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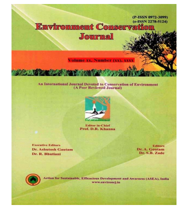

Efficacy of different agro-techniques on growth, yield and disease incidence on tomato (*Solanum lycopersicum* l.) crop of north western Himalayan region

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ABSTRACT

A field experiment was conducted during 2 consecutive years (2017-18 and 2018-19)with 12 treatment combinations at Vegetable Research Farm, Nauni, Solan with an objective to study the effects of different planting methods, mulches and training systems on flowering, fruiting, yield and incidence of diseases of tomato (*Solanum Lycopsersicum* L.) var. *Solan Lalima.* Plants grown on raised beds had minimum incidence of buckeye rot (4.19%), severity of *Alternaria* leaf blight (3.80%), incidence of bacterial leaf spot (2.38%) and incidence of *Fusarium* wilt (3.45%) and higher yield per plot (127.57 kg) and per hectare (899.96 q). Black polythene mulch responded best for lower incidence of buckeye rot (4.45%), severity of *Alternaria* leaf blight (4.01%), incidence of bacterial leaf spot (2.47%) and incidence of *Fusarium* wilt (3.62%) and higher yield per plot (129.42 kg) and per hectare (913.05 q), respectively. T_1 also recorded lower incidence of buckeye rot (4.09%), severity of *Alternaria* leaf blight (3.67%), incidence of bacterial leaf spot (2.33%) and incidence of *Fusarium* wilt (3.36%) and higher yield per plot (46.46 kg) and per hectare (327.74 q). Regarding consortium effect, the minimum incidence of buckeye rot (3.46%), severity of *Alternaria* leaf blight (2.80%), incidence of bacterial leaf spot (1.84%) and incidence of *Fusarium* wilt (2.60%) disease was recorded in $P_1M_1T_1$ treatment combination (raised bed + black polythene mulch + two stem training system). This combination was also better for all the growth and yield contributing characters.

Introduction

Tomatoes are one of the most extensively farmed crops in Himachal Pradesh, both in sheltered and open fields. Tomato fruits from open field conditions are designated for a direct consumption, as well as for processing industry (Sowinska and Turczuk, 2018). Both fresh fruits and tomato preserves have great biological value, including their antioxidant properties and popular salad vegetable which is taken with great relish (Toor *et al*., 2005). Tomato is a valuable source of nutrients, minerals, carotenoids, lycopene, vitamins particularly E and C, which prevents from cancerous and various circulatory system diseases (Pavlovic *et al*., 2017). According to Pavlovic *et al*. (2017) the biological values depends on various factors one amongst them is agro technical factor which comprises of various cultivation practices.

Inspite of wide cultivation of tomato, the average yield is rather low because little attention is paid towards scientific methods of production. The use of herbicides and other chemicals in agriculture are becoming limited, because of their expense and environment issues which have recently caused much concern. Therefore, new approaches to control weeds, insect-pests, diseases and improve yield are necessary both for assuring an adequate

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crop yield and for respecting the environment. Sustainable management practices, such as raised bed planting methods, mulching applications and suitable training systems can improve crop conditions, soil fertility and environmental conditions too. Tomato is an important off-season vegetable crop of Himachal Pradesh. The state is a key provider of fresh market tomatoes to the plains, while high temperatures and constant rains hinder output in such locations during the wet season. Thus, tomatoes from the hills find a ready market in the northern plains since they are often planted as a summer and rainy season crop, delivering lucrative returns to hill farmers. Himachal Pradesh produces 502.42 metric tonnes of tomato every year from an area of 11.75 thousand acres (Anonymous, 2018). Despite their economic importance, producers are unable to produce high-quality tomatoes with high productivity due to a variety of biotic (pests and illnesses), abiotic (rainfall, temperature, relative humidity, and light intensity) and agricultural variables that impede vegetable production. As a result, there is an urgent need to enhance tomato productivity and output in both the country and the state. Weed suppression, reduced insect pest infestation and improved yield because of useful micro-organisms activity have become suitable cause for sustainable crop production.

Raised beds are commonly used to improve soil warming and drainage and to decrease the disease incidence also (Locher *et al*., 2003). Raised bed planting for solanaceous crops in many parts of the world is gaining importance (Sayre, 2007). It can save 25-30% irrigation water, increasing water use efficiency (Hassan *et al*., 2005; Malik *et al*., 2005; Choudhary *et al*., 2008; Ahmad *et al*., 2009) and providing better opportunities to leach salts from the furrows (Bakker *et al*., 2010).

Sometimes, many of the farmers can't able to provide irrigation due to unavailability of irrigation facilities or even can't afford the expenses of irrigation. Under this situation mulching could be a good substitute means for irrigation to make soil moisture available. Mulching has been reported to be increased yield by creating favorable soil temperature and moisture regimes (Ma and Han, 1995). Plastic mulches are used in many agricultural crops to suppress weed growth, conserve soil moisture, and alter soil and air temperature (microclimatic modifications) in the rhizosphere under both protected and open conditions (Abhivyakti *et al.,* 2016), by modifying the surface's radiation budget (absorbitivity vs. reflectivity) and decreasing soil water loss, which increases crop yield and quality. According to Prakash *et al.* 2016, mulching may be utilized to tackle the problem of weed infestation, it increases microbial activity in soil by improving soil characteristics, and it reduces the need for nitrogen fertilizer. It is widely accessible and reasonably priced on the market.

