Vives (1986), found that black, blue and red polyethylene mulches increased tomato yields and quality more than rice husks or sawdust mulches.

Effects of Mulching on Yield and Quality of Vegetable Crops in General

Bell (1984), showed that black plastic mulch gave early harvesting and yields of Cantaloupe melons than when the melons were grown on standard raised beds. Wells et al. (1984), found that reflective foil mulch treatment resulted in greater yields than treatment without foil mulch. The foil plus carbaryl treatments were additive and produced the highest yields. The foil mulch was effective in repelling leafhoppers early in the experiment and accelerated plant growth and maturity.

Goyal and Santiago (1984), evaluated how plastic mulch types affect growth parameters of drip irrigated summer peppers. transparent, white, black or

silver coated black plastics, and organic mulch and non mulching affect capsicum 'Cubanelle'. Transparent plastic gave the lowest plant height and fruit weight while black and silver coated black plastics increased yield by 46% and 132% respectively, compared with no-mulching, and accelerated flowering and fruit set.

Yield of winter-grown cultivar 'Cubanelle' capsicums, mulched with transparent plastic, white plastic, black plastic, silver coated black plastic or an organic mulch were 28.8, 32.5, 31.9, 41.9 and 29.9 tons per hectare, respectively. Yields of summer grown crops subjected to the same treatments were 12.5, 26.3, 23.3, 25.3, and 17.9 tons per hectare, respectively. Yields of unmulched crops were 32.7 tons per hectare in winter and 24.25 tons per hectare in summer. Plant growth and fruit weight, width and length were greater in winter than in summer, whereas the percentage of defective fruits was higher in summer than in winter.

Schales et al. (1990) , showed that yields with black film varied from 10.9 to 11.1 ton/ ha, depending on fertilizer rate, compared with 8.8 ton/ha for unmulched, fertilized treatment. In a comparison of black plastic and plant residues as mulches on capsicum, the highest values for diurnal and nocturnal soil temperatures, plant survival, plant growth, rate of flower development, and yield were given by black plastic followed by plant residues, with the non-mulched control giving the lowest values. The non-mulched treatment required 225-270 more man days of hand weeding per hectare than the mulched treatments.

Black polyethylene mulch and weed control strategies were evaluated by Ricotta and Masiunas (1991) for potential use by small acreage herb producers.

The mulch greatly increased fresh and dry weight yields of basil (*Ocimum basilicum* L.) and rosemary (*Rosmarinus officinalis* L.), although parsley (*Petroselinum crispum* Nym.) yield did not respond to the mulch.

Studies conducted by Paterson et al. (1970) to determine the effects of mulch treatment and soil moisture on plant production, soil temperature and the metabolism of sweet potato roots, showed that the use of petroleum agricultural mulch resulted in the harvest of sweet potato slips 2 weeks before any of the other mulch treatments produced usable plants. A single layer of clear plastic, roofing felt, and also black plastic increased the earliness of sweet potato plant production.

Brien et al. (1979) observed that mulch significantly affected yield and mean fruit weight. Fruit yields were 65.1 and 59.1 MT/ha, and mean fruit weights were 11.3 and 10.9kg for mulched and unmulched treatments, respectively.

Perforated, double-slitted, and spunbonded, polyester bed covers increased the number and weight of sweet potato transplants at the first harvest compared with the bare soil or black polyethylene (Wayne, 1991).

In 4 years of research comparing production of short-day onions (*Allium cepa* L.) on plastic mulch versus bare ground in southern Florida, U.S.A., greater marketable yields were obtained when onions were grown on plastic mulch. Results showed that in a semitropical environment, white-on-black plastic mulch provided the greatest yield enhancement from increased weight and bulb size. Yield loss due to splitting, while apparent, was not sufficient to reduce the impact of mulch on the increase in individual bulb weight (Vavrina and Roka, 2000).

Hanna (2000), conducted eight studies in 1994, 1995, and 1996 to determine the effects of mulching spring tomatoes with black vs. white polyethylene mulch on the growth and yield of subsequent cucumber crops. Soil temperature recorded at 4:00 pm for 3 weeks after planting cucumbers was higher under black mulch than under white mulch. Color of the mulch did not affect leaf length, leaf width, and plant dry weight of cucumbers in six of the eight studies. Cucumbers grown on black mulch produced longer leaves in one study and wider leaves in two studies, and plant dry weight was lower in two studies. Mulch color had no significant effect on the premium or total yields of cucumbers in all but one study. Cucumbers grown on black mulch produced lower percentages of culls in two studies.

Sanders et al. (1999) evaluated the yield response of watermelon to planting density, planting pattern and polyethylene mulch. They observed highest yields of marketable fruits (4.5 kg/melon) using polyethylene mulch and areas per plant between 0.4 and 0.9 m².

The efficacy and cost efficiency of using various plastic soil mulches in the production of pepper (*Capsicum annuum* L.), corn (*Zea mays* L.) and muskmelon (*Cucumis melo* L.) were examined over four growing experiments in Saskatchewan, Canada by Waterer (2000). Clear mulch with or without pre-emergent herbicides was compared with black or wavelength selective mulches. In all three crops, mulches enhanced yields relative to bare ground in most site-year combinations. Clear mulch usually produced the highest yields. Herbicides applied

under the clear plastic provided effective weed control with no observable changes in product efficacy or toxicity to the crop. The weed control provided by the herbicides had no effect on yields in the clear mulch treatments. Consequently, clear mulch without added herbicide usually represented the most cost-effective production option for all three crops.

The Role of Total Non-Structural Carbohydrates on Crop Yield

Carbon partitioning between individual organs, reproductive and vegetative, is dependent upon photo-assimilate supply from photosynthesis and storage carbohydrate, as well as the ability of the translocation system to deliver these resources to sinks (Layne and Flore, 1995). Sink strength of individual organs varies with time of year, and age of the plant, as the sink demands, and seasonal development pattern of the plant changes with time.

Storage carbohydrates are necessary to sustain growth under periods of stress, during dormancy, and are important during initiation of growth in the spring. Nonstructural carbohydrates of sweet cherry fruit change quantitatively and qualitatively during the season (Keller and Loescher, 1989). Nonstructural carbohydrates in sweet cherry consist mainly of starch, sorbitol, sucrose, fructose, glucose, and raffinose. Keller and Loescher (1989) reported that total nonstructural carbohydrates (TNC) were highest at leaf abscission. Shortly before bud break, TNC decreased in all perennial tissues except the spurs, where they increased. TNC then increased slowly once provided with current year's assimilate

until fruit harvest, after which they accumulated at a higher rate. Starch was the most common storage material, sucrose the most predominant soluble carbohydrate during dormancy, and sorbitol the most common soluble carbohydrate during spring bud break.

Sugars, mainly glucose and fructose, account for about half of the dry matter or 65% of the sugar content ranges from 1.7 to 4% fruit fresh weight and the total soluble solids range from 4% to 9% dry matter depending on cultivar (Davies and Hobson, 1981). The content of total soluble solids is inversely related to fruit yield (Stevens and Rudich, 1978), but positively related to the ratio of leaf area to fruit number (Hewett and Stevens, 1981).

Sucrose accounts for only 1% dry matter in a range of 0.1 – 0.2 % fruit fresh weight, but the metabolism of sucrose is important for fruit growth. Although sucrose is the principal imported assimilate, the sucrose content in tomato fruit remain low throughout (Walker and Ho, 1977a). The cessation of assimilate import occurring about 10 days after the first change of colour is caused by the formation of the abscission layer between the calyx and fruit (Mc Collum and Skok, 1960).

More assimilates move to fruiting trusses at the expense of roots at an air temperature of 30°C/24°C (day/ night), while more move to roots at the expense of fruiting trusses at 17° C/12°C (day/ night), (Shishido and Hori, 1979).

Water stress impairs the translocation of assimilates and the resulting accumulation of these substances in the leaf may inhibit photosynthesis. Several sources (Stevens and Rudish, 1978) report that translocation is more sensitive than photosynthesis to water stress. Reductions in translocation are attributed to an inhibition of the sink (Stevens and Rudich, 1978).

The main sink of tomato is the fruit. At their peak of development, these fruits may be influenced by a decline in their turgor, thus slowing down the growth rate and activity of the sink. The metabolic activity and growth rate of the tomato fruit are clearly related to the translocation rate (Ho, 1976). The entry of assimilates into the fruit is controlled in part by its chemical composition with a high content retarding translocation of sugars into the fruit. Enhanced sink activity and rapid utilization of sucrose for the creation of other sugars, starch and cell wall substances in the developing fruit stimulate translocation to the fruit (Hewitt et al., 1982 and Walker et al., 1978).

Zielin et al. (1975), suggested that stored carbohydrates serve as reservoir for the development of flowering shoots especially under insufficient light. Competition for current photo-assimilates has been cited as a major factor in premature abscission of flowers and young fruits in cowpea (Adedipe, et al., 1976) and snap bean (Mauk and Breen, 1986). Fruit set and initial growth of tomato were highly correlated with changes in soluble carbohydrates and starch concentration in the ovaries (Marre and Murneek, 1953), as cited by (Darnell and Martin, 1988). Archbold et al. (1982), showed that fruit set in cherry tomato did

not involve source leaf assimilate mobilization. However, their investigation was limited to analysis of ^{14}C accumulation from ^{14}C -labeled sucrose application to a subtending leaf and did not include determinations of the carbohydrate content of tomato ovaries.

