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Effect of planting systems and mulching on soil hydrothermal regime, plant physiology, yield and water use efficiency in tomato

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ABSTRACT

A two year study was conducted to determine the response of a tomato crop to three planting systems and three mulch materials. Results indicated that planting systems significantly influenced the soil moisture regimes; weed growth and water use efficiency but did not affect the yield and other parameters. Mulch materials significantly influenced the hydrothermal regime of soil, physiological traits, yield and water use efficiency. Black polythene and paddy straw mulch have significantly higher soil water tensions (-56.6 to -38.4 kPa) and moisture in soil profile (15.1-18.4%). The maximum leaf area (0.426 m^2/plant), specific leaf area (8.47 mg/cm^2), fruit yield (400.08 q/ha) and water use efficiency (96.58 kg/ha-mm) were obtained under paddy straw mulch. The lowest dry weed biomass (5.5 g/m^2) was recorded under black polythene. Black polythene, transparent polythene and paddy straw mulch saved 17, 11.3 and 15.4% water than unmulched control. Furrow irrigated raised bed saved about 36% water over flat bed planting. As for as the interaction of planting system and mulch is concerned, the maximum dry matter production (231.03 g/plant), fruit yield (449.36 q/ha) and water use efficiency (143.57 kg/ha-mm) was noticed under raised bed planting coupled with paddy straw mulching. This combination also saved about 49% water with 55% higher yield over absolute control.

Key words: Tomato, planting system, mulch, hydro-thermal regime, chlorophyll fluorescence, water use efficiency.

INTRODUCTION

Tomato is one of the important commercial vegetable crops grown in India. The field irrigation requirement of tomato is moderately high in Indo-Gangetic plains (about 550-600 mm), while the crop evapo-transpiration demand is about 250-270 mm. Agriculture is by far the leading user of freshwater worldwide, accounting for almost 85% of global consumption. Scarcity of water resources and competition for water in many sectors reduce its availability for agricultural use. Considering water scarcity more intense in future, the planning and management of this resource for its optimal, economic and judicious use has become very important for sustaining its availability for agricultural use. Raised bed planting (RBP), in which water is supplied in furrows and crops are raised on elevated bed, offers better opportunity to the farmers for managing water resources more efficiently. The benefits of the raised bed-planting system with furrow irrigation includes water savings (up to 30%) combined with enhanced water use efficiency, improvement in soil physical status and nitrogen use efficiency, better utilization of sunlight, low crop-weed competition and enhancement in yield (Zhang *et al*., 12; Kumar *et al*., 7).

Organic (plant materials) and synthetic mulches (plastic of different colours) are widely used in vegetable production for their efficacy to conserve soil moisture by altering water distribution between soil evaporation and plant transpiration, and modifying soil temperature. By creating a barrier between soil surface and adjacent atmosphere, mulching minimizes the evaporation loss from soil surface and thus utilizes the conserved water for higher transpiration and improves yield and WUE of tomato (Ramalan and Nwokeocha, 10; Bahadur *et al*., 2; Mukherjee *et al*., 8). The present investigation aimed to study the effect of various planting systems used for vegetable production and mulch materials on hydrothermal regime of soil, plant physiology, productivity and water use efficiency in tomato.

MATERIALS AND METHODS

A field experiment was conducted in split-plot design during October to March 2007-08 and 2008-09, where three planting patterns (ridge and furrow-RF, raise bed-RB and flat bed-FB) were kept in the main plots and four mulch managements (black polythene-BP, transparent polythene-TP, paddy straw-PS and no mulch-MO) were allotted in subplots. Each treatment combination was replicated thrice. In RF planting, the ridge of 30 cm high was made at 70 cm apart and crop row was irrigated from both sides. In RB planting, bed of 20 cm height, 90 cm wide with 50 cm wide furrows at both sides were made. Crop was transplanted on both sides of the bed, leaving 10 cm each side.