Training maximizes the plant's ability to obtain the sunlight needed for growth and development (Gou *et al*., 1991). Similarly, training and pruning at later phases of plant growth minimises competitors for sunlight and photosynthetic products among fruits. Staking is another key activity that is conducted to make training more effective, especially during the wet season, for enhancing quality, yield, and protecting the crop from assault by soil-borne diseases (Ansari et al., 2017). Furthermore, the typical staking approach causes plants to become more bushy, making it difficult to accommodate a greater number of plants per unit space. Patil et al. (1973) observed that indeterminate plants have excessive leaf burden and may be aggressively trimmed without reducing output. More plants may be accommodated per unit area with correct training, trimming, and staking, improving yields.

This study was conducted to determine the effects of planting systems (raised-bed, flat-bed), mulching types (black polythene mulch, silver/grey polythene mulch and no mulch)and training systems (two stem and three stem trained plants) on flowering, fruiting, yield and incidence of diseases on tomatoes grown in open field farming system.

Material and Methods

Field experiments to determine the effect of crop management practices on growth and yield attributing characters such as, days to 50 % flowering, number of flower clusters per plant, days to marketable maturity, number of fruits per plant, weight of the fruits, yield per plant, yield per hectare, plant height and leaf area index and various soil and air borne diseases of tomato like, incidence of buckeye rot (%), severity of *Alternaria* leaf blight (%), severity of bacterial leaf spot (%), incidence of *Fusarium* wilt (%) was conducted in randomized block design (factorial) during *Khraif* seasons (April to September) of 2017-18 and 2018-19 at the Research Farm, Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP. The experiment comprised of two planting methods *viz*., P_1 (raised bed planting method) and P_2 (flat bed planting method), three levels of mulch materials *viz*., M_1 (black polythene mulch), M_2 (silver/grey polythene mulch) and M_3 (no mulch) and two training levels *viz*., T_1 (two stem training system) and T_2 (three stem training system) (Table 1). Thus, there were 12 treatment combinations which were replicated thrice.

The beds were raised to the height of 15 cm above the ground level and two beds were separated by 45 cm distance. Tomato seedlings were transplanted on well prepared plots on April, 2017 and 2018 at a spacing of 90×30 cm in a plot having dimensions of 1.8 × 6.3 m, accommodating 42 plants of tomato per plot. Mulches of 50μ (200 gauge thickness) were applied in plots according to the treatment combinations. After that holes were made on the mulch as per the recommended spacing of the plants. The mulches were spread manually and holes of 5 cm diameter were made accordingly.

Table 1: Detail of treatments used in the studies

S. No.	Treatment code	Treatment details		
1	$P_I M_1 T_I$	Raised bed	+ Black mulch	+ Two stem training
2	$P_I M_1 T_2$	Raised bed	+ Black mulch	+ Three stem training
3	$P_I M_2 T_1$	Raised bed	+ Silver/black mulch	+ Two stem training
4	$P_I M_2 T_2$	Raised bed	+ Silver/black mulch	+ Three stem training
5	$P_I M_3 T_1$	Raised bed	+ No mulch	+ Two stem training
6	$P_I M_3 T_2$	Raised bed	+ No mulch	+ Three stem training
7	$P_2 M_1 T_I$	Flat bed	+ Black mulch	+ Two stem training
8	$P_2 M_1 T_2$	Flat bed	+ Black mulch	+ Three stem training
9	$P_2 M_2 T_1$	Flat bed	+ Silver/black mulch	+ Two stem training
10	$P_2 M_2 T_2$	Flat bed	+ Silver/black mulch	+ Three stem training
11	$P_2 M_3 T_1$	Flat bed	+ No mulch	+ Two stem training
12	$P_2 M_3 T_2$	Flat bed	+ No mulch	+ Three stem training

In this study, the tomato cultivar "Solan Lalima" was employed. This cultivar was released by the Department of Vegetable Science, Dr YSP UHF Nauni, Solan. Tomato cultivar 'Solan Lalima' was used for the present study. It bears medium sized and round shaped fruits of deep red colour having TSS 4-5 ^{0}Brix. It is a self-pollinated indeterminate variety developed by selection. After transplanting, the crop is ready for the first plucking around 70-80 days. The typical fruit weight is 70-80 g, with a yield of 75-85 t/ha. This variety has received a tremendous response from the tomato growing farmers of the state being a very popular variety well suited for the mid-hills of Himachal Pradesh. All cultural activities and plant protection measures were implemented in order to maintain a homogenous plant population and optimal circumstances for plant growth and development. The seeds of 'Solan Lalima' were procured from the Seed Sale Counter of the Directorate of Extension Education, Dr YSP UHF, Nauni, Solan.

