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Influence of Drip Irrigation Schedule and Mulching Material on Yield and Quality of Greenhouse Tomato (*Lycopersicon esculentum* Mill. 'Money Maker')

G.M. Kere, M.O. Nyanjage, G. Liu and S.P.O. Nyalala
Department of Horticulture, Egerton University , P.O. Box 536, Njoro, Kenya

Abstract: Water is a scarce resource for irrigation use in many parts of the tropics. Water usage for irrigation and plant water use efficiency can be improved by drip irrigation schedule and/or mulching materials whose influences vary with locality. A study was conducted between September 2001 and August 2002 to investigate the influence of irrigation schedule and mulching materials on the yield and quality of greenhouse-grown fresh market tomato in the Kenya highlands (2200m above Sea Level). The experimental design was split-plot embedded in randomized complete block design replicated three times with irrigation schedules as main plot consisting of irrigation on daily basis, after every two and three days, respectively. Mulching material which included clear (transparent) plastic, dry grass and no mulch (control) formed the sub-plot. The data was subjected to Analysis of Variance (ANOVA) using MSTAT and means separated by LSD or Duncan Multiple Range Test ($P\leq 0.05$). Dry grass mulch and irrigation after every two days significantly produced the lowest fruit dry weight. Total marketable tomato fruit yields were not significantly affected by either drip irrigation schedule or mulch type. Dry grass mulch produced the lowest total soluble solids. Under these conditions grass mulch and irrigation after every three days should be adopted for greenhouse tomatoes in warm tropics. The grass mulch is cheap and readily available whereas, three days irrigation interval saves water. Further research should be conducted to incorporate different irrigation rates.

Key words: Irrigation schedule, mulching materials, greenhouse, tomato, yield, quality

INTRODUCTION

Tomato is increasingly becoming popular in Kenya in fresh market and processing industry. Production is mainly outdoors where yields and quality are adversely affected by unfavourable environmental factors (temperature extremes, erratic and unreliable rainfall, diseases and pests and poor management of scarce water). Greenhouse creates a favourable microclimate for production of tomatoes (Perry and Sanders, 1986), but its potential is not well explored in Kenya especially in the highlands where chilling temperature and high relative humidity adversely affect tomato production.

Water is essential for greenhouse tomato production since rainfall is excluded. There is inadequate supply of water for agricultural use in Kenya and the available water is applied to crops through drip, sprinkler or furrow irrigation. Plant water requirement varies with environmental factors (Kadam and Magar, 1993). Drip irrigation is preferred because it significantly reduces water usage for irrigation besides contributing to higher tomato yield than sprinkler or furrow irrigation (Tan, 1995; Liu, 2000).

The amount of water applied is dependent on irrigation schedule, soil properties and evapotranspiration rates (Hartz, 1993) which are in turn influenced by crop environment and stage of growth. Irrigation schedule can impact positively or negatively on the growth and yield of tomato (Locascio *et al*., 1981; Lecoeur and Sinclair, 1996; Obreza *et al*., 1996) depending on the amount of water applied. Therefore, it is important to determine optimal irrigation regime that promotes yield and quality of tomato for specific localities, which are essential for successful marketing of tomato (Phill and Lambeth, 1981). Irrigation scheduling involves decisions on when to irrigate and how much water to apply (Doorenbos and Pruitt, 1977).

Mulching reduces the rates of water loss from soil surface and facilitates moisture distribution, hence influencing irrigation schedule (Bhella, 1988; Wien and Minotti, 1988; Brown *et al*., 1991). Organic (plant materials) and synthetic mulches (plastics of different colours - transparent, yellow, green, red, black and white) are widely used in vegetable production for various reasons including conservation of soil moisture. Clear plastic mulches substantially promote growth, yield and quality of tomatoes (Perry and Sanders, 1986; Liu and Hu, 2000) by readily warming the soil, conserving moisture and directing carbon dioxide from soil to the plant leaves. Ogarnic mulches such as grass, sawdust, corncobs, rice husks, straws of wheat and rice are also beneficial to crops (Garnaud, 1981; Shrivastava *et al.*, 1994; Hwang and Tae, 2000) and locally available.

Studies on drip irrigation and/or mulching have been conducted under field conditions in Kenya. The objectives of this study were to investigate the influence of drip irrigation schedule, mulching materials and their interactions on the yield and quality of greenhouse grown fresh market tomato ('Money Maker').