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For both, BP and TP, plastic films of 25 μ thickness were used. A well-dried paddy straw @ 7.5 tonnes/ha was used as organic mulch. Total 11 irrigations were applied uniformly in all treatments at about 12 days intervals. Fertilizers were applied @ 120 kg N, 60 kg each of P_2O_5 and K_2O along with 20 tonnes of farmyard manure per hectare to meet the nutritional requirement of crop. The soil of experimental plot was sandy loam with pH 6.8, EC 0.43 dS/m, organic carbon 0.39% and available N, P and K as 258, 20.5 and 250 kg/ ha, respectively. Moisture content (30 cm depth) at 0.33 bars (field capacity) and at 15 bars (wilting point) was 22.6 and 6.1%, respectively, whereas, the bulk density of the soil was 1.53 g/cm^3.

Soil water potential and soil temperature were monitored continuously at every 4 h with automatic tensiometer-cum-temperature probes. However, the graph depicted in Fig. 2 represents the average values recorded at mid-day just before each of the irrigation. Both these parameters were recorded at 15 and 30 cm depths. Soil water content (SWC) was determined by Gopher (Soil Moisture Technology, Queensland, Australia) to a depth of 10-60 cm before irrigation. The relative water content (RWC) was determined using the upper third-fourth leaves during mid-day before irrigation.

The leaf area was measured with portable area meter Li-3000 A (LiCOR Inc., Nebraska, USA). Specific leaf area (SLA) was estimated as the ratio of the leaf area and dry weight of the leaf. Chlorophyll content index (CCI) of leaf was measured with the CCM-200 Portable Chlorophyll Meter (Opti-Sciences, Tyngsboro, MA) at the ratio of 655/940 nm. Leaf fluorescence was measured from Plant Efficiency Analyzer (Hansatech Instrument Co. Norfolk, UK). The minimal fluorescence (Fo), maximum fluorescence (Fm) and the ratio of variable fluorescence (Fv = Fm - Fo) to maximum fluorescence (Fv/Fm) were recorded at the adaxial surface of top third leaf adopted for 30 min. in dark. Relative leaf water content (RWC) was measured as per method suggested by Barrs and Weatherley (4). All physiological measurements were taken on fully expanded leaves, second to fourth from the top just before irrigation at active growth stage. Dry matter production and partitioning was measured at 75 days after transplanting by oven drying of leaves, stems, roots and fruits at 108°C for 24 h. Weeds of 1 x 1 m^2 area in each replication were removed and oven dried until constant weight to get dry weed biomass per unit area. Water use efficiency (WUE) was calculated as fruit yield divided by total water applied.

RESULTS AND DISCUSSION

It is clear from Fig. 1 that mulches caused significant change in soil water potential and soil temperature.

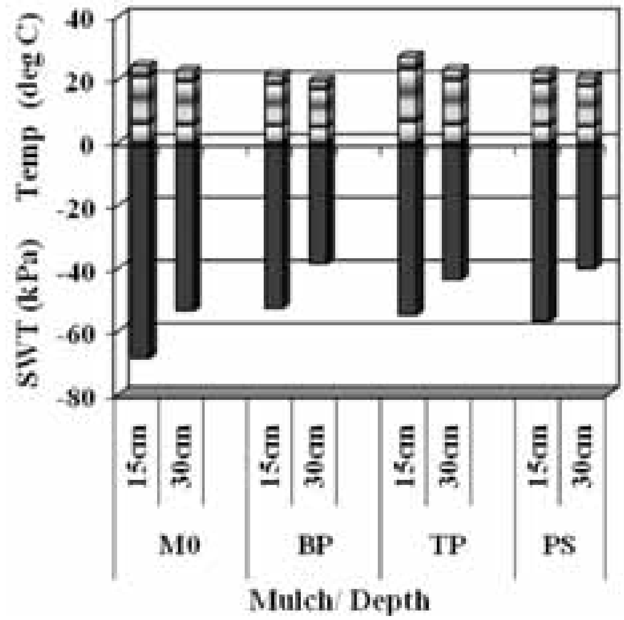

Fig. 1. Effect of mulch on soil water potentials and soil temperatures.