The leaf area index (LAI) was calculated after the third harvest of the fruits. The leaf area of the selected leaves on these plants was recorded using Area measurement system MK-2 (Delta-T Device Ltd. Burwell, Cambridge, England) as suggested by Redford (1967) here.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Incidence of buckeye rot (%)

The incidence of Buckeye rot was recorded as per cent of infected fruits in ten randomly marked plants at each harvest and average incidence was worked out with the following derivation.

$$\text{Incidence of Buckeye rot (\%)} = \frac{\text{Number of infected fruits per plot}}{\text{Total number of fruits per plot}} \times 100$$

Severity of *Alternaria* leaf blight (%)
In order to record the occurrence of the disease, observations were recorded periodically. The leaf blight severity in different treatments was recorded as per the scale given by Shekhawat and Chakarvarti (1974) as shown in Table 2:
The disease severity was worked out according to Mckinney (1923) as given below:

$$\text{Disease severity (\%)} = \frac{\textit{sum of all the disease ratings}}{\textit{Total number of ratings} \times \textit{maximum disease grade}} \times 100$$

Table 2: Scale used for recording severity of *Alternaria* leaf blight (%)

Grade	(%) Plant area infected by the disease	Category
0	0.00	Highly resistant
1	10.1-15.0	Resistant
2	15.1-30.0	Moderately resistant
3	30.1-50.0	Moderately susceptible
4	50.1-75.0	Susceptible
5	75.1 and above	Highly susceptible

Severity of bacterial leaf spot (%)
In order to record the occurrence of the disease, the observations were recorded periodically. The bacterial leaf spot severity in different treatments was recorded as per the scale given by Shekhawat and Chakarvarti (1976) mentioned in Table 3:
The disease severity was worked out according to Mckinney (1923) as given below:

$$\text{Disease severity (\%)} = \frac{\text{Sum of all the disease ratings}}{\text{Total number of ratings} \times \text{Maximum disease grade}} \times 100$$

Table 3: Scale used for recording severity of bacterial leaf spot (%)

Grade	(%) Plant area infected by the disease	Category
0	0	Highly resistant
1	0.1-5.0	Resistant
2	5.1-10	Moderately resistant
3	10.1-25	Moderately susceptible
4	25.1-50	Susceptible
5	>50	Highly susceptible

Incidence of *Fusarium* wilt (%)
The incidence of *Fusarium* wilt was recorded as per cent infected plants in ten randomly marked plants and average incidence was worked out with the following derivation.

$$\text{Disease Incidence (\%)} = \frac{\text{Number of diseased plants}}{\text{Total number of plants observed}} \times 100$$

MS-Excel and OPSTAT were used to analyze the data collected. The mean value of the data was submitted to analysis of variance using Randomized Block Design (RBD) Factorial, as defined by Panse and Sukhatme (2000).

Results and Discussion
Among the different soil and plant improvement practices, planting methods; raised bed and flat bed; mulching treatments; black polythene mulch, silver/grey polythene mulch and no mulch; training methods; two stem trained plants, three stem trained plants it was cleared that raised bed planting method, black polythene mulch and two stem trained plants were able to increase flowering, fruiting, yield and decrease incidence of disease parameter significantly as compared to other crop improvement practices. The findings in Table 4, 5, 6, 7, 8, 9, 10, 11 and 12 show that there was a substantial influence of different planting methods, mulches, and training levels on tomato illnesses, growth, yield, and yield contributing variables.

Effect on flowering, fruiting, yield attributing traits, yield and incidence of diseases on tomato

Planting methods
When compared to flat-grown plants, those grown on raised beds had a significantly lower number of days to 50% flowering (29.82 days), a higher number of flower clusters per plant (11.24), a lower number of days to marketable maturity (74.87 days), a higher number of fruits per plant (38.89), a higher fruit weight (77.98), a higher fruit yield per plot (127.57 kg), a higher fruit yield per hectare (899.96 q). Whereas, the plants raised on flat bed planting method observed higher incidence of buckeye rot (4.19 %), severity of *Alternaria* leaf blight (3.80 %), incidence of bacterial leaf spot (2.38 %) and incidence of *Fusarium* wilt (3.45 %) disease. Raised beds contributed significantly

towards early flowering. This might be due to the warming up of the bed because of its bigger exposed surface and absorbance of more radiations which could create a significant difference in soil temperature especially of the root zone as compared to the flat bed mainly during day time. The current findings are consistent with those of Locher *et al.* (2003) in sweet pepper. Raised bed causes a significant difference in the root zone temperature during day time thus hastens the metabolic activities inside the plant cells and thereby approaches the reproductive phase more rapidly rather than vegetative phase (Locher *et al.,* 2003).