MATERIALS AND METHODS

Experimental site: The study was conducted in plastic tunnel at Egerton University, Kenya (at latitude of approximately 0° 23' South, Longitude of 35° 35' East and altitude of 2200 m above the Sea Level). The mean temperature, humidity, evaporation rate and rainfall over ten year period (1991 to 2000) are about 19.68 °C, 62.45%, 3.93 mm day^{-1} and 907 mm year^{-1}, respectively (Egerton University Meteorological Station, 2000). The soil pH (H_2O) and (0.01M $CaCl_2$) at 0-30 cm depth was 6.26 and 5.37, respectively. The soil texture was clay loam (40% clay, 31% silt and 29% sand).

Experimental design and treatments: The experimental design was split-plot in randomized complete block replicated three times. The main plot factor was irrigation schedule, which consisted of irrigations on daily basis and after every two and three days, respectively. Sub-plots were made of mulching materials, which consisted of no mulch clear (transparent), plastic mulch (0.014 mm thick) and dry grass. The main grass was *Hyperrhenia spp*. Individual sub-plots measuring 1.6 m wide and 3.2 m long were planted with 'Money Maker' indeterminate tomato seedlings spaced at 50 cm between rows by 40 cm within rows. There were four rows per sub-plot and each row had nine plants (36 plants per plot). Paths measuring 0.5 m separated the sub-plots. Two outer rows formed guard rows while the two inner rows were used for data collection. A path measuring 1.0 m wide separated two main plots. Polyethylene sheet was buried at 60 cm to prevent water flow from other plots.

The plants were irrigated uniformly in the first 21 days after transplanting to ensure proper take-off of the transplants. Irrigation treatments then followed. The water application rate ranged from 1 liter for young (non-flowering) plants to 2 liters for older (flowering and fruiting) plants per day (Liu and Nyalala, 2002). The water discharge rate from each emitter was 4 l h^{-1}. The irrigation-time to supply two liters of water per plant for daily, two and three days schedule was 56 min, 1 h and 52 min and 2 h 48 min, respectively.

Nursery establishment and operations: The potting media was prepared by mixing topsoil with well rotten pig manure in the ratio of 2:1 (v/v). The mixture was filled to plastic pots measuring 9 cm and 5cm in diameter at the top and bottom, respectively with a hole at the bottom. Two seeds of tomato, 'Money Maker' were directly sown in pots at about 2 cm depth within the plastic tunnel. Two seeds were sown to guard against failure of seedling emergence. The seedlings were later thinned to one at two weeks from emergence. The pots were watered thoroughly using a watering can with a fine rose. Adequate water was provided on daily basis immediately after sunset for three weeks. Thereafter, water application frequency was gradually reduced to once every two days to harden the seedlings in readiness for transplanting. Weeds were spotted and carefully pulled out of the pots.

Cultural practices: Greenhouse soil was cultivated to a fine tilth and leveled. Well-decomposed pig manure was uniformly applied on the soil surface at the rate of 10 t ha^{-1} (1 kg m^{-2}) and worked into the soil to a depth of 15 cm to allow exploitation by shallow roots of tomato seedlings at transplanting (Oikeh and Asiegbu, 1992). Pig manure was used because it has been shown to have adequate nitrogen content (Oikeh and Asiegbu, 1992) and was more available than poultry manure. Phosphorus in the form of Diammonium phosphate (DAP 18:46:0) was evenly broadcasted on soil surface at 123 kg P ha^{-1} and incorporated into the soil to a depth of 15 cm to improve phosphorus uptake (Thompson and Doerge, 1995).

Planting beds, raised 0.15 m above the ground were made in each main plot prior to transplanting. The beds were leveled using a rake. Inflatable plastic drip tapes with emitters spaced 0.33 m apart were placed at the centre of each row so that each Dripline irrigated two rows. Mulching materials were randomly applied as per the treatment combinations. The clear plastic mulch (gauge 0.014 mm) was tightly spread on the bed and each edge firmly covered with 20 cm of soil after laying out the drip lines. Openings for planting holes 10 cm in diameter spaced at 0.5 m between the rows and 0.4 m within the rows (between plants) were made on the clear plastic mulch using a razor blade. The planting holes were then made using a wooden peg 10 cm in diameter. The dry grass mulch was applied at a thickness of 8 cm to cover 100% of the sub-plot immediately after transplanting.

Transplanting was done on the fourth week after sowing when the seedlings had attained 4 to 6 true leaves (Liu and Nyalala, 2002). Transplanting was carried out on 29th/9/2001 and 25th/4/2002 for experiments 1 and 2, respectively. Only healthy, vigorous and normal seedlings were selected and transplanted.