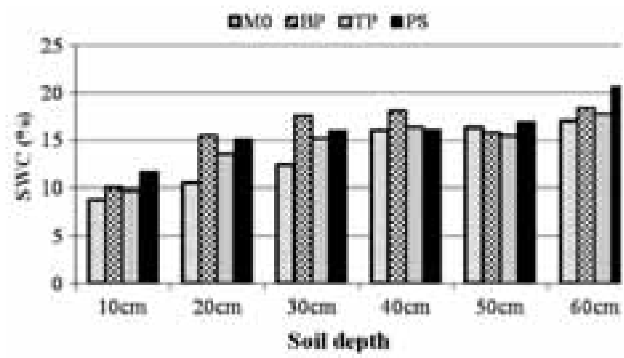

Fig. 2. Effect of mulch on soil water content at various soil depths.

The maximum increase in soil temperature at noon was observed under TP, particularly at 15 cm depth, which expressed about 3°C higher temperature than 'no mulch' at similar depth. Soil temperature recorded at 15 and 30 cm depth did not show any variation with different planting systems, and it ranged from 23.1 to 23.9°C at 15 cm depth and 21.4 to 21.6°C at 30 cm depth. In correspondence to our findings, Moreno and Moreno (9) also observed 5.5-6.9°C increase in soil temperature up to 10 cm depth in tomato crop with use of biodegradable or polythene mulch. Relatively higher mid-day temperature under transparent polythene was due to fact that the incoming solar radiations easily pass through the transparent polythene and trap the longer wavelengths re-radiating from soil, thereby warming the soil underneath. On the other hand, the maximum soil water tension (SWT) before irrigation was observed under BP followed by PS mulch. These two mulches maintained SWT around or more than -40 kPa at 30 cm depth, where most of the active roots confined. In contrast to this, the SWT under 'no mulch' was remarkably lower (more negative), *i.e.*, -68.5 and -53.4 kPa, respectively at 15 and 30 cm depth. Among the planting systems, FB had significantly higher SWC (12.6%) at 30 cm depth. Similar to our findings, Kumar *et al.* (7) also recorded low soil moisture under raised bed than flat bed planting. This might be due to rapid drying of raised beds in comparison to flat bed, which resulted into higher soil moisture content in latter. However, in contrast to these findings, under similar environmental conditions, Aggarwal *et al*. (1) observed higher soil water content in 0 to 20 cm layer in wheat sown on raised bed than the conventional flat planting. Soil water content at various depths also varied considerably under different mulch materials (Fig. 2). At 10 cm depth, the maximum soil water before irrigation was recorded under PS (11.6%), whereas, from 20-40 cm depth, it was recorded maximum under BP, and at 50 and 60 cm depth, it registered maximum under PS. Under mulch condition there was very less weed growth and evaporational loss of water reduced to a notable extent. These two conditions helped in maintaining higher moisture content in the root zone, which enhanced both transpiration rate and nutrient uptake by the roots (Mukherjee *et al*., 8). The interaction of planting systems and mulch was also found highly significant. The maximum soil water content at 30 cm depth was recorded under flat bed planting combined with black polythene (14.2%) followed by FBTP (13.8%). The minimum soil water content was observed under RFM_0 (8.1%).

Planting systems did not affect the leaf area and specific leaf area (SLA) in present study, whereas, the mulching materials had significant effects. The maximum leaf area (0.407 and 0.426 m^2/plant) and SLA (8.26 and 8.47 mg/cm^2) were found under BP and PS mulch. Most of the interactions wherein mulches had been included showed significantly higher leaf area and SLA. Mulching avoids the fluctuation in temperature in upper 20-30 cm soil depth and maintains optimum soil moisture. These conditions favour the root proliferation and nutrient uptake, which might have contributed for better foliage growth. Earlier, Bahadur *et al*. (2) also noticed higher leaf area in tomato with use of black polythene mulch. Kar and Kumar (5) observed 21-35% more leaf area index (LAI) in potato with the use of paddy straw mulch, whereas Mukherjee *et al*. (8) recorded 36-63% increase of LAI in tomato with plastic or paddy straw mulch. The relative water content (RWC) in leaves was influenced significantly by the mulch. All types of mulch used in study retained significantly higher RWC (83.2-83.7%) in leaves. Since mulches retained relatively higher soil moisture content in effective rhizospheres (Table 1), thereby, it was reflected as higher RWC in leaves.