The ability of the fruit to dictate directional flow of assimilates and to utilize them in growth may well relate to their high hormone levels, and is associated with high metabolic activity. Hormone applications to developing fruit are known to increase their growth, and the inward movement of assimilates (Weaver et al., 1969). Similarly, applications of auxins and gibberellins to barley (Wagner, 1974) and wheat grains (Prochazka, 1978; Radley, 1978) increased translocation of photosynthates from the flag leaf and accumulation in the ear, and cytokinins also promoted assimilate accumulation in grain (Aufhammer and Solansky, 1976). Transport of assimilates to citrus fruit (Kadoya, 1974; Powell and Krezdorn, 1977), grape (Alleweldt et al., 1975), tomato, potato and eggplant (Quast, 1977), cowpea (Adedipe et al., 1976) and stawberry (Lis and Antoszewski, 1979) is increased by specific organ or general applications of either gibberellins, cytokinins or auxins. By contrast, ABA applications to fruit or grains inhibit assimilate accumulation (Kormoker and Van Stevenick, 1979).

CHAPTER THREE

MATERIALS AND METHODS

Experimental Site

The study was conducted at Egerton University, Njoro, Tatton Farm, Field 3, in two experiments. The farm lies at latitude $0^{\circ} 23'$ South, longitude $35^{\circ} 35'$ East, and at a mean altitude of 2200 metres above sea level. The soils at the experimental site area are well drained sandy loams. The rainfall at the site is bimodal with the long rains from March to August and the short rains from October to December. The mean temperature, humidity, evaporation rate, radiation and rainfall for September to December 2001 were 19.4°C , 81.0%, 3.68mm/day, $543.65\text{cal}/\text{cm}^2/\text{day}$ and 87.75mm, respectively and December to May were 18.98°C , 83.2%, 4.08mm/day, $579.85\text{cal}/\text{cm}^2/\text{day}$ and 85.58mm, respectively (Egerton University Meteorological Station, 2001).

The project was carried out in a greenhouse with solarized soil. The first experiment was conducted between September, 2001, to December 2001. The second experiment started in December, 2001 and ended in June, 2002.

The experimental design used was a factorial experiment in a Randomized Complete Block, with three replications. The two factors were mulch treatment at five levels and two cultivars of tomato

Treatments

The mulch treatment included black, clear, and white painted polyethylene mulches, wheat straw mulch, and the control (bare soil weeded only once two weeks after transplanting). The two tomato cultivars used in the study were 'Money Maker' and 'Cal J'. The experimental plots were 3.9 metres by 1.2 metres each.

The soil was thoroughly worked, levelled, and graded to provide an even water distribution from the irrigation system and enhance water infiltration, minimizing waterlogging.

Nursery Establishment and Operations

Commercially available seeds of 'Money Maker' and 'Cal J' varieties were planted in pots where single seeds were placed in pots which contained soil-manure mixture at the rate of 3:1 and then watered adequately. The seedlings were watered daily until they attained a 15-20 cm height.

Irrigation and Fertilizer Application

The plants were grown at 13mm deficit and 13 L of water per square metre (Willmott, 1982) was applied every week. During transplanting, DAP fertilizer was applied at a rate of 5g per plant to supply both nitrogen and phosphorus. A solution of potassium sulphate was prepared by dissolving 200g of the fertilizer

compound into twenty litres of water (200 ppm). This solution was applied through the irrigation line.

Mulching

Before laying out the mulches, planting holes were made at a spacing of 40 cm between plants, and 30cm within rows (Nyalala, 2000, personal communication). There were 30 plots and each block had 10 plots assigned at random. The blocks were laid across the gradient of variability in the greenhouse.

Plastic mulches were laid over the beds after drip lines were put in place. Holes were made through the plastics at 40cm X 30cm before transplanting. The wheat straw mulch was laid after transplanting with a thickness of 2cm.

Transplanting

Tomato seedlings were plugged out with the root media from the seedling pots and transplanted when they had attained 15 - 20cm height in four rows per bed, at a spacing of 40cm × 30cm. The holes on mulching film were sealed with soil after transplanting.

Pest and Disease Control

Pests and diseases were judiciously controlled. Ridomil (40g/kg metaxyl-M +640g/kg mancozeb) was applied at a rate of 120g/20 litres of water, sprayed weekly against pests such as mites, whiteflies and aphids. Brigade (bifenthrin) was

applied at a rate of 30ml/20 litres of water, sprayed weekly against blight and wilt diseases.

Training

Tomatoes 'Money Maker' which is indeterminate was supported from the beginning of growth by tying the plants around a vertical string. A horizontal wire ran along the soil surface closely parallel to the tomato row under the complimentary one fixed along the roof of the greenhouse. The string was tied top and bottom with enough slack to make it easy to twist around the tomato stem. The string was supported every 4 m by a strong pole.

Pruning / De-leafing

Progressive removal of the lower leaves of the plant was done when the upper leaves shaded the lower leaves. This corresponded roughly to the ripening of the fruit. As each truss got swollen and individual fruits began to color, all the leaves below that truss were removed by snapping.

Harvesting

Harvesting commenced as soon as the first fruits attained breaker stage (10% of the fruits were red in colour). Fruits were harvested twice a week from 20 plants within the inner 3.6 x 0.8m (inner two rows).

Parameters Studied

The following parameters were considered in this study:

Soil Moisture

Soil moisture was monitored throughout the experimental period. Tensiometers placed at 40cm depth were used to monitor the soil moisture status. The readings were taken at 4 p.m. daily (when water evaporation had occurred to appropriately determine the mulch effect on soil moisture conservation), beginning one week after planting to 10 weeks after transplanting.

Soil Temperature

One thermometer was placed on each plot, planted with 'Money Maker' variety on two replicates at 15 cm depth and readings taken daily at 1:30 p.m. and 3:30 p.m. (when soil temperatures are maximum) on weekdays beginning one week after planting to 10 weeks after transplanting. No thermometers were placed in 'Cal- J' plots, because it would nullify the mulch effect on soil temperature due to its vegetative cover over the soil.

Weed Growth

Weed samples were taken using a quadrant measuring 30cm by 30cm by uprooting and roots were cut off at the stem base. The soil on the roots was removed manually by rubbing it off. The samples were then oven dried at 70°C for 48 hours and dry weight determined using analytical balance at the end of the experiment after removing the mulches from the mulched plots, except that weeds were sampled on wheat straw plots with the mulch intact.

Tomato Plant Growth Parameters

Plant Height

Plant height was taken on 20 inner row plants (plants on which yield data was based), every week on Tuesday for 8 weeks, starting two weeks after planting.

Root Distribution per Unit Volume of Soil

Root growth was estimated, using a modified trench profile method (Bohm et al., 1977) and samples taken. Trenches 140cm long and 30cm deep were dug by hand, parallel to the row on each side of the mulched and unmulched plot, far enough away not to cut any of the roots. The trench sides near the plants were carefully excavated until the tips of the three longest roots of each plant were just visible. The sampled roots were measured and root length recorded.

Non-Structural Carbohydrate Partitioning among Roots, Stems and Leaves

This was determined at the end of harvesting when most of the carbohydrates had been utilised for fruit development and a balance between TNC being translocated to the leaves, stems, and roots had been attained. Total non-structural carbohydrates (TNC) in roots, stems and leaves were determined by Gough's method (Gough, 1981) as modified by Bore, (2001).

The amount of starch concentration was estimated as 0.9 x glucose concentration liberated from the sample (Rong et al., 1996). Total non-structural carbohydrates were calculated as the sum of soluble sugars and starch (Rong et al.,

1996; Kool et al., 1996). Non-structural carbohydrates are considered as the reserves immediately available for plant use and growth (Volenec, 1986).

Quality Parameters

Fruit Size

The fruit size was determined by measuring the fruit diameter at the widest part of the fruit using the vanier calipers.

Fruit Firmness

The fruit firmness was determined by using fruit pressure tester (Bishops' Instruments, Italy). Sampled fruits were stored at 20°C in ventilated boxes and fruit firmness was monitored after every other day throughout the ripening period.

Total Soluble Solutes

Total soluble solutes of the juice of five randomly selected table-ripe tomato fruits per sub-plot, per harvest were measured using a hand refractrometer (0- 30% brix).

Yield Parameters

Total Yield

All fruits picked per plot were counted and weighed separately at each harvesting date. The values obtained were used to calculate the yield per treatment in terms of fruit count (expressed as number of fruits per hectare) and fresh fruit

weight (expressed in metric tonnes per hectare). The unit fruit weight was calculated for each treatment.

Marketable and Unmarketable Yields

Fruits were separated into two lots for each treatment. Those marketable and those unacceptable in the local markets (based on the presence or absence of physiological disorders and the size of the fruits) and weight and number of each determined.

The data so obtained were subjected to the analysis of variance. Where F-test was significant ($P \leq 0.05$), mean separation was done using the LSD or the Duncan's Multiple Range Test procedures, (Little and Hills, 1979; Gomez and Gomez, 1984) depending on the number of means to be separated.

CHAPTER FOUR

RESULTS AND DISCUSSION

The main objective of the study was to determine if mulching could be used to regulate soil temperature and moisture, and thus improve the yields of tomato grown under greenhouse conditions in Kenyan highlands.

In this chapter, the results of the study have been presented and discussed in eight sections: (1) effects of mulching and tomato cultivar on soil moisture, (2) effects of mulching and tomato cultivar on soil temperature, (3) effects of mulching and tomato cultivar on non-structural carbohydrates partitioning between roots, stems and leaves, (4) effects of mulching and tomato cultivar on weeds growth, (5) effects of mulching and tomato cultivar on plant growth, (6) effects of mulching and tomato cultivar on fruit yield, (7) effects of mulching and tomato cultivar on fruit quality, and (8) interrelationship between total non-structural carbohydrates in tomato leaves, stems, and roots and tomato fruit yield.

Effects of Mulching and Tomato Cultivar on Soil Moisture

One of the objectives of this study was to determine if different mulches and tomato cultivars had any significant influence on soil moisture. This section presents results to address the above objective.