Poles 2.8 m were fixed 4 m apart and 2.2 m high supported the wires stretched horizontally at 0.3 m and 2.2 m above the ground. Sisal twines on which single stem of tomato plants were twisted joined the wires. Lateral shoots, senescing or diseased leaves were removed regularly by hand snapping as they appeared.

Tomato pests such as white fly, thrips, leaf miner, aphids, red spider and rousette mites found to be common in greenhouses were regularly controlled by application of broad spectrum pesticide, Brigade (Bifenthrin 25 g l^{-1}) at the rate of 2 ml l^{-1} of water after every two weeks. Tomato early and late blights were controlled by application of Ridomil (40 g kg^{-1} metaxyl-M + 640 g kg^{-1} mancozeb) at 40 g l^{-1} of water. Tomato plants that were severely attacked by bacterial wilt, were carefully uprooted and destroyed in both experiments.

Parameter assessments: To assess the effects of treatments on tomato crop the following parameters were determined:

Yield and its components: The number of trusses, flowers and fruits of plants that were selected for harvesting in each sub-plot were counted. The number of flowers and fruits of the first two trusses were counted. The percentage fruit set per truss of the first two trusses were calculated by dividing the number of fruits by that of flowers.

Tomato fruits with any externally detectable colour change (breaker stage) were considered mature and harvested. The tomato fruits were sorted into marketable and unmarketable (diseased, malformed, damaged by insect pests) categories. In experiment 1, harvesting was carried out from 12th December 2001 to 3rd February 2002. In experiment 2, harvesting commenced on 6th April 2002 and ended on 10th July 2002. Harvesting was carried out seven and eight times at weekly intervals in experiments 1 and 2, respectively. In experiment 1, harvesting was terminated earlier due to severe attack by tomato late blight disease.

Dry matter partitioning: Three randomly selected plants per sub-plot were assessed for dry matter partitioning at 68 days after transplanting when most trusses had formed fruits. The plant parts were separated into stem, leaves and fruits and weighed. The stem and leaf samples were put in brown paper bags and oven dried for four days at 70°C for four days. The fruit samples were cut into small pieces, spread out in single layers and dried at 70 °C for one week (Nyabundi and Hsiao, 1989). Oven dried samples were then weighed. Harvest index was calculated by dividing the fruit dry weight by total shoot (leaves, stems fruits and pruned plant parts) dry weight.

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

Total soluble solids: Total soluble solids of the juice from 50 randomly selected cherry-red ripe tomato fruits per sub-plot were measured using a hand refractometer (0-30° brix).

Data analysis: The data obtained was subjected to analysis of variance (ANOVA) and the treatment means separated by Least Significant Difference (LSD) or Duncan's Multiple Range Test (DMRT) at (P=0.05) using MSTATC computer software package (Michigan State University, 1993).

RESULTS

Significantly ($P \leq 0.05$) highest and lowest fresh fruit weight was attained with irrigation after every two days and no mulch and irrigation once every three days and clear plastic mulch, respectively (Table 1a).

Mulching material significantly ($P \leq 0.05$) influenced fruit dry weight. Dry grass mulch resulted in significant ($P \leq 0.05$) lowest fruit dry weight compared to bare soil and clear plastic mulch (Table 1b). Irrigation after every two days and grass mulch resulted into significantly ($P \leq 0.05$) lowest dry fruit weight while irrigation after every two days and no mulch produced the highest dry fruit weight (Table 1b).

Significantly ($P \leq 0.05$) highest harvest index was obtained from no mulch (Table 2). Irrigation schedule and mulching material significantly ($P \leq 0.05$) interacted to influence harvest index (Table 2). Significantly ($P \leq 0.05$) highest harvest index was obtained from daily irrigation and no mulch (Table 2). Clear plastic mulch significantly ($P \leq 0.05$) produced the highest fruit number (Tables 3). Clear plastic mulch and daily irrigation significantly ($P \leq 0.05$) produced the highest fruit number (Table 3).