Chlorophyll is one of the major chloroplast components for photosynthesis, and relative higher chlorophyll content (stay green) had a positive relationship with photosynthesis (Shangguan *et al*., 11). The chlorophyll content index (CCI) of leaves was unaffected with planting system. However, significantly higher values for CCI were observed under BP or PS, irrespective of planting systems. Chlorophyll fluorescence represents the photochemical efficiency of photosystem II (PS II) estimated from variable to maximal fluorescence (Fv/Fm). The photochemical efficiency of PS II (Fv/Fm) was not affected by the planting systems; however, Kong *et al*. (6) have noticed greater leaf photosynthetic capacity, photosynthetic efficiency of PS II and actual quantum yield of photochemical processes in wheat under furrow irrigated raised bed planting. Chlorophyll fluorescence significantly varied under various kind of mulch and interaction of planting system and mulch. The maximum efficiency of PS II was observed under BP (Fv/Fm = 0.79) and PS mulch (Fv/Fm = 0.78). So for interaction is concerned, significantly higher Fv/Fm was noticed under RFBP (0.785), RBBP (0.791), FBBP (0.783) and FBPS (0.788). These treatments also showed relatively higher minimal fluorescence (Fo) and lower maximum fluorescence (Fm) as compared to unmulched control (Fig. 3). Similar to present findings, earlier Bahadur *et al*. (2) observed significant increase in CCI, photochemical efficiency of PS II and yield in tomato with the use of black polythene. Furthermore, Bahadur *et al*. (3) also noticed significant increase in physiological traits such as photosynthetic rates, stomatal conductance, RWC and water use efficiency in spring-summer okra with the use of pea straw mulch. An optimum soil moisture and hydrothermal soil regime with relatively higher RWC and leaf water potentials might have contributed for improved physiological attributes of plant under mulched conditions.

Both, RF and RB planting systems had significantly less weeds biomass than flat bed but RB planting had maximum reduction in weed biomass (20% less than flat bed) because in this system water was applied in furrows only and rest of the areas were always dry which did not permit much growth of weeds. Mulching significantly suppressed the weeds. The least weed biomass was observed under black polythene (5.5 g/m^2) followed by paddy straw (33.6 g/m^2). These

Table 1. Effect of planting system and mulch on growth, physiological and yield parameters in tomato.

Treatment	RWC (%)	Leaf area/ plant (m^2)	SLA (mg/cm^2)	FV/ Fm	SWC (%)	Weed (dw g/m^2)	Fruits/ plant (no.)	Yield (kg/plant)	Yield (q/ha)
Planting system (PS)									
Ridge & furrow (RF)	81.7	0.388	7.54	0.74	10.2	61.3	47.9	3.55	339.28
Raised bed (RB)	82.5	0.392	7.44	0.73	11.2	56.3	46.3	3.63	369.86
Flat bed (FB)	83.8	0.391	7.94	0.72	12.6	70.6	50.3	3.60	337.71
S_E (N = 12)	0.19	0.06	0.146	0.04	0.12	2.26	2.91	0.62	14.47
CD (P = 0.05)	ns*	ns	ns	ns	0.48	8.85	ns	ns	ns
Mulch (M)									
No mulch (M_0)	80.1	0.340	6.21	0.65	8.9	150.3	38.4	2.97	298.06
Black polythene (BP)	83.6	0.407	8.26	0.79	12.7	5.5	48.5	3.55	363.36
Transparent polythene (TP)	83.2	0.399	7.64	0.71	11.9	57.6	53.7	3.87	337.30
Paddy straw (PS)	83.7	0.426	8.47	0.78	11.8	33.6	52.1	3.97	400.08
CD (P = 0.05)	1.76	0.062	0.54	0.06	0.52	10.40	6.40	0.38	35.67
PS × M	ns	s	s	s	s	s	ns	s	s

Abbreviations used: RWC = relative leaf water content; SLA = specific leaf area; Fv/Fm = photochemical efficiency of PS II; SWC = soil water content; CCI = chlorophyll content index.