Table 4. Effect of planting methods, mulches and training systems on flowering, fruiting and yield contributing characters of tomato

Treatments	Days to 50 % flowering (%)	Number of flower clusters per plant	Days to marketable maturity	Number of fruits per plant	Fruit weight (g)
Planting methods (P)					
P_1^*	29.82	11.24	74.87	38.89	77.98
P_2	31.45	10.05	79.42	36.55	75.90
$CD_{0.05}$	**0.24**	**0.39**	**1.04**	**0.22**	**0.50**
Mulches (M)					
M_1^*	29.10	11.60	73.08	39.22	78.52
M_2	29.62	11.29	74.38	38.72	77.83
M_3	33.19	9.04	83.97	35.22	74.48
$CD_{0.05}$	**0.29**	**0.16**	**1.28**	**0.27**	**0.61**
Training System (T)					
T_1^*	30.32	10.83	76.29	38.31	77.64
T_2	30.95	10.46	77.99	37.13	76.24
$CD_{0.05}$	**0.24**	**0.19**	**1.04**	**0.22**	**0.50**

Table 5: Effect of planting methods, mulches and training systems on yield contributing characters, plant height and leaf area index of tomato

Treatments	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Plant height (cm)	Leaf area index
Planting methods (P)				
P_1^*	127.57	899.96	172.12	4.09
P_2	116.61	822.62	165.97	3.59
$CD_{0.05}$	**1.14**	**8.03**	**3.14**	**0.11**
Mulches (M)				
M_1^*	129.42	913.05	173.31	4.21
M_2	126.64	893.37	169.63	4.05
M_3	110.20	777.45	164.19	3.27
$CD_{0.05}$	**1.39**	**9.84**	**3.84**	**0.14**
Training System (T)				
T_1^*	125.12	882.66	174.11	4.01
T_2	119.06	839.91	163.97	3.68
$CD_{0.05}$	**1.14**	**8.03**	**3.14**	**0.11**

Raised bed facilitate the drainage in high rainfall areas, provides channels for furrow irrigation and warm the soil faster in order to take the advantage of early market (Bracy *et al.*, 1993 and Wilkes and Hobgood, 1969). It can also be attributed to better assimilation of micro and macro nutrients by the plants, prevention of soil compaction and plant damage by reduced trafficking. The benefits of raised bed planting system includes water saving combined with water use efficiency, improvement of soil physical status and nitrogen use efficiency, better utilization of sunlight, low crop weed competition and enhancement in yield and yield related attributes also (Zhang *et al.,* 2008 and

Kumar *et al.,* 2010). Other reasons for increased yield on raised beds could be longer growing period, warming up of the bed, improved drainage, better management of water, fertilizers, mulch and other soil amendments and reduced foot trafficing (Berle and Westerfield, 2013). According to Bahadur *et al.* (2013) in tomato the higher yield in the plants grown on raised bed covered with black mulch was also due to the natural drainage facility, reduced incidence of diseases and also one more important thing is favourable root zone temperature which is considerably important for flowering and fruiting. Possibly in raised bed planting system, more and larger area is exposed, therefore plants are able to facilitate more photosynthetic activity and larger leaf area is responsible for higher leaf area index (Alagoz and Ozer, 2019).

Table 6: Effect of two way interactions P × M, M × T and P × T on flowering, fruiting and yield contributing characters of tomato

Treatment combination	Days to 50 % flowering (%)	Number of flower clusters per plant	Days to marketable maturity	Number of fruits per plant	Fruit weight (g)
P_1M_1	28.06	12.30	70.63	40.76	79.69
P_1M_2	28.63	11.88	72.50	40.19	78.91
P_1M_3	32.78	9.54	81.47	35.72	75.34
P_2M_1	30.14	10.90	75.53	37.68	77.34
P_2M_2	30.60	10.70	76.26	37.25	76.74
P_2M_3	33.60	8.54	86.46	34.72	73.62
$CD_{0.05}$	**0.41**	**0.63**	**3.78**	**0.38**	**2.79**
M_1T_1	28.64	11.88	71.76	40.01	79.23
M_1T_2	29.56	11.33	74.39	38.42	77.80
M_2T_1	29.21	11.52	73.55	39.43	78.36
M_2T_2	30.02	11.07	75.21	38.00	77.29
M_3T_1	33.10	9.10	83.58	35.48	75.34
M_3T_2	33.28	8.98	84.36	34.97	73.61
$CD_{0.05}$	**0.41**	**0.53**	**3.01**	**0.38**	**3.08**
P_1T_1	29.36	11.43	73.71	39.50	78.64
P_1T_2	30.28	11.05	76.02	38.28	77.32
P_2T_1	31.27	10.24	78.88	37.12	76.64
P_2T_2	31.62	9.86	79.96	35.98	75.15
$CD_{0.05}$	**0.34**	**0.57**	**2.88**	**0.33**	**2.84**