Dry grass mulch had significantly ($P \leq 0.05$) highest individual fruit weight (Table 4). There was no significant ($P \leq 0.05$) interaction between drip irrigation and mulching material on mean fruit weight (Table 4). Daily irrigation

Table 1a: The effects of drip irrigation schedule and mulching materials on the fruit fresh weight per plant

	Irrigation schedule at intervals of			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	1556.00bc	2454.33a	1686.00bc	1432.11a
Dry grass	1684.00bc	1201.67c	1749.33bc	1545.00a
Clear plastic	1872.00ab	2086.67ab	1122.67c	1693.78a
Irrigation effects	92.00a	73.22a	84.22a	

Table 1b: The effects of drip irrigation schedule and mulching materials on tomato fruit dry weight

	Irrigation Schedule at intervals of			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	244.67bc	424.00a	298.67abc	322.45k
Dry grass	221.00bc	165.33c	244.33bc	210.29k
Clear plastic	328.33ab	422.67a	204.67bc	318.56k
Irrigation effects	264.67m	303.33m	249.22m	

Table 2: The influence of drip irrigation schedule and mulching materials on harvest indices of tomato

	Irrigation schedule			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	0.69abc	0.65ab	0.60abc	0.65g
Dry grass	0.54bc	0.48c	0.54bc	0.52k
Clear plastic	0.56ab	0.65ab	0.52bc	0.58k
Irrigation effects	0.60m	0.60m	0.56m	

Table 3: Effects of drip irrigation schedule and mulch materials on tomato fruit numbers

	Irrigation Schedule at intervals of			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	73.33bcd	86.00bcd	58.00cd	72.44n
Dry grass	47.68cd	70.33bcd	105.00b	74.44n
Clear plastic	155.00a	88.33bcd	96.33bc	113.22m
Irrigation effects	92.00k	81.56k	86.56k	

Table 4: Effects of drip irrigation schedule and mulching materials on marketable individual tomato fruit weight (g $fruit^{-1}$)

	Irrigation Schedule at intervals of			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	65.11a	67.83a	65.83a	66.25n
Dry grass	66.99a	69.68a	84.25a	73.64m
Clear plastic	64.76a	57.77a	65.22a	62.58n
Irrigation effects	65.62g	65.091g	71.77g	

Table 5: Effects of drip irrigation schedule and mulch materials on marketable tomato fruit yields (t ha^{-1})

	Drip irrigation schedule at intervals of			
Mulching materials	Daily	Two days	Thee days	Mulch effects
No mulch	67.29bc	75.12bc	87.38abc	69.27g
Dry grass	55.67c	70.68bc	100.25ab	75.53g
Clear plastic	115.15a	82.12abc	57.72c	92.55g
Irrigation effects	79.37k	76.20k	81.78k	

The means followed by same letters are not significantly different by row and columns for interactions (n = 9), by column for mulching effects (n = 3) and by row for irrigation effects (n = 3), Duncan Multiple Range Effects (p<0.05)

Table 6: Effects of drip irrigation schedule and mulch materials on tomato total soluble solids (°brix)

	Irrigation schedule			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	4.35	4.69	4.57	4.55ab
Dry Grass	4.32	4.42	4.14	4.29b
Clear Plastic	4.40	5.17	4.36	4.69a
Irrigation effects	4.40e	4.76e	4.35e	

The means followed by same letters are not significantly different by row and columns for interactions (n = 9), by column for mulching effects (n = 3) and by row for irrigation effects (n = 3), Duncan Multiple Range Effects (p<0.05). L.S.D. value for interaction effect is 0.18

Table 7: Effects of drip irrigation schedule and mulch materials on tomato fruit firmness (N) at day 2 after harvesting

	Irrigation schedule at intervals of			
Mulch materials	Daily	Two days	Three days	Mulch effects
No mulch	6.43ab	5.20bcde	6.07abc	5.90g
Dry grass	7.03a	4.07e	4.80de	5.30g
Clear plastic	5.03cde	5.50bcde	5.47bcde	5.30g
Irrigation effects	6.17k	4.92k	5.44k	

Mulch and irrigation effects were separated by columns and rows, respectively n=9. Interaction effects were separated by columns and rows using, n = 3. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P≤0.05)

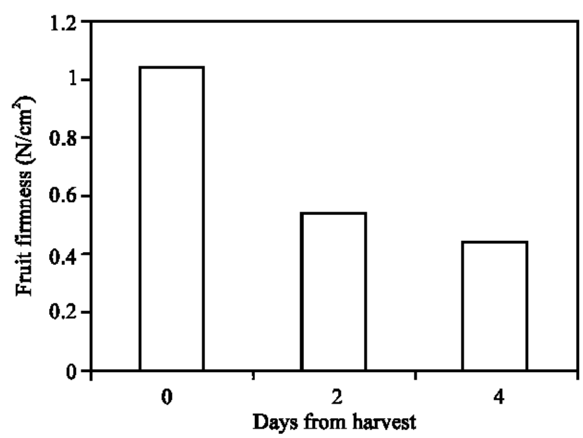

Fig. 1: The influence of days from harvest on the tomato firmness

and clear plastic mulch significantly (P≤0.05) produced the highest yield (Table 5).