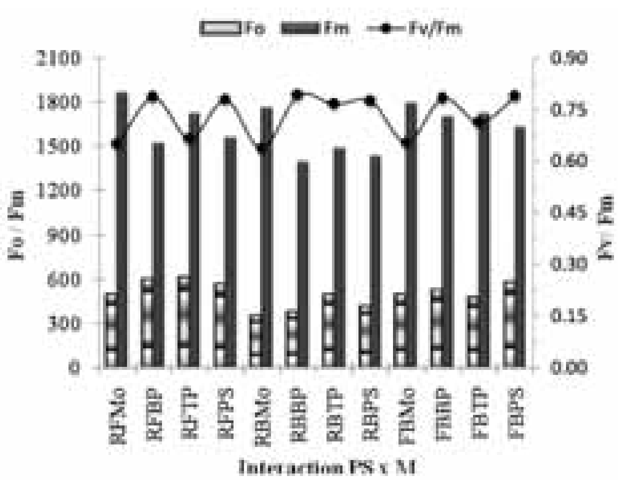

Fig. 3. Effect of planting system and mulch on chlorophyll fluorescence.

two mulch materials noticed around 96 and 78% less weed biomass than 'no mulch'. In interactions, the least weed biomass was noticed under flat bed planting coupled with black polythene mulch (4.70 ± 6.1 g/m²). Similarly, Bahadur *et al.* (2) also observed 89% reduction in weed growth in tomato with the use of black polythene mulch under drip irrigation system. The restricted weed growth under black polythene and paddy straw mulch might be due to poor light penetration beneath the mulch. In addition, black polythene had ability to reflect about 90% of the incident solar radiations, thereby very less weed growth.

Results obtained on biomass production and its allocation in different plant parts indicated that raised bed planting produced maximum dry matter (208.04 g/plant) followed by flat bed (data not given). Among the mulch materials, paddy straw produced the maximum total dry matter (208.17 g/plant) followed by transparent polythene. It is obvious from the Fig. 4 that the maximum total dry matter (231.03 g/plant) was obtained under treatment RBPS. In treatment RBPS, the biomass was also proportionately allocated in various plant parts (36.5% in leaf, 18.2% in stem, 4.2% in roots and 41.1% in fruit). The carbohydrates accumulated in leaves and stems during early growth stage were efficiently translocated to the sink (developing fruits) in the later stage, thereby an optimum biomass partitioning in various plant parts and maximum dry matter production was reflected in RBPS.

Fruit yield including number of fruits per plant was not influenced under different planting systems. However, the mulching materials significantly influenced the yield traits. Under all three mulches, higher number of fruits per plant was noticed. Interaction of planting system and mulch was not significant for the number of fruits per plant. With regard to fruit yield is concerned, the maximum and significantly higher fruit yield (4.14 kg/plant and 400.08

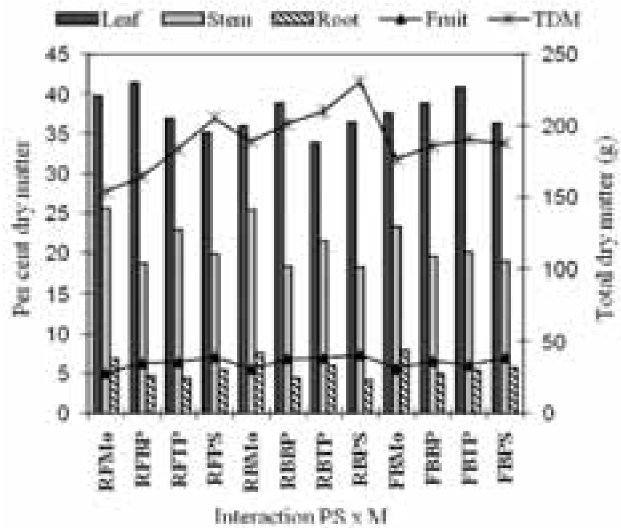

Fig. 4. Effect of planting system and mulch on dry matter production and distribution.