There was a significant ($P \leq 0.05$) effect of mulch on soil moisture in both experiments. The plastic mulches were more effective in conserving moisture than the organic mulches (Fig. 1 and 2). The mulches maintained soil moisture at higher

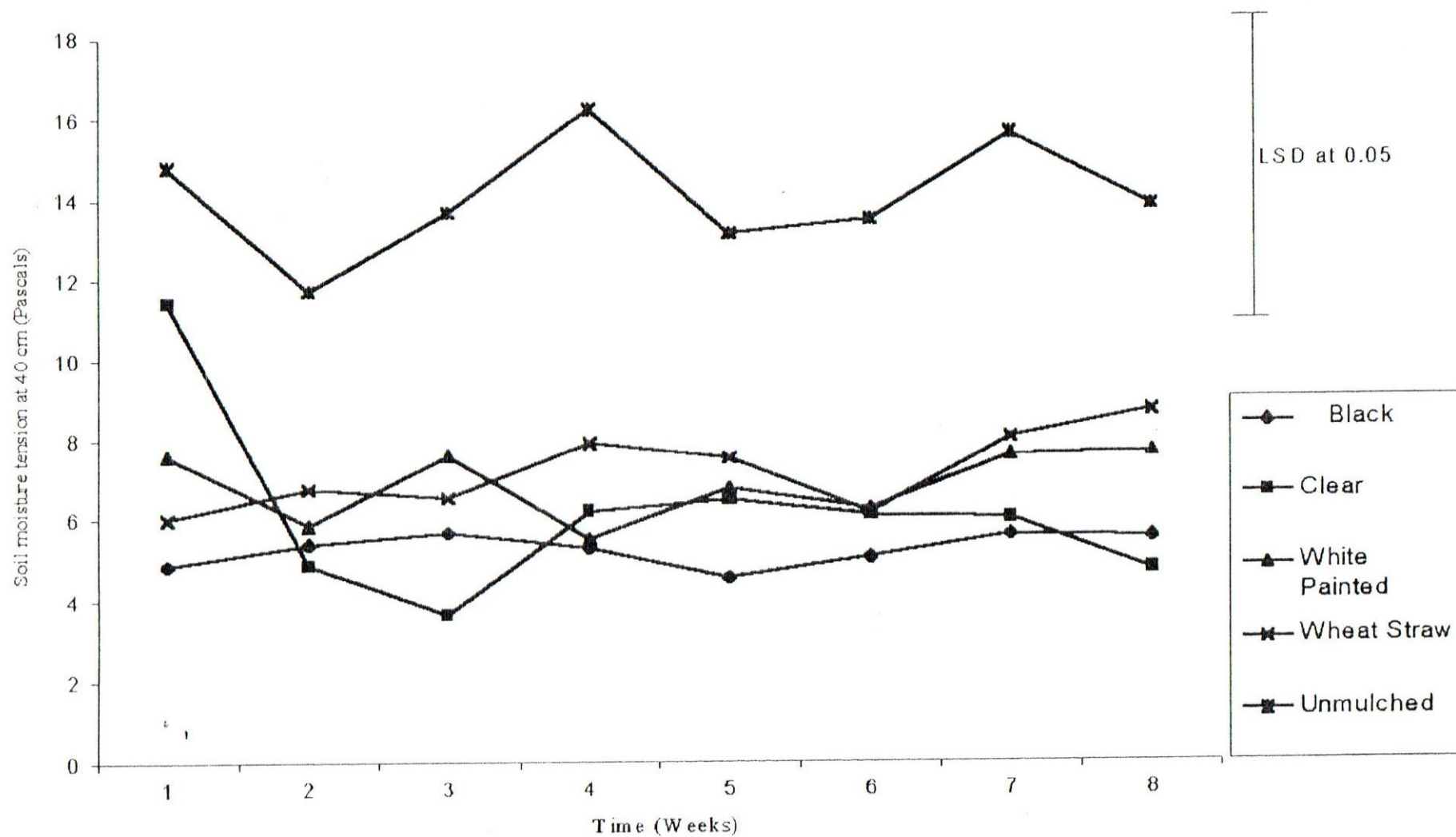


Fig. 1. Effect of mulches on soil moisture (September, 2001, Experiment)

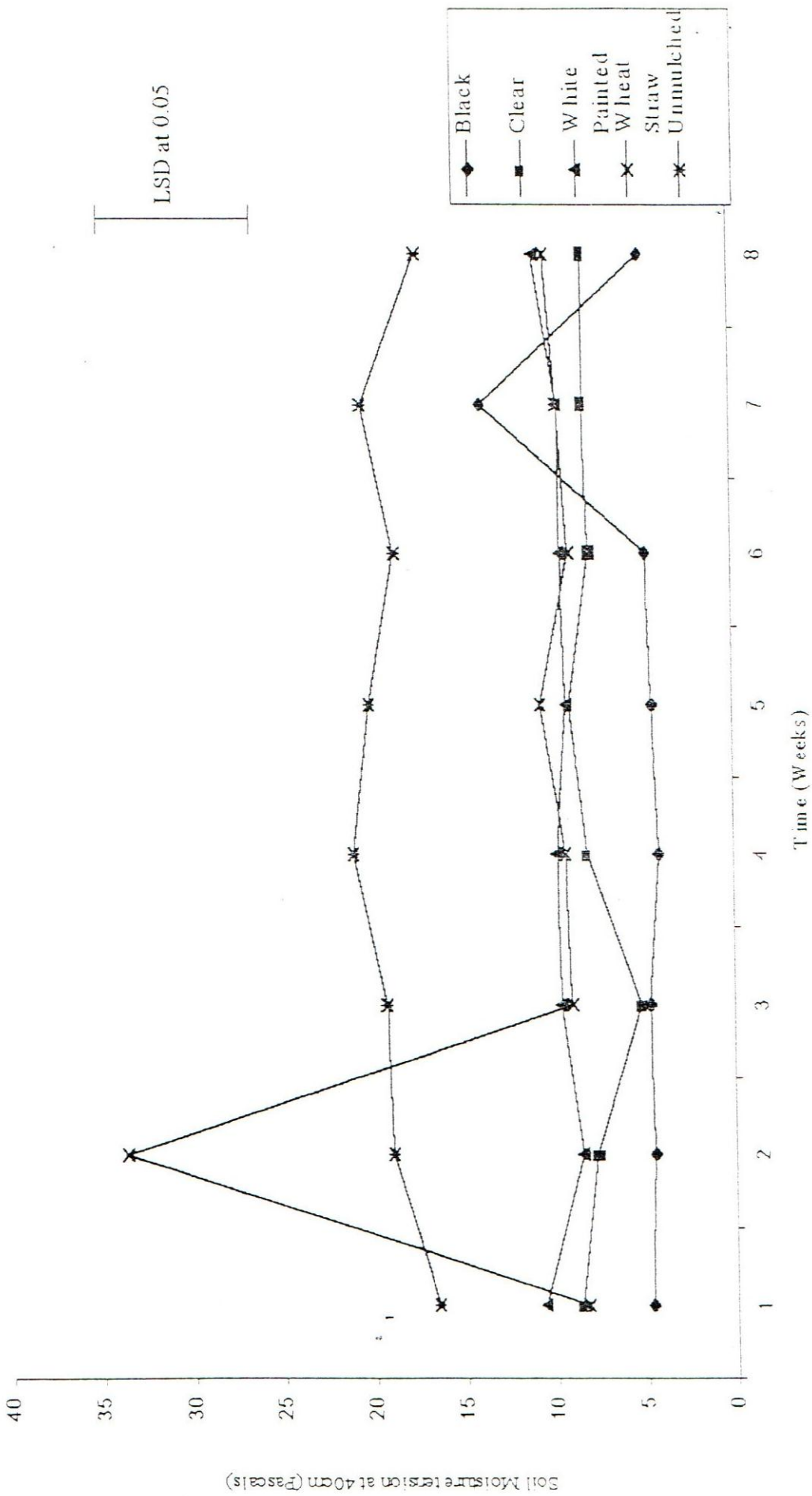


Fig. 2. Effect of mulch on soil moisture (December, 2001, Experiment)

levels than bare soil in both experiments (Fig. 1 and 2). Other researchers (Hoyt and Hargrove, 1986; Bristow, 1989) made similar observations. Moisture distribution under the mulches was relatively more uniform throughout the data collection period (Fig. 1 and 2), compared with the unmulched. The same observation was made on vegetables by (Knavel and Morh, 1967).

There was a significant ($P \leq 0.05$) effect of cultivar on soil moisture in both experiments (Tables 1 and 2). 'Cal J' maintained soil moisture at higher levels than 'Money Maker' (Tables 1 and 2). This can be attributed to the growth pattern of 'Cal J' which is determinate with growth cessation early in the growth period but with extensive branching that causes a heavy vegetative cover over the soil reducing the rate of soil surface evaporation and lowering the soil temperature, which are responsible for the loss of water from the soil.

There was a significant interaction between cultivar and mulch in both experiments (Tables 1 and 2). Mulching maintained a higher level of soil moisture on 'Cal J' plots due to the fact that 'Cal J' has a vegetative cover which is associated with a mulch effect on the soil moisture compared to 'Money Maker' which has an upright growth habit.

Table 1. Effects of mulch and cultivar on soil moisture

(September, 2001, Experiment)

Cultivar			
Soil water tension at 40cm in pascals			
Mulch	Cal-J	Money Maker	Mulch Means
Black	1.90d	8.19bc	5.05b**
Clear	4.33cd	8.06bc	6.20b
White painted	8.68bc	5.12d-b	6.90b
Wheat Straw	4.78d-b	9.32b	7.05b
Unmulched	9.12b	19.50a	14.31a
Cultivar Means	5.76b	10.04a	

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Table 2. Effects of mulch and cultivar on soil moisture
(December, 2001, Experiment)

Cultivar			
Soil water tension at 40 cm in pascals			
Mulch	Cal-J	Money Maker	Mulch Means
Black	5.99c	5.27c	5.63c**
Clear	5.50c	10.33bc	7.9bc
White painted	10.92bc	8.33c	9.63bc
Wheat Straw	8.36c	15.93b	12.15b
Unmulched	15.06b	23.06a	19.06a
Cultivar Means	9.17b	12.58a	

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Effects of Mulch and Cultivar on Soil Temperature

The effect of mulch on soil temperature at 15cm depth was of specific interest. This section presents results on experiment two data, because experiment one was used to determine the appropriate depth at which soil temperature readings were based.