Mulching levels

29.10 days to 50 per cent flowering were recorded when the plants were raised using black mulch (M_1). This treatment also produced significant differences with silver/black mulch i.e. M_2 (29.62 days) while maximum days (33.19) were recorded when the plants were raised without mulch (M_3). Black mulch (M_1) also produced (11.60) flower clusters which were significantly more (11.29) than in silver/black mulch (M_2), minimum (73.08) number of days to marketable maturity, more number of fruits (39.22), maximum (78.52 g) fruit weight, maximum value (129.42 kg/plot) of fruit yield per plot, maximum value (913.05 q/ha) of yield per hectare, produced maximum leaf area index (4.21), produced taller plants (173.31 cm) as well as. Whereas, the plants grown on the beds which were not applied with mulch observed higher incidence of buckeye rot (4.45 %), severity of *Alternaria* leaf blight (4.01 %), incidence of bacterial leaf spot (2.47 %) and incidence of *Fusarium* wilt (3.62 %) disease. Mulches have been demonstrated to impact tomato blossoming early. Plastic mulches have a direct impact on the microclimate around theplant by changing the surface's radiation budget (absorbitivity vs. reflection) and minimising soil water loss. The temperature of the soil beneath a plastic mulch is determined by the

Table 7: Effect of two way interactions P × M, M × T and P × T on yield contributing characters, plant height and leaf area index of tomato

Treatment combination	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Plant height (cm)	Leaf area index
P_1M_1	136.45	962.64	176.84	4.51
P_1M_2	133.20	939.71	170.42	4.38
P_1M_3	113.05	797.52	169.09	3.39
P_2M_1	122.40	863.45	169.77	3.90
P_2M_2	120.07	847.02	168.83	3.72
P_2M_3	107.36	757.38	159.29	3.15
$CD_{0.05}$	**1.97**	**13.91**	**5.43**	**0.19**
M_1T_1	133.23	939.93	180.53	4.41
M_1T_2	125.61	886.17	166.09	4.00
M_2T_1	129.85	916.02	173.66	4.23
M_2T_2	123.42	870.71	165.59	3.88
M_3T_1	112.27	792.04	168.15	3.38
M_3T_2	108.13	762.85	160.23	3.15
$CD_{0.05}$	**1.97**	**13.91**	**5.43**	**0.21**
P_1T_1	130.65	921.71	179.05	4.22
P_1T_2	124.48	878.20	165.19	3.97
P_2T_1	119.58	843.62	169.17	3.79
P_2T_2	113.63	801.62	162.76	3.39
$CD_{0.05}$	**2.01**	**13.91**	**4.44**	**0.19**

Table 8. Consortium/interaction effect on flowering, fruiting and yield contributing characters of tomato

Treatment Combinations	Days to 50 % flowering (%)	Number of flower clusters per plant	Days to marketable maturity	Number of fruits per plant	Fruit weight (g)
T_1 ($P_1M_1T_1$)*	27.52	12.64	68.86	41.64	80.47
T_2 ($P_1M_1T_2$)	28.60	11.97	72.39	39.88	78.92
T_3 ($P_1M_2T_1$)	28.10	12.07	71.22	40.80	79.47
T_4 ($P_1M_2T_2$)	29.16	11.69	73.78	39.58	78.35
T_5 ($P_1M_3T_1$)	32.46	9.58	81.06	36.06	76.00
T_6 ($P_1M_3T_2$)	33.10	9.50	81.89	35.39	74.69
T_7 ($P_2M_1T_1$)	29.76	11.12	74.66	38.39	77.99
T_8 ($P_2M_1T_2$)	30.52	10.69	76.40	36.96	76.68
T_9 ($P_2M_2T_1$)	30.33	10.97	75.87	38.07	77.25
T_{10} ($P_2M_2T_2$)	30.33	10.97	75.87	38.07	77.25
T_{11} ($P_2M_3T_1$)	30.87	10.44	76.65	36.42	76.23
T_{12} ($P_2M_3T_2$)	33.47	8.47	86.03	34.55	72.54
$CD_{0.05}$	**1.56**	**0.42**	**3.04**	**1.61**	**3.49**

thermal qualities (reflectivity, absorbtivity, or transmittancy) of the mulch material in proportion to incoming solar radiation (Abhivyakti et al., 2016). The current findings accord with those of Singh et al. (2017), Angmo *et al.* (2018), and Kumari *et al.* (2018) in tomato. The possible reason could be the modification of light environment sufficiently to enhance photosynthetic rate and/or light stimulus of morphogenic development with the use of black plastic mulches; and its effects on crop growth and development. Decoteau *et al.* (1988), Bhujbal *et al.* (2015) and Rahman *et al.*

(2016) also showed similar results and narrated that black polyethylene mulch produced the highest number of flower clusters per plant in tomato. The present findings are also in line with those of Rahman *et al.* (2016) in tomato. Black mulch applied to the planting bed prior to planting will warm up the soil and promote faster growth in early season, which generally leads to earlier harvest (Tarara, 2000 and Lamont, 2005). Because of the availability of adequate nutrients and light to the plant as a result of two stem training, which resulted in the accumulation of maximum photosynthates and the induction of early flowering and early harvest as compared to the three stem training system, which enhanced better growth and development of the tomato fruit. The results are likewise consistent with those of Singh *et al*. (2017) in tomato.