Total soluble solids were highest in tomatoes mulched with clear plastic compared to dry grass mulch in both experiments (Table 6). There was no significant (P≤0.05) interaction between drip irrigation schedule and mulch type on total soluble solids in the two experiments (Table 6).

Daily irrigation and dry grass mulch had significantly (P≤0.05) highest fruit firmness at day two after harvesting (Table 7). The fruit firmness was significantly (P≤0.05) lowest with dry grass mulch with day 2 after harvesting (Table 7). Fruit firmness was generally highest and lowest at 0 and 4 days, respectively after harvesting (Fig. 1).

DISCUSSION

Effects of drip irrigation and mulching material on tomato yield and yield components: Higher tomato fruit yields under grass or clear plastic mulches may be partly due to low weed population, which resulted in reduced competition for nutrients and water (Shrivastava *et al*., 1994). The higher flower number with daily irrigation is due adequate moisture available to the flowers, which reduced flower abortion. This is in line with findings of Ramalan and Nwokeocha, (2000).

The high fruit number under clear plastic mulch led to increased fruit competition for assimilates and probably moisture, which reduced fruit expansion hence, low individual fruit weight. This shows that clear plastic mulch only increases tomato yield by increasing tomato fruit number but not individual tomato fruit weight. Clear plastic mulch probably increased salinity build up around the plant rhizosphere due to maintained higher soil temperature (Gupta and Achrya, 1993), which increased transpiration rate compared to dry grass mulch. The high soil electrical conductivity might have reduced the rate of fruit growth by reducing water flow into the fruit and consequent reduced fruit expansion under clear plastic mulch (Mitchell *et a*l., 1991; Dorais *et al*., 2001). However, Sweeney *et al.* (1987) reported higher tomato yield with black plastic mulch under field conditions. The variation of the findings can be associated with plant protection system used, the colour of polyethylene mulch and soil type. The high relative humidity within the greenhouse reduces consumptive water use as evaporation demand is decreased (Sweeney *et al*., 1987). Humidity within the greenhouse might have confounded the effect of mulching on tomato yield in the greenhouse (Perry and Sanders, 1986).

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

Effects of drip irrigation schedule and mulching materials on quality of tomato fruit: Lowest soluble solids obtained with dry grass mulch can be attributed to low soil water tension maintained by dry grass mulch, which led to higher water uptake and hence dilution of the concentration of the total soluble solids (Muller, 1993; Tan 1995). Delayed first 50 % flowering by dry grass mulch made fruiting to coincide with increased competition between vegetative and fruit growth for photosynthates. This might have lowered the amount of photosynthates partitioned to the fruit hence reduced concentration of total soluble solids in the ripe fruits (Mitchell *et al*., 1991).

The highest total soluble solids obtained from clear plastic can be associated with increased photosynthesis due to the plastic reflective properties, which increased light reception onto the leaves and fruits of tomatoes (Mathieu and Aure, 2000). The reflection of more light onto the tomato shoot by clear plastic is known to increase transpiration rate, amount of photosynthesis available to fruits and sugar: acid ratio (Dorais *et al*., 2001) and hence the higher brix value of tomato fruits. Also the high rate of transpiration and high temperature below plastic mulch may cause localized soil salinity build-up (Dorais *et al*., 2001). This stimulated starch accumulation in the mature tomato fruits leading to sucrose unloading into the developing fruits, which were hydrolyzed on maturation into soluble hexoses thereby increasing total soluble solids contents (Dorais *et al*., 2001).

Plastic mulches concentrate carbon dioxide around the plant canopy as the planting holes acts as vents for carbon dioxide escaping from beneath the mulch (Sanders, 2000). This relatively elevated carbon dioxide concentration might have accounted for the increased total soluble solids.

Higher fruit firmness realised with clear plastic mulch may be due to thicker flesh of the fruits as reflected by high dry matter content. Falluji *et al.* (1982) reported that fruit firmness is strongly influenced by tomato fruit flesh tissues. Also, it can be suggested that the high firmness of tomato fruit immediately after harvesting is due to skin strength, which weakens upon ripening and senescence.

In conclusion, irrigation of up to three days interval does not affect yield and quality of greenhouse fresh market tomato if the water application rate is uniform. Clear plastic mulch enhances tomato fruit total soluble solids while dry grass mulch reduces it. Irrigation schedule interacts with mulch type to influence yield and quality of greenhouse tomato.

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