It was observed that each type of mulch created its own unique soil-temperature regime, (Fig. 3). Soil temperatures were significantly influenced by mulch, with black polyethylene recording overall higher soil temperatures than other mulch treatments. These results are contrary to Mashingaidze et al. (1996) who showed that mean weekly soil temperatures at 2 cm depth at 14 week were highest under clear plastic and were lowest under the black plastic covers. Results of this study support Ashworth's and Harrison's (1993) explanation that dark coloured mulches, such as black polyethylene, absorb the sun's rays and may increase soil temperatures considerably, especially during sunny periods. Straw maintained soil temperatures cooler than other mulches (Fig. 3). The unmulched plots recorded the lowest soil temperatures (Fig. 3). Ham et al. (1993) found that clear mulch produced maximum daily temperature that were lower than those achieved by black plastics. However their experiments were conducted without a crop to maximize solar irradiance on the surface, and thus, intensify the effect of mulch optical properties. These observations are consistent with those made by Litzow and Pellet (1983) as cited by Robinson (1988).

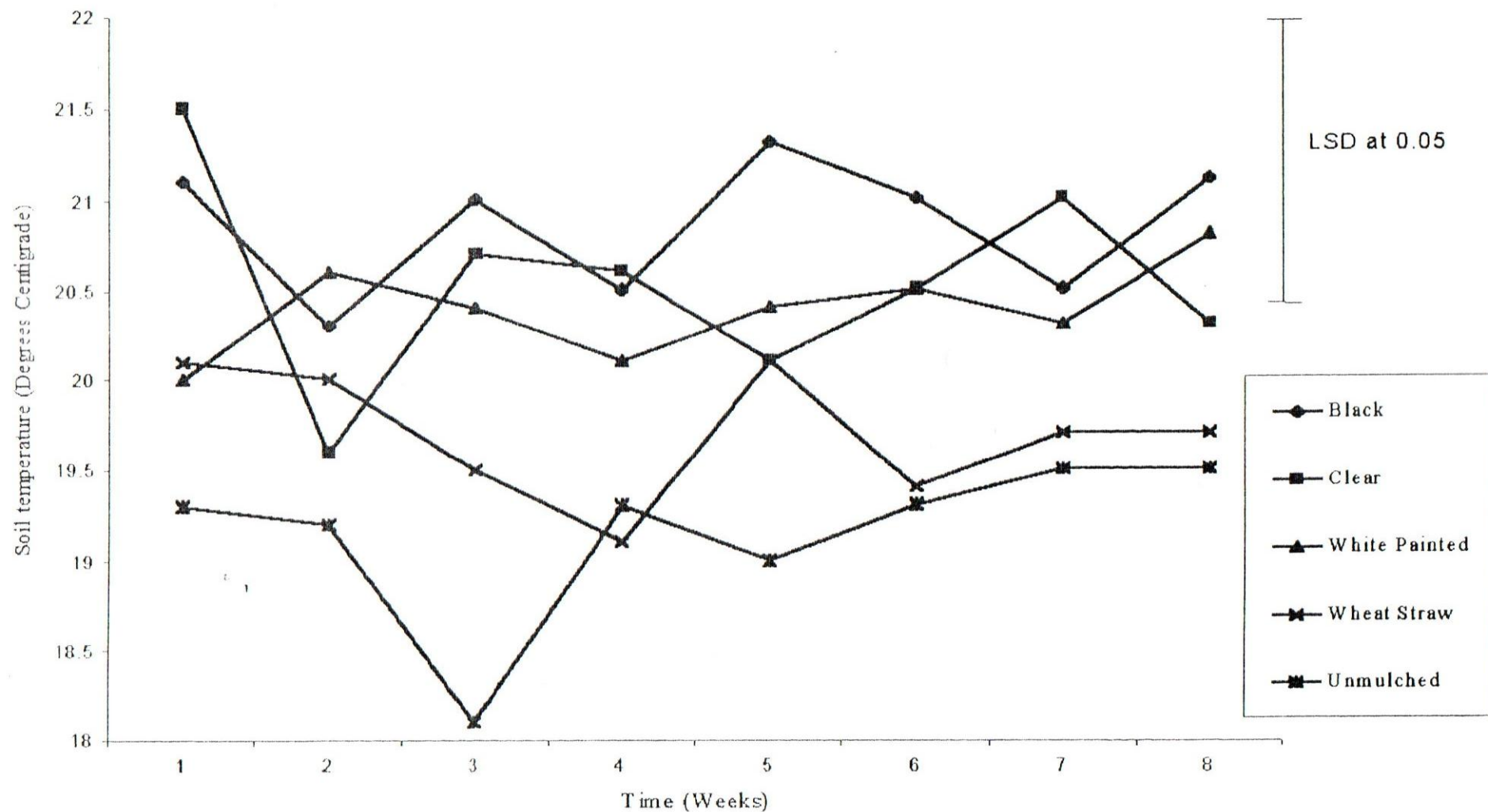


Fig. 3. Effect of mulch on soil temperature (December, 2001, Experiment)

Effects of Mulch and Cultivar on Total Non-Structural Carbohydrate

Partitioning among Tomato Leaves, Stems, and Roots.

The total amount of available Non-Structural Carbohydrates (TNC) was significantly ($P \leq 0.05$) influenced by the plant part used in the analysis. There were higher levels of TNC in the leaves than were in the stems and roots in both experiments (Tables 3 and 4). This is contrary to observation by Zieslin et al. (1975) and Menoud et al. (1991) who found highest starch concentrations in the roots in agreement with the distribution of carbohydrates reserves usually found in woody plants (Loescher et al. 1990). The TNC levels varied from 109.67-164.67 g/kg, 71.91-95.21 g/kg., and 60.58-74.80 g/kg, in leaves, stems, and roots, respectively, in experiment one (Table 3). In experiment two, however, the range was 106.39-242.71 g/kg, 62.58-92.90 g/kg, and 60.80-78.9 g/kg, in leaves, stems, and roots, respectively. Leaves accumulate more TNC than stems and roots because photosynthesis takes place in the tomato leaves which fix carbon dioxide to produce carbon metabolites. A mature leaf exports 20-30% of the ^{14}C fixed within two hours and up to 45-50% within two days. The subsequent export is small and gradual, and the amount of ^{14}C remaining in the leaf at the end of the crop can be quite substantial (Khan and Sagar, 1969).

Total Non-Structural Carbohydrate partitioning among leaves, stems, and roots of tomato was not significantly ($P \leq 0.05$) influenced by mulch in both experiments (Tables 3 and 4).

Table 3. Effects of mulch and cultivar on total non-structural carbohydrate partitioning among tomato leaves, stems, and roots
(September, 2001 Experiment).

Plant part	Black		Clear		White		Straw		Unmulched		Plant part means
	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	
Leaves	135.46*	141.89	140.20	109.67	133.62	122.11	121.45	135.13	123.11	164.67	132.73a**
Stems	78.17	91.41	82.27	89.25	77.91	87.09	87.09	95.21	81.86	85.56	85.58b
Roots	67.99	60.58	67.19	72.22	65.32	66.29	66.29	71.59	73.46	74.80	68.57c
Cultivar means	93.87	97.96	96.55	90.38	92.28	91.83	91.61	100.64	92.75	108.34	
Mulch means	95.92		93.47		92.06		96.13		100.58		

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Table 4. Effects of mulch and cultivar on total non-structural carbohydrate partitioning among tomato leaves, stems, and roots (December, 2001 Experiment)

Plant part	Black		Clear		White		Straw		Unmulched		Plant part means
	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	
Leaves	127.04 *	242.71	150.58	155.51	126.14	150.71	128.51	106.39	136.89	135.98	146.05a**
Stems	76.51	72.75	87.94	72.57	85.85	77.50	62.58	92.90	72.05	83.92	78.46b
Roots	60.80	71.41	78.94	61.87	72.43	65.91	62.10	63.11	71.44	68.09	67.61b
Cultivar means	88.13	128.96	105.82	96.65	94.81	98.04	84.40	87.47	93.46	96.10	
Mulch means	108.54		101.24		96.43		85.94		94.78		

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

There was no significant ($P \leq 0.05$) effect due to cultivar on the partitioning of Non-Structural Carbohydrates among tomato leaves, stems, and roots (Tables 3 and 4).

Effects of Mulch and Cultivar on Weed Growth

There have been reports of satisfactory weed control with a wide variety of mulching materials. This section presents results on how the mulch treatments and cultivar used in the current study affected weed growth expressed in weed numbers and weed dry matter.

Weed Numbers

There was a significant ($P \leq 0.05$) effect of mulch on weed population density in both experiments. The highest weed population density was recorded on the unmulched plots in experiment one and the lowest was on black and white mulches. In experiment two, the highest weed population density was recorded in the straw mulch (Tables 5 and 6). This high number on straw mulch is due to the wheat seeds that germinated. The low number of weeds recorded on black mulch is similar to the observation made by Asiegbu (1991) who found that black mulch was the most effective in weed control. Similar observations were made by Ashworth and Harrison (1983), who showed that the opaque synthetic mulches, black polyethylene, woven polypropylene and heavy-duty green plastic remained

Table 5. Effects of mulch and cultivar on weed numbers per m²

(September, 2001, Experiment)

Mulch	Cultivar		Mulch Means
	Cal-J	Money Maker	
Black	11*	0	6b**
Clear	56	39	48b
White painted	46	73	60ab
Wheat Straw	105	144	125a
Unmulched	53	80	67ab
Cultivar Means	54	67	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Table 6. Effects of mulch and cultivar on weed numbers per m²
(December, 2001, Experiment).