Table 9. Consortium/interaction effect on yield contributing characters, plant height and leaf area index of tomato

Treatment Combinations	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Plant height (cm)	Leaf area index
T_1 ($P_1M_1T_1$)*	140.71	992.64	186.96	4.71
T_2 ($P_1M_1T_2$)	132.20	932.64	166.73	4.31
T_3 ($P_1M_2T_1$)	136.16	960.58	176.40	4.48
T_4 ($P_1M_2T_2$)	130.25	918.84	164.44	4.29
T_5 ($P_1M_3T_1$)	115.09	811.91	173.78	3.47
T_6 ($P_1M_3T_2$)	111.01	783.12	164.39	3.30
T_7 ($P_2M_1T_1$)	125.76	887.21	174.09	4.11
T_8 ($P_2M_1T_2$)	119.03	839.69	165.45	3.70
T_9 ($P_2M_2T_1$)	123.53	871.46	170.92	3.98
T_{10} ($P_2M_2T_2$)	123.53	871.46	170.92	3.98
T_{11} ($P_2M_3T_1$)	116.60	822.58	166.75	3.47
T_{12} ($P_2M_3T_2$)	105.26	742.58	156.07	3.01
$CD_{0.05}$	**10.54**	**18.78**	**14.12**	**0.79**

Table 10: Effect of planting methods, mulches and training systems on disease parameters of tomato crop.

Treatments	Incidence of buckeye rot (%)	Severity of *Alternaria* leaf blight (%)	Severity of bacterial leaf spot (%)	Incidence of *Fusarium* wilt (%)
Planting Methods (P)				
P1	14.91 (3.85)	11.40 (3.35)	4.78 (2.18)	9.57 (3.08)
P2	17.64 (4.19)	14.48 (3.80)	5.69 (2.38)	11.94 (3.45)
CD0.05	**0.02**	**0.03**	**0.03**	**0.02**
Mulches (M)				
M1	14.15 (3.76)	10.90 (3.28)	4.64 (2.15)	9.21 (3.02)
M2	14.87 (3.85)	11.83 (3.43)	4.94 (2.22)	9.96 (3.15)
M3	19.80 (4.45)	16.09 (4.01)	6.14 (2.47)	13.10 (3.62)
CD0.05	**0.03**	**0.04**	**0.04**	**0.03**
Training Systems (T)				
T1	15.68 (3.94)	12.33 (3.48)	5.02 (2.23)	10.12 (3.16)
T2	16.87 (4.09)	13.55 (3.67)	5.46 (2.33)	11.40 (3.36)
CD0.05	**0.02**	**0.03**	**0.03**	**0.02**

The results are likewise consistent with those of Singh et al. (2017) in tomato. Weed competition was minimal beneath the black polythene mulch because higher temperatures under the mulch hampered weed development, and regular moisture conservation throughout the growing season may be responsible for enhanced performance, resulting in increased blooming and fruiting (Bhujbal *et al*., 2015). As mulch films are nearly impervious to carbon dioxide which is necessary for photosynthesis, 'Chimney effect' might have been created resulting in abundant CO_2 for the plants which might have added higher plant growth, fruit weight and fruit yield grown under different plastic mulches.

Training system

As regards training systems, the plants which were trained with two stem (T_1) took least (30.32) number of days to 50 per cent flowering, produced maximum (10.83) flower clusters per plant, minimum (76.29) number of days to marketable maturity, more (38.31) number of fruits, maximum (77.64 g) fruit weight, maximum (125.12 kg/plot) yield, maximum (882.66 q/ha) fruit yield per hectare, maximum values (4.01) for leaf area index, maximum plant height (174.11 cm). Plants trained on three stem trained plants observed higher incidence of buckeye rot (4.09 %), severity of *Alternaria* leaf blight (3.67 %), incidence of bacterial leaf spot (2.33 %) and incidence of *Fusarium* wilt (3.36 %) disease. In case of two stem training techniques also had considerable impact on days to 50 per cent flowering. Early flowering might be due to the result of diversion of photosynthates towards flowering branches which could rather have been used for growth of new shoots and leaves. These plants might have completed vegetative phase much early and the photosynthates might have been shifted to the reproductive parts rather than to vegetative parts (Frank, 2000). Similar findings were also narrated by Ara *et al.* (2007), Muhammad *et al.* (2014) and Mbonihankuye *et al.* (2013) in tomato. The reason for more number of flower clusters in the plants grown on the raised bed planting system could be the availability of more nutrients because of minimum tillage (Naresh *et al*., 2012). In case of two stem training system, there would be maximum sunlight penetration and enhanced photosynthetic activity making more assimilates available for flower cluster setting (early shift from vegetative to reproductive phase) as compared to three stem training system, early and higher rate of morphogenesis (cell division, cell differentiation, cell elongation and cell maturation) and also good aeration through the canopy which might be a valid reason to increase the number of flower clusters per plant and ultimately increased fruit set (Ara *et al.,* 2007; Mbonihankuye *et al.,* 2013 and Ansari *et al.,* 2017). Yadav et al. (2017) also observed the highest number of fruits per plant (86.59) with a twin stem training technique due to greater levels of carbohydrates and soluble chemicals in the fruits. Plants clipped to two stems produced considerably more big fruits than plants treated to three stems, four stems, or no pruning. The results of increased average fruit weight by cutting side branches were consistent with Cebula's (1995) findings that fewer shoots per plant generated heavier pepper fruits. In the present case also, less soil compaction and increased oxygen intake from the atmosphere might have helped the plant to perform better resulting into conditions that favors better growth and higher yield. The increased yield in two stem training system might be attributed to availability of more space for individual plant growth, more leaf area for better photosynthesis, ample sunlight and aeration. These results are consistent with the findings of Bhattarai et al. (2015) and Singh and Kumar (2005) in cherry tomato. Earlier plant growth as a result of mulching allows for higher solar radiation interception and a rapid increase in leaf area assimilation (Kumar and Lal, 2012). Two stem trained plants produced the tallest plants compared to the other treatments which could be the possible reason for the larger leaf area of the two stem plants because of less competition for space and light which consequently lead to higher leaf area index (Razzak *et al.* 2013). Taller plants were observed in two-stem pruned plants which could be due to reduced competition for photosynthates among the branches (Frank, 2000).