q/ha) was recorded under PS mulch. Significantly higher fruit yield over 'no mulch' was also found in BP and TP mulches, however, these two mulching materials noticed yield *at par* with one another. Earlier, Kar and Kumar (5) also reported that paddy straw mulch increased the potato tuber production by 24-42% in the different irrigation regimes, whereas, Mukherjee *et al*. (8) recorded significantly higher yield in tomato with use of black polythene mulch than the paddy straw mulch. Higher tomato fruit yield under mulches might be partly due to low weed population, causing a reduction in competition for nutrient and water and partly for a better water availability due to moisture conservation by mulching. Raised bed planting coupled with paddy straw mulching (RBPS) gave maximum fruit yield (449.36 ± 20.80 q/ha), and an increase of 55% yield over absolute control (FBM_0) was noticed under this treatment combination (Table 2). Similar to our findings, Ramalan and Nwokeocha (10) also reported that the interaction of furrow irrigation and paddy straw mulch had significant effect on marketable fruit yield and on water use efficiency of tomato. The differences in plant growth and yield in the present study are the results of the several favourable edaphic, plant growth, physiological and yield factors due to planting system and mulch. Modification of soil microclimate, availability of sufficient soil moisture, better nutrients uptake and less crop-weed competition for water and nutrients under mulch coupled with better soil aeration and light interception in raised bed planting have contributed for improved plant growth and yield.

Planting system and mulch had significant impact on water savings and water use efficiency (WUE). Under ridge & furrow and raised bed planting systems, about 15 and 36% water saving, respectively was noticed over flat bed planting (Table 3). There was 17, 11.3 and 15.4% water saving, respectively under BP, TP and PS mulch than 'no mulch'. It is noteworthy that the raised bed planting combined with paddy straw mulch (RBPS) had the maximum water saving (49%). However, considerable water saving over FBM_0 was also recorded under RBBP (42.4%) or RBTP

Table 2. Interaction effect of planting system and mulch on growth, physiological and yield parameters in tomato.

Interaction	Leaf area/ plant (m^2)	SLA (mg/cm^2)	CCI	Weed (g/m^2)	SWC (%)	Yield/plant (kg)	Yield (q/ha)
RFM_0	0.348	5.85	35.1	137.33	8.1	2.87	308.89
RFBP	0.404	7.88	47.3	6.30	12.1	3.58	348.70
RFTP	0.396	8.38	40.1	65.27	10.8	3.82	324.60
RFPS	0.405	8.07	47.0	36.43	9.9	3.94	374.95
RBM_0	0.345	6.01	38.1	127.00	8.8	2.98	295.40
RBBP	0.419	8.14	45.8	5.53	11.9	3.46	382.76
RBTP	0.388	7.24	43.7	63.43	11.3	3.95	351.90
RBPS	0.415	8.37	46.3	29.43	12.8	4.17	449.36
FBM_0	0.327	6.75	37.7	186.67	9.8	3.08	289.90
FBBP	0.396	8.77	40.4	4.70	14.2	3.62	358.63
FBTP	0.412	7.28	43.8	44.17	13.8	3.84	326.38
FBPS	0.428	8.97	44.2	34.93	12.7	3.87	375.94
CD (P = 0.05)	0.050	0.94	7.13	18.09	0.91	0.65	61.79

Table 3. Water use and water use efficiency under different treatments.

PS/Mulch	Water used (mm)					Water use efficiency (kg/ha-mm)				
	M_0	BP	TP	PS	Mean	M_0	BP	TP	PS	Mean
RF	569	432	459	478	485	54.28	80.72	70.72	78.44	71.04
RB	409	354	377	313	363	72.22	108.12	93.34	143.57	104.31
FB	615	533	578	555	570	47.14	67.29	56.47	67.74	59.66
Mean	531	440	471	449		57.88	85.37	75.31	96.58	

(38.7%). Among the planting systems, the maximum WUE of 104.31 kg/ha-mm was achieved under RB planting, whereas, among the mulching materials, PS had registered the maximum WUE (96.58 kg/ha-mm). The treatment combination RBPS obtained the highest WUE (145.57 kg/ha-mm) followed by RBBP (108.12 kg/ha-mm). It is well-established fact that mulch (organic or plastic ones) is known to conserve soil moisture due to curtailing soil evaporation and retaining more moisture in the soil profile. Therefore, the higher water saving and water use efficiency were achieved under raised bed planting system and mulch alone or in their combinations. Earlier, Zhang *et al*. (12) also noticed higher WUE and water saving (20.2%) in wheat under FIRB than the flat planting.

It can be concluded from present study that tomato planted over furrow irrigated raised bed and mulched with either paddy straw or black polythene is the better technological option for improving crop as well water productivity.

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