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
	6*	8	7b**
Black			
	52	39	46b
Clear			
	50	73	62ab
White painted			
	109	144	127a
Wheat Straw			
	56	85	71ab
Unmulched			
Cultivar Means	55	70	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

intact throughout the study period and thus provided the most effective weed control. Wood bark followed as a close second. The worst weed problems were associated with straw and clear polyethylene. This is attributed to the fact that being opaque, black excludes light inhibiting weed seed germination.

The high number of weeds recorded on the clear polyethylene mulch was because it allows for light penetration to the soil enhancing a vigorous weed growth beneath the mulch.

There was no significant ($P \leq 0.05$) effect of cultivar on weed population in both experiments. However, higher weed population was recorded on 'Money Maker' than on 'Cal J' (Tables 5 and 6) This is because 'Cal J', being a trailing cultivar, smothered the weeds, resulting in the lower numbers.

There was no significant ($P \leq 0.05$) interaction between cultivar and mulch on weed population in both experiments.

Weed Weight

There was significant ($P \leq 0.05$) effect of mulch on weed weights in both experiments. The highest weed suppression was by black mulch and the lowest on the unmulched plots (Tables 7 and 8).

There was no significant ($P \leq 0.05$) effect of cultivar on weed dry weights in both experiments. However, higher weed weights were recorded on 'Money Maker' than on 'Cal J' (Tables 7 and 8).

Table 7. Effects of mulch and cultivar on weed weight g/per m² (September, 2001, Experiment).

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	12.7*	0	6.35c**
Clear	49.07	52.18	50.63bc
White painted	43.74	75.19	59.47b
Wheat Straw	25.16	55.70	40.43bc
Unmulched	75.44	117.48	96.46a
Cultivar Means	41.22	60.11	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Table 8. Effects of mulch and cultivar on weed weight g/m² (December, 2001, Experiment).

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	7.33*	9.46	8.40c**
Clear	50.41	47.24	48.83bc
White painted	45.20	74.43	59.82b
Wheat Straw	27.18	57.67	42.43bc
Unmulched	79.73	123.68	101.71a
Cultivar Means	41.97	62.50	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

There was no significant ($P \leq 0.05$) interaction between mulch and cultivar in both experiments.

Effects of Cultivar and Mulch on Plant Height

While mulch significantly influenced height in experiment one, there was no significant ($P \leq 0.05$) effect of mulch on plant height in experiment two. In experiment one, the unmulched plants gave the highest tomato plant height, followed by the black polyethylene mulch (Table 9), contrary to experiment two where the black polyethylene mulch gave the highest plant height with the control giving the lowest plant height (Table 10). The higher plant height in the black mulch in experiment two could be due to increased soil temperature, which has been shown (Gosselin and Trudel, 1982) to cause an increase in shoot growth measured by plant height. Olasantan (1995) also found that plants mulched with plastic grew taller.

Schalk (1987), made contradicting observations that plants grown on unmulched plots were intermediate in height while black produced the shortest plants. The experiments were conducted in the field and in Fall season unlike the current experiments which were conducted in a greenhouse.

There was a significant ($P \leq 0.05$) effect of cultivar on plant height in both experiments. This is explained by the fact that 'Money Maker' which had a significantly taller plants height (Tables 9 and 10) is indeterminate, while 'Cal J' with shorter plants is determinate and hence, increase in plant height ceases early

Table 9. Effects of mulch and cultivar on plant height (cm) (September, 2001, Experiment)

Weeks	Black			Clear			White			Straw			Unmulched			Weeks means
	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM				
1	15.54*	32.05	9.30	15.89	19.17	20.37	18.85	22.57	18.25	31.35	20.33					
2	19.34	44.02	14.06	24.83	26.42	28.52	24.96	31.87	25.73	41.19	28.09					
3	25.22	55.43	17.84	33.88	33.55	36.13	30.35	42.15	31.38	50.91	35.68					
4	32.73	68.63	25.82	47.36	39.44	56.17	37.59	56.06	40.50	69.93	47.42					
5	52.37	68.74	42.07	55.77	55.94	58.55	53.05	56.35	58.82	64.71	56.64					
6	59.45	80.75	49.83	66.38	68.24	64.96	62.29	66.05	68.18	75.50	66.16					
7	67.68	91.38	57.86	76.40	80.03	75.24	72.22	75.90	78.13	83.78	75.86					
8	76.93	103.27	68.55	90.53	90.92	85.82	87.26	92.03	86.12	93.34	87.48					
Mulch x	43.70bc**	68.04a	35.67c	51.38c-a	51.72c-a	53.22c-a	48.32c-a	55.37c-a	50.89c-a	63.59ab						
Cultivar means																
Mulch means		55.87ab		43.52b		52.47ab		51.85ab		57.24a						

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$ ** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Table 10. Effects of mulch and cultivar on plant height (cm) (December, 2001, Experiment)

Weeks	Black		Clear		White		Straw		Unmulched		Weeks means
	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	Cal J	MM	
1	22.71*	33.17	21.40	31.56	21.01	33.13	23.74	31.01	21.64	33.74	27.29
2	29.61	42.20	27.95	42.97	26.37	41.59	29.31	40.79	27.93	43.21	35.20
3	34.74	52.06	34.31	54.71	32.58	50.79	36.31	52.59	33.48	51.72	43.33
4	41.15	62.11	41.40	62.83	41.39	59.01	41.24	61.62	39.73	64.62	51.51
5	69.79	61.60	53.55	69.77	55.39	62.26	56.94	63.97	59.52	62.98	61.58
6	70.15	70.70	60.32	77.25	64.58	71.13	66.99	73.83	67.06	70.95	69.3
7	79.09	79.12	68.12	84.34	73.67	78.80	73.68	81.78	71.24	80.03	76.9
8	86.18	89.58	77.79	91.87	79.97	89.90	82.45	91.52	80.76	63.99	83.42
Mulch x Cultivar means	54.15	61.32	48.13	64.41	49.37	60.83	51.33	62.13	50.19	58.91	
Mulch means	57.74		56.27		55.10		56.74		54.54		

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

during the growing period, unlike 'Money Maker' whose increase in height progresses until late in the growth period.

There was a significant ($P \leq 0.05$) interaction between mulch and cultivar in experiment one (Table 9) and no significant ($P \leq 0.05$) interaction in experiment two (Table 10).

Root Distribution Per Unit Volume of Soil

There was no significant ($P \leq 0.05$) effect of mulch on root distribution as expressed in root length (Tables 11 and 12). These results are contrary to those of Wien et al. (1993), who noted that roots were significantly longer for mulched than for unmulched plants in all experiments. They showed that plants growing on clear polyethylene mulched showed a dramatic increase in root length over plants grown on bare soil. However, the plants were grown on nutrient film.

There was a significant ($P \leq 0.05$) cultivar effect on root growth. The determinate 'Cal J' had longer roots than the indeterminate 'Money Maker' in both experiments (Tables 11 and 12). These cultivar differences could be attributed to genetic differences between the two cultivars.

There was no significant ($P \leq 0.05$) interaction between mulch and cultivar in both experiments.

Table 11. Effects of mulch and cultivar on root length (cm) (September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	37.13*	29.07	33.10
Clear	30.40	25.58	27.99
White painted	31.36	25.30	28.33
Wheat Straw	29.48	33.53	31.51
Unmulched	30.74	28.34	29.54
Cultivar Means	31.82a**	28.36b	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Table 12. Effects of mulch and cultivar on root length (cm)

(December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	31.00*	24.60	27.80
Clear	31.40	23.47	27.44
White painted	28.13	22.00	25.07
Wheat Straw	32.93	31.80	32.37
Unmulched	31.47	25.53	28.50
Cultivar Means	30.99a**	25.37b	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$

Effects of Mulching and Cultivar on Yield of Tomato

This section presents results on the effects of mulching and tomato cultivar on fresh fruit yield.

Fruit Numbers Per Plant

Mulching had no significant ($P \leq 0.05$) effect on tomato fruit numbers per plant in both experiments (Tables 13 and 14). This is contrary to observations made by Famosa and Bautista (1983) who found that mulch significantly influenced the tomato total yield per plant, although they worked with sugarcane bagasse as a mulch. Gudoy et al. (1996) also found that tomatoes planted with mulch significantly had more numbers of fruits per plant than unmulched plants.

There was no significant ($P \leq 0.05$) effect of cultivar on fruit numbers per plant in both experiments. The number of fruits per plant of 'Money Maker' tended to be lower than 'Cal J' (Tables 13 and 14).

There was no significant ($P \leq 0.05$) interaction between mulch types and tomato cultivars in both experiments.

Table 13. Effects of mulching and cultivar on fruit numbers per plant

(September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	47.51*	32.42	39.97
Clear	42.83	31.95	37.39
White painted	37.35	25.65	31.50
Wheat Straw	45.77	35.70	40.74
Unmulched	33.53	34.72	34.13
Cultivar Means	41.40	32.09	

* Values not followed by a letter are not significantly different according to the

F-Test at $P \leq 0.05$

Table 14. Effects of mulching and cultivar on fruit numbers per plant

(December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	30.27*	20.20	25.24
Clear	26.25	21.89	24.07
White painted	22.07	20.46	21.23
Wheat Straw	30.82	26.09	28.46
Unmulched	21.70	29.99	25.85
Cultivar Means	26.21	23.73	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Fruit Weight per Plant

Mulching had no significant ($P \leq 0.05$) effect on tomato fruit weight per plant in both experiments (Tables 15 and 16). This is contrary to observations made by Famosa and Bautista (1983) who found that sugarcane bagasse mulch significantly influenced the tomato total yield per plant.