Consortium/interaction effect

The interaction of P, M and T was found to be significant for all the flowering, fruiting, yield contributing factors, yield and disease parameters. The treatment combination including raised bed planting method, black polythene mulch and plants trained to two stem training system ($P_1M_1T_1$) took minimum (27.52 days) number of days to 50 % flowering, produced maximum number of flower clusters per plant (12.64), lesser number of days to marketable maturity (68.86 days), maximum number of fruits per plant (41.64), maximum fruit weight (80.47), excellent fruit yield per plot (140.41 kg), per hectare (992.64 q), maximum plant height (186.96 cm) and leaf area index (4.71) compared to other treatment combinations. The minimum incidence of buckeye rot (3.46 %), severity of *Alternaria* leaf blight (2.80 %), incidence of bacterial leaf spot (1.84 %) and incidence of *Fusarium* wilt (2.60 %) disease was recorded in $P_1M_1T_1$ treatment combination (raised bed + black polythene mulch + two stem training system).

Table 11: Effect of two way interactions P × M, M × T and on P × T on incidence of buckeye rot and severity of *Alternaria* leaf blight in tomato crop

Treatment combination	Incidence of buckeye rot (%)	Severity of *Alternaria* leaf blight (%)	Severity of bacterial leaf spot (%)	Incidence of *Fusarium* wilt (%)
P_1M_1	12.85 (3.58)	8.79 (2.96)	4.10 (2.02)	7.83 (2.79)
P_1M_2	13.38 (3.66)	10.19 (3.18)	4.61 (2.15)	8.74 (2.95)
P_1M_3	18.50 (4.30)	15.23 (3.90)	5.64 (2.37)	12.16 (3.49)
P_2M_1	15.46 (3.93)	13.01 (3.61)	5.19 (2.28)	10.58 (3.25)
P_2M_2	16.35 (4.04)	13.47 (3.67)	5.26 (2.29)	11.18 (3.34)
P_2M_3	21.10 (4.59)	16.96 (4.12)	6.63 (2.57)	14.05 (3.75)
$CD_{0.05}$	**0.04**	**0.06**	**0.05**	**0.04**
M_1T_1	13.26 (3.64)	10.15 (3.16)	4.23 (2.04)	8.43 (2.89)
M_1T_2	15.05 (3.87)	11.64 (3.40)	5.06 (2.55)	9.98 (3.15)
M_2T_1	14.19 (3.76)	10.82 (3.27)	4.77 (2.18)	9.34 (3.05)
M_2T_2	15.55 (3.94)	12.84 (3.58)	5.11 (2.26)	10.58 (3.25)
M_3T_1	19.59 (4.42)	16.02 (4.00)	6.07 (2.46)	12.58 (3.54)
M_3T_2	20.01 (4.47)	16.17 (4.02)	6.20 (2.49)	13.63 (3.69)
$CD_{0.05}$	**0.04**	**0.06**	**0.05**	**0.04**
P_1T_1	14.33 (3.77)	10.58 (3.22)	4.44 (2.09)	8.80 (2.95)
P_1T_2	15.49 (3.92)	12.23 (3.48)	5.13 (2.26)	10.35 (3.21)
P_2T_1	17.03 (4.11)	14.08 (3.74)	5.61 (2.36)	11.43 (3.70)
P_2T_2	18.24 (4.26)	14.87 (3.85)	5.78 (2.40)	12.45 (3.52)
$CD_{0.05}$	**NS**	**0.05**	**0.04**	**0.03**

Table 12: Effect of P × M × T interaction on incidence of diseases in tomato crop