There was no significant ($P \leq 0.05$) effect of cultivar on fruit weight per plant in both experiments. The weight of fruits per plant of 'Money Maker' tended to be lower than 'Cal J' (Tables 15 and 16), because 'Cal J' has more fruit bearing branches hence more fruits per plant and subsequent fruit weight.

There was no interaction between mulch type and tomato cultivar in both experiments.

Table 15. Effects of mulching and cultivar on fruit weight per plant

(September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	1.80*	1.62	1.71
Clear	1.63	1.81	1.72
White painted	1.44	1.49	1.47
Wheat Straw	1.88	1.81	1.85
Unmulched	1.86	1.93	1.90
Cultivar Means	1.72	1.73	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Table 16. Effects of mulching and cultivar on fruit weight per plant

(December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	1.45 [*]	1.30	1.38
Clear	1.26	1.56	1.41
White painted	1.18	1.33	1.26
Wheat Straw	1.67	1.57	1.62
Unmulched	1.68	1.78	1.73
Cultivar Means	1.45	1.51	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Fruit Numbers per Hectare

There was no significant ($P \leq 0.05$) effect of mulches on the fruit numbers of tomatoes in both experiments. The highest numbers of fruits in both experiments were recorded on black plastic mulch (Tables 17 and 18). This is consistent with observation by Kaniszewski (1994), Chiesa et al (1997) and Bell (1984). This yield increase in black plastic mulch though not significant can be attributed to enhanced plant growth by changing the temperature and light microenvironment of the plant. Pan et al. (1998) also reported that the yields were high on black mulch than on control due to higher soil and air temperature of the mulch, early in the experiment and improved water and nutrient availability provided by fertigation.

There was no significant ($P \leq 0.05$) effect of cultivar on the fruit numbers of tomato. 'Money Maker' gave lower fruit numbers than 'Cal J' in experiment one (Table 17), while 'Cal J' gave lower fruit numbers than 'Money Maker' in experiment two. The determinate 'Cal J' yielded lower in experiment two because it being a bushy plant, it was more susceptible to early and late blights which were severe in experiment two than in experiment one on nights with very low temperatures ($4.0-8.67^{\circ}\text{C}$) (Appendix 1) and high relative humidity (95% RH) (Appendix 2). There was also a mice attack on the 'Cal J' fruits in experiment two.

There was no significant ($P \leq 0.05$) interaction between mulching and cultivar in both experiments.

Table 17. Effects of mulching and cultivar on fruit numbers (in '000) per hectare
(September, 2001, Experiment).

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	5292*	2702	3997
Clear	3569	2663	3116
White painted	3113	2138	2626
Wheat Straw	3815	2975	3395
Unmulched	2794	2893	2844
Cultivar Means	3717	2674	

*Values not followed by a letter are not significantly different according to the
F-Test at $P \leq 0.05$

Table 18. Effects of mulching and cultivar on fruit numbers (in '000) per hectare
(December, 2001, Experiment).

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	1929*	2181	2056
Clear	1865	2103	1984
White painted	2077	2017	2047
Wheat Straw	1718	2301	2010
Unmulched	2100	1927	2014
Cultivar Means	1938	2106	

*Values not followed by a letter are not significantly different according to the
F-Test at $P \leq 0.05$

Fruit Weight per Hectare

There was no significant ($P \leq 0.05$) effect of mulches on tomato fruit weight in both experiments. These results are in agreement with those of West and Peirce (1988) who reported that total fruit weight from mulched and mulched with row covers were not statistically different from bare ground. However, Olasantan (1985) observed that mulched plants gave greater weights of fruits than unmulched plants. Goyal et al., (1984) recorded the lowest fruit weight on the clear plastic mulch.

There was no significant ($P \leq 0.05$) effect of cultivar on fruit weight in both experiments. In experiment one 'Cal J' gave a lower fruit weight than 'Money Maker' (Table 19). This could be attributed to the fact that 'Cal J' had higher fruit numbers resulting into smaller fruits, and hence, the lower fruit weight. In experiment two, however, there were fewer fruits giving large fruits leading to higher fruit weight (Table 20).

There was no significant ($P \leq 0.05$) interaction between mulch and cultivar in both experiments, indicating that the treatment effects were additive and independent.

Table 19. Effects of mulching and cultivar on fruit weight (MT) per hectare
(September, 2001, Experiment).

Mulch	Cultivar		
	Cal-J	Money Maker	Mulch means
Black	150.15*	134.91	142.53
Clear	135.95	150.95	143.45
White painted	119.84	124.3	122.07
Wheat Straw	156.78	151.25	154.02
Unmulched	155.46	161.24	158.35
Cultivar Means	143.64	144.53	

*Values not followed by a letter are not significantly different according to the
F-Test at $P \leq 0.05$

Table 20. Effects of mulching and cultivar on fruit weight (MT) per hectare
(December, 2001, Experiment).

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	97.65*	123.93	110.79
Clear	98.08	83.76	90.92
White painted	66.30	108.76	87.53
Wheat Straw	85.04	103.21	94.13
Unmulched	107.26	104.91	106.09
Cultivar Means	90.99	104.91	

*Values not followed by a letter are not significantly different according to the
F-Test at $P \leq 0.05$

Marketable Fruit Numbers

Marketable fruit numbers is the proportion of fruits free from defects, physiological disorders and of medium to large fruits acceptable in the local market.

Marketable fruit numbers were not statistically ($P \leq 0.05$) affected by mulches in both experiments (Tables 21 and 22). These results are in agreement with Perry's and Samders', (1986), observations that average marketable fruit numbers were not statistically influenced by mulching. On the other hand, Elkaner and Kaniszewski (1995) showed that mulching with black increased marketable yield by about 24%. Gudoy et al. (1996) observed that mulch significantly increased marketable fruits harvested compared to no mulch.

There was significant ($P \leq 0.05$) effect of cultivar on marketable fruit numbers. 'Cal J' gave higher marketable fruit numbers than 'Money Maker' in experiment one (Table 21) while 'Money Maker' gave higher marketable fruit numbers in experiment two (Table 22). This observation can be attributed to the fact that 'Cal J' fruits were damaged by mice and also by both late and early blights which reduced the number of fruits produced in experiment two where it was severe. Overall, the marketable fruit numbers recorded in experiment one were higher than those recorded in experiment two (Tables 21 and 22)

There was no significant ($P \leq 0.05$) interaction between mulching and cultivar on marketable fruit numbers.

Table 21. Effects of mulching and cultivar on marketable fruit numbers (in '000) per hectare (September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	2523*	1683	2103
Clear	2187	1823	2005
White painted	1834	1705	1770
Wheat Straw	2568	2174	2371
Unmulched	1808	2499	2154
Cultivar Means	2184	1977	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Table 22. Effects of mulching and cultivar on marketable fruit numbers (in '000) per hectare (December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	1357*	1590	1473
Clear	1156	1603	1379
White painted	1459	1498	1478
Wheat Straw	1244	1603	1423
Unmulched	1474	1438	1456
Cultivar Means	1338	1546	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Marketable Fruit Weight Per Unit Area

There was no significant ($P \leq 0.05$) effect of mulch on marketable fruit weight per unit area in both experiments (Tables 23 and 24). This is contrary to observations by Olasantan (1985) who showed that mulches significantly influenced total tomato marketable fruit weights. However, his experiments were conducted under field conditions and he tested mulches, intercropping and staking, all of which could have led into the compounded effect of mulch on fruit weights.

There was no significant ($P \leq 0.05$) effect of cultivar on marketable fruit weight. 'Cal J' tended to give lower marketable fruit weight than 'Money Maker' in December experiment (Tables 23 and 24). This observation can be attributed to the fact that 'Cal J' fruits were damaged by mice and also by both late and early blights which reduced fruit numbers, and hence, weight of fruits produced in experiment two where it was severe. Marketable fruit weights recorded in experiment one tended to be higher than those recorded in experiment two (Tables 23 and 24).

There was no significant ($P \leq 0.05$) interaction between mulch and tomato CV on marketable fruit weight.

Table 23. Effects of mulching and cultivar on marketable fruit weight (in MT) per hectare
(September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	120.66*	107.89	114.28
Clear	105.57	130.02	117.80
White painted	97.99	111.06	104.53
Wheat Straw	138.78	130.37	134.58
Unmulched	140.02	149.29	144.65
Cultivar Means	120.61	125.73	

*Values not followed by a letter are not significantly different according to the
F-Test at $P \leq 0.05$

Table 24. Effects of mulching and cultivar on marketable fruit weight (in MT) per hectare
(December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	77.16*	101.71	89.43
Clear	73.72	98.07	85.90
White painted	74.15	89.10	81.63
Wheat Straw	67.52	76.92	72.22
Unmulched	84.19	86.75	85.47
Cultivar Means	75.35	90.51	

*Values not followed by a letter are not significantly different according to the
F-Test at $P \leq 0.05$

Effects of Mulch and Cultivar on Quality of Tomato

Part of the specific objectives of this study was to determine whether or not mulching and cultivar affect tomato quality. Quality parameters assessed in this study included the percentage of marketable numbers and weights, fruit firmness, fruit size and fruit total soluble solutes (TSS). This section presents results of the above parameters.

Percent Marketable Yields

The major concern was to determine the proportion of total yields that a grower can be able to sell by adopting the various treatment combinations. Angular transformations were done on the data before analysis of variance, because the marketable yield percentages were greater than 40%. Values presented in Tables 25 and 26 are, however, the original means.

Percentage of Marketable Fruit Numbers

There was no significant ($P \leq 0.05$) effect of mulch on percent marketable fruit numbers (Tables 25 and 26). These results contradict observations by Perry and Sanders (1986) who showed that percentage of marketable fruit numbers were significantly influenced by mulching in the early season harvest. However, they are in agreement with those of Taber (1983) who observed that percentage of marketable fruit numbers were not affected by mulch treatments.

Table 25. Effects of mulch and cultivar on percent marketable fruit numbers
(September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	70.71*	72.81	71.76
Clear	75.53	73.42	74.47
White painted	61.48	77.97	69.73
Wheat Straw	73.40	72.70	73.05
Unmulched	68.64	73.13	70.89
Cultivar Means	69.95	74.01	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Table 26. Effects of mulch and cultivar on percent marketable fruit numbers

(December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	64.95cd**	63.83cd	64.39*
Clear	61.93d	68.03c	64.98
White painted	61.71d	79.83b	70.77
Wheat Straw	67.71c	85.74a	76.73
Unmulched	55.82e	86.47a	71.14
Cultivar Means	62.42	76.78	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$.

There was no significant ($P \leq 0.05$) effect of cultivar on percent marketable fruit numbers. 'Money Maker' gave higher percent marketable fruit numbers than 'Cal-J' in both experiments (Tables 25 and 26).

There was no significant interaction between mulch and cultivar in experiment one, but there was significant ($P \leq 0.05$) interaction between mulch and cultivar in experiment two. Mulching favoured 'Money Maker' more than 'Cal J' because most of 'Cal J' fruits were damaged by mice given that fruits lay down on the mulches.

Percent Marketable Fruit Weight

There was no significant ($P \leq 0.05$) effect of mulch on percent marketable fruit weight in experiment one (Table 27). However, mulching significantly ($P \leq 0.05$) affected the percentage marketable fruit weight in experiment two (Table 28). In experiment two, the highest percent marketable fruit weight was recorded on unmulched plots although it was not significantly different from the wheat straw mulch. The lowest percent fruit weight was obtained on black polyethylene mulch.

There was no significant ($P \leq 0.05$) effect of cultivar on percent of marketable fruit weight in both experiments (Tables 27 and 28).

There was no significant ($P \leq 0.05$) interaction between cultivar and mulch on percent marketable fruit weight in both experiments (Tables 27 and 28).

Table 27. Effects of mulch and cultivar on percent marketable fruit weight

(September 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	79.16*	82.04	80.6
Clear	81.26	81.72	81.49
White painted	73.58	84.38	78.98
Wheat Straw	80.52	64.11	72.32
Unmulched	76.74	80.95	78.85
Cultivar Means	78.25	78.64	

*Values not followed by a letter are not significantly different according to the

F-Test at $P \leq 0.05$

Table 28. Effects of mulch and cultivar on percent marketable fruit weight

(December 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	80.30*	76.19	78.25d**
Clear	77.52	80.16	78.84cd
White painted	81.81	89.36	85.59bc
Wheat Straw	88.74	86.80	87.77ab
Unmulched	89.95	92.58	91.27a
Cultivar Means	83.66	85.02	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$.

Fruit Firmness

Results obtained on the effects of mulch and cultivar on fruit firmness are presented in this section.

Fruit firmness was not significantly ($P \leq 0.05$) influenced by mulching in both experiments.

There was significant ($P \leq 0.05$) difference in fruit firmness between the two tomato cultivars in both experiments (Tables 29 and 30). This confirms Kader's (1986) observation that textural quality of tomato is characterized by skin toughness, flesh firmness and internal structure, which vary greatly among cultivars. Each cultivar showed a loss in fruit firmness with longer storage (Figures 4 and 5).

Table 29. Effects of mulch and cultivar on tomato fruit firmness (Brix)

(September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	2.74*	2.71	2.73
Clear	2.90	2.61	2.76
White painted	2.65	2.67	2.66
Wheat Straw	2.79	2.57	2.68
Unmulched	2.62	2.46	2.54
Cultivar Means	2.74a**	2.60b	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$.

Table 30. Effects of mulch and cultivar on tomato fruit firmness (Brix)

(December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	2.84*	2.76	2.73
Clear	2.88	2.61	2.75
White painted	2.77	2.70	2.74
Wheat Straw	2.80	2.60	2.70
Unmulched	2.61	2.52	2.57
Cultivar Means	2.78a**	2.64b	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$.

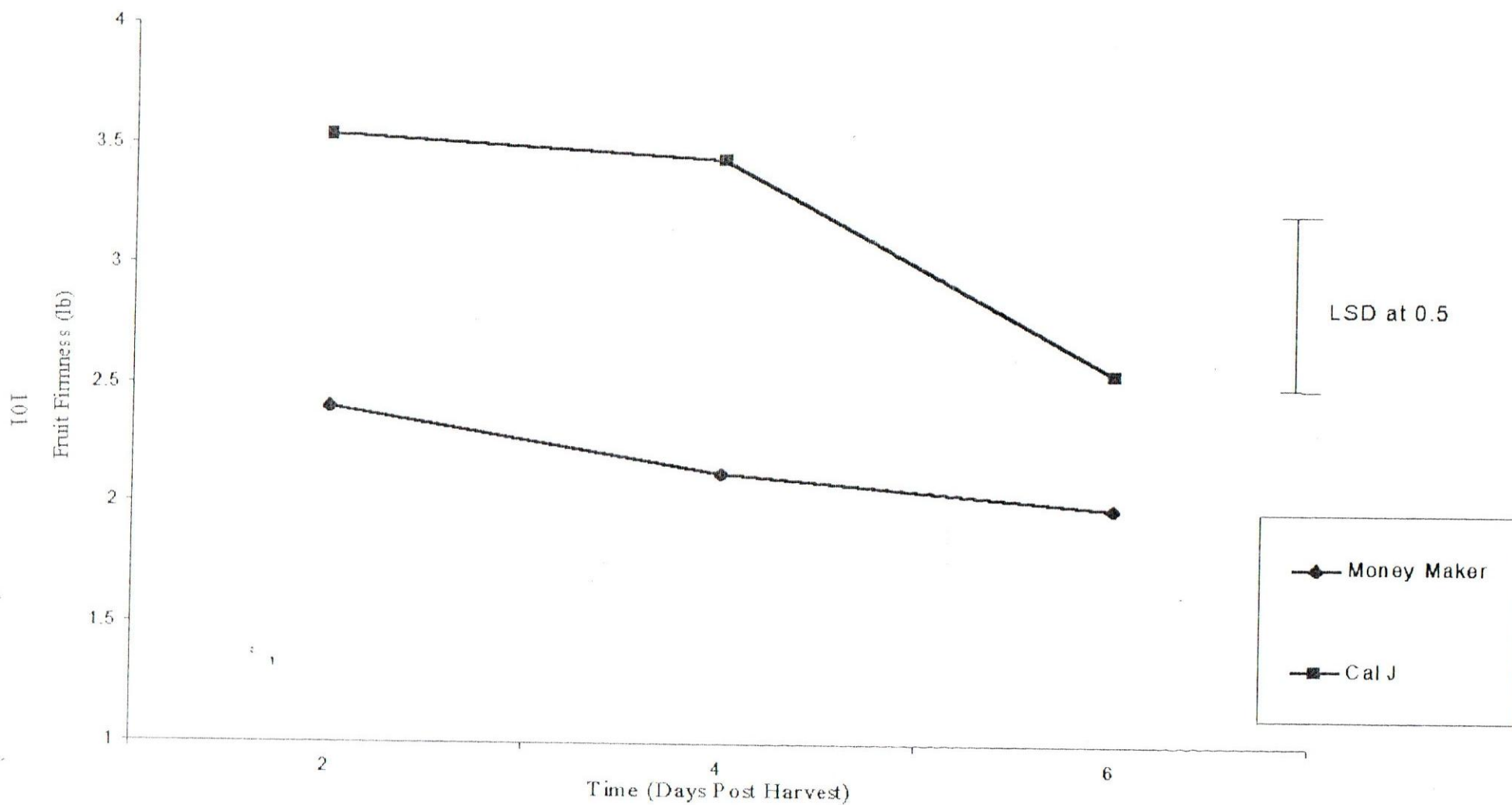


Fig. 4. Effects of cultivar on fruit firmness (September, 2001, Experiment)