Treatment combination	Incidence of buckeye rot (%)	Severity of *Alternaria* leaf blight (%)	Severity of bacterial leaf spot (%)	Incidence of *Fusarium* wilt (%)
$P_1M_1T_1$*	11.99 (3.46)	7.84 (2.80)	3.38 (1.84)	6.76 (2.60)
$P_1M_1T_2$	13.71 (3.70)	9.74 (3.12)	4.36 (2.19)	8.91 (2.98)
$P_1M_2T_1$	12.87 (3.59)	8.81 (2.97)	4.36 (2.09)	7.90 (2.81)
$P_1M_2T_2$	13.89 (3.73)	11.58 (3.40)	4.86 (2.20)	9.57 (3.09)
$P_1M_3T_1$	18.12 (4.26)	15.09 (3.88)	5.57 (2.36)	11.76 (3.43)
$P_1M_3T_2$	18.88 (4.35)	15.37 (3.92)	5.71 (2.39)	12.56 (3.54)
$P_2M_1T_1$	14.54 (3.81)	12.47 (3.53)	5.08 (2.25)	10.11 (3.18)
$P_2M_1T_2$	16.38 (4.05)	13.55 (3.68)	5.30 (2.30)	11.05 (3.32)
$P_2M_2T_1$	15.50 (3.94)	12.83 (3.58)	5.17 (2.27)	10.79 (3.28)
$P_2M_2T_2$	15.50 (4.15)	12.83 (3.58)	5.17 (2.27)	10.79 (3.28)
$P_2M_3T_1$	17.21 (4.15)	14.10 (3.75)	5.36 (2.31)	11.58 (3.40)
$P_2M_3T_2$	21.13 (4.60)	16.97 (4.12)	6.69 (2.59)	14.71 (3.83)
$CD_{0.05}$	**0.06**	**0.04**	**0.07**	**0.05**

*The figures in parentheses represent square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Buckeye rot appears on tomato under mid-hill conditions any time after May, when the warm and rainy season begins and continues till September or late fall. The disease is caused by *Phytophthora nicotianae* var. *parasitica*. The fungus overwinters in the soil in the form of oospores or chlamydospores and can remain active in soil for at least one year without the support of a susceptible host. With the onset of monsoon rains, in the presence of high soil moisture and moderate temperatures (20-25°C), the chlamydospores and oospores start germinating by producing mycelium and sporangia. The disease is caused by three different species of *Alternaria viz., Alternaria solani Alternaria alternata* and *Alternaria alternata* f.sp. *lycopersici*. *Alternaria* species survive in diseased plants debris and can persist for one to two years. Primary infection of lower leaves first takes place through conidia formed on crop debris in soil. Secondary spread of the disease occurs through conidia developed on primary spots. These conidia are blown by wind, water and insects to the neighbouring leaves of plants. Leaf spot is caused by *Xanthomonas campestris* pv. *vesicatoria.* The *Fusarium* wilt caused by the fungus *Fusarium oxysporum* Schlechtend f.sp. *lycopersici* (Sacc.) Snyder and Hans. The pathogen is soil borne in nature and overwinters in the infected plant debris and in the soil as mycelium and spore forms especially as chlamydospores. It spreads over small distances by means of water and contaminated farm. Raised bed method of planting offer better conditions for the plant to grow since they warm up more quickly and drain better. In the present case, better drainage conditions coupled with quick warming of the upper layer as well as beneath of the soil might have created conditions which are not suitable for the development of various disease causing organisms. This might have resulted into less growth of the germinating spores and insufficient disease causing inoculum. Similar are the findings of Sharma *et al.* (2016) who observed that the disease incidence in the bell pepper plants grown on raised beds and ridges were low as compared to the flat beds. The results of present study also revealed low incidence of buckeye rot in different treatments may be due to the prevalence of non-congenial environmental conditions. However, the incidence was comparatively less in the black polythene as compared to the others. The reduced buckeye rot incidence with black polythene mulch may be due to the fact that mulches mitigate the harmful effect of soil borne fungi and create a barrier to the pathogen which causes the disease (Mukherjee *et al*. 2010). The findings are consistent with those of Mehta et al. (2010) in tomato. The lowest incidence of early blight was recorded with black polythene mulch, which might be attributed to the fact that plastic mulching works as a barrier between soil and plant, keeping foliage and fruits away from soil contact (Suresh *et al*. 2014). Mulch also prevents soil splash on lower canopy as soil often consist disease causing conidial spores (Bhujbal *et al.,* 2015). Mulching (black polythene or other) resulted in increased temperature in soil ecosystem which proves to be lethal to tomato wilt pathogen (Mahadeen, 2014). Mulching is basically an addition of a thick layer of mulch on the soil surface to help control weeds, optimise soil moisture and keep the soil cooler which influence plant response to *Fusarium* wilt incidence. It helps in disease control by standing as a barrier between the plant parts above the ground and plant pathogen in the soil. Since it helps to control weeds, it also helps in altering the environment for these pathogens thereby creating unfavourable conditions for them and controlling diseases (Seyfi and Rashidi, 2007). In order to