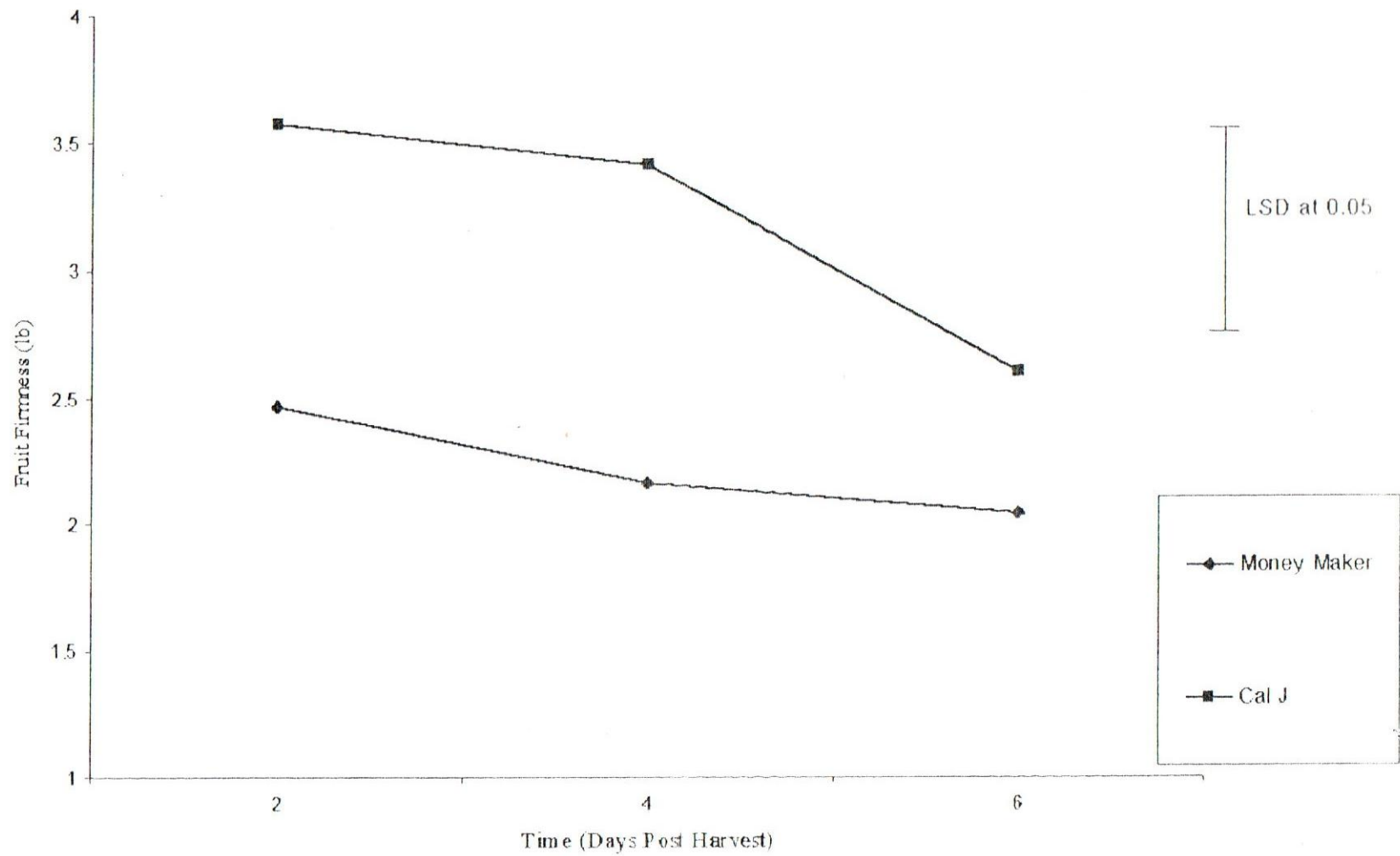


Fig. 5. Effect of cultivar on fruit firmness (December, 2001, Experiment)

Fruit Size

This is an important quality attribute of tomato quality. There was no significant ($P \leq 0.05$) effect of mulch on fruit size in both experiments. Gudoy et al. (1996) found that mulched plants had significantly bigger fruit size than unmulched contrary to the current study.

There was a significant ($P \leq 0.05$) effect of cultivar on tomato fruit size in September, but not in December experiments (Tables 31 and 32). 'Cal J' gave smaller fruits compared to 'Money Maker' (Tables 31 and 32).

There was no significant ($P \leq 0.05$) interaction between cultivar and mulch in both experiments.

Table 31. Effects of mulch and cultivar on fruit size (mm) (September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	38.69*	44.46	41.57
Clear	40.41	47.64	44.03
White painted	41.71	47.68	44.70
Wheat Straw	40.60	47.14	43.87
Unmulched	41.54	46.23	43.89
Cultivar Means	40.59a**	46.63a	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different according to the Duncan's Multiple Range Test at $P \leq 0.05$.

Table 32. Effects of mulch and cultivar on fruit size (mm) (December, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	32.11*	39.03	35.57
Clear	35.29	38.22	36.76
White painted	36.03	41.68	38.86
Wheat Straw	34.14	36.84	35.49
Unmulched	32.86	37.24	35.05
Cultivar Means	34.09	38.60	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Total Soluble Solutes

Consumers consider good quality tomatoes as those that look good, are firm and offer good flavour and nutritive value. Fruit flavour is determined by, among others, the total soluble solutes (sum of sugars and salts in the fruit).

There was no significant ($P \leq 0.05$) effect of mulch on fruit total soluble salts in both experiments (Tables 33 and 34). These results are similar to those by Abdul – Baki et al. (1994) that fruit pH, TSS concentration and colour equaled values obtained using bare soil production practices.

There was no significant ($P \leq 0.05$) effect of cultivar on fruit total soluble solutes in both experiments (Tables 33 and 34). These results support observations by Abdul – Baki et al. (1994) that with the exception of pH, yield and fruit quality component responses to mulch treatment were not cultivar dependent. Generally 'Money Maker' had higher TSS than 'Cal J', in both experiments. These results agree to a suggestion by Hewitt and Stevens (1981) that fresh market tomato cultivars have highest TSS than processing cultivars.

There was no significant ($P \leq 0.05$) interaction between mulches and cultivar in both experiments.

Table 33. Effects of mulch and cultivar on fruit total soluble solutes (brix)

(September, 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	2.90*	3.02	2.96
Clear	3.12	3.04	3.08
White painted	2.81	3.12	2.97
Wheat Straw	3.07	3.14	3.11
Unmulched	3.09	3.13	3.11
Cultivar Means	3.00	3.09	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Table 34. Effects of mulch and cultivar on fruit total soluble solutes (brix)
(December 2001, Experiment)

Mulch	Cultivar		Mulch means
	Cal-J	Money Maker	
Black	3.41*	3.45	3.43
Clear	3.07	3.51	3.29
White painted	3.49	3.25	3.37
Wheat Straw	3.20	3.47	3.34
Unmulched	3.00	3.43	3.22
Cultivar Means	3.23	3.42	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

Interrelationship between Total Non-Structural Carbohydrates in Tomato Leaves, Stems, Roots and Tomato Fruit Yield.

Data in Table 35 present the correlation coefficients between total non-structural carbohydrates (TNC) in leaves, stems, and roots and tomato fruit yield.

Non significant negative corrections were established between TNC in leaves, stems and roots and total fruit numbers and between leaves and total fruit weight per hectare in experiment one. On the other hand, positive correlations were established between TNC in stems and roots and total fruit weight per hectare, with positive significant ($P \leq 0.05$) correction between TNC in roots and total fruit weight.

During the December experiment, positive correlations were established between TNC in leaves, stems and roots and total fruit numbers and weight per hectare. However, the correlations were not significant except for TNC in leaves with total fruit weight and TNC in stems with total fruit numbers per hectare.

Table 35. Coefficients of Correlation (R) between total non-structural carbohydrates in tomato leaves, stems, and roots and tomato fruit yield.

Experiment	Plant part used	Total Fruit Numbers	Total fruit Weight
September, 2001	Leaves	-0.066	-0.252
	Stems	-0.24	0.045
	Roots	-0.48	0.484*
December, 2001	Leaves	0.200	0.471*
	Stems	0.499*	0.180
	Roots	0.097	0.028

* Significant at 5% probability level.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study and the foregoing discussion, it can be concluded that:

1. Mulching maintains higher soil moisture at a depth of 40 cm than no mulching.
From the results of this study, plastic mulches are most effective in soil moisture retention than organic mulches.
2. Mulching maintains higher soil temperature at a depth of 15 cm. Black plastic mulch is more effective than other mulches in maintaining high soil temperature.
3. Black plastic mulch is the most effective in weed growth control, compared with other mulches, because it is opaque, and therefore excludes light from the soil, while wheat straw introduces wheat seeds which grow and compete with the tomato crop.
4. Mulching does not influence the non-structural carbohydrates accumulation in tomato roots, stems, and leaves.
5. Mulching does not increase tomato marketable yields in greenhouse.
6. Mulching does not improve tomato fruit quality.

From the foregoing, the following recommendations can be made:

1. Although no mulch gave high marketable yields, I recommend that plastic mulches be adopted in irrigated greenhouse tomato production, because of their advantage in water conservation.

2. Because of the low soil temperatures in the Kenyan highland areas it is recommended that greenhouses should be used and black mulches be used to raise soil temperature.
3. Cultivars selected for greenhouse production should be based on growth habit, therefore 'Money Maker' is recommended for greenhouse production, because it yields higher than 'Cal J' in the greenhouse.
4. Further research should be done on the effects of mulching and other cultural factors such as leaf defoliation, spacing and nitrogen fertility on non-structural carbohydrate partitioning and subsequent effects on flowering and fruiting of tomato.
5. Further research should be done to determine whether mulches influence the soil temperature at soil profiles deeper than 15 cm.
6. A comparative experiment between greenhouse and field conditions should be conducted to determine under which conditions mulching is best suited under the Kenyan highland conditions.

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APPENDIX 1: Air Temperatures (September, 2001, and December, 2001, Experiments)

Table 36. Air Temperature (September, 2001, Experiment)

Weeks	Maximum	Maximum	Minimum	Minimum
Averages	Day	Night	Day	Night
1	33.71	12.29	16.57	6.15
2	31.29	12.71	15.00	9.7
3	34.00	12.57	20.71	7.71
4	33.00	12.81	18.85	7.93
5	32.48	12.52	19.72	7.85
6	34.28	13.28	20.57	4.85
7	33.00	11.00	20.71	7.14
8	32.30	10.75	18.00	7.25

Table 37. Air Temperature (December, 2001, Experiment)

Weeks	Maximum	Maximum	Minimum	Minimum
Averages	Day	Night	Day	Night
1	35.57	22.86	11.86	5.14
2	35.29	12.86	11.29	7.00
3	35.17	25.00	11.00	4.00
4	33.00	22.00	11.85	5.57
5	36.50	26.67	15.00	8.67
6	31.29	18.29	11.14	6.29
7	31.67	21.33	12.83	5.67
8	32.98	20.19	11.90	5.87

**APPENDIX 2: Greenhouse Relative Humidity (September, 2001, and
December, 2001, Experiments)**

Table 38. Relative Humidity (September, 2001, Experiment)

Weeks Averages	Maximum Day	Maximum Night	Minimum Day	Minimum Night
1	60	90	95	98
2	40	80	95	99
3	38	90	96	98
4	35	95	97	99
5	38	95	96	99
6	40	95	96	98
7	38	94	95	98
8	38	92	96	99

Table 39. Relative Humidity (December, 2001, Experiment)

Weeks Averages	Maximum Day	Maximum Night	Minimum Day	Minimum Night
1	60	90	95	98
2	42	91	94	97
3	42	93	90	90
4	35	96	93	95
5	38	95	92	98
6	30	90	95	95
7	35	90	96	95
8	38	92	93	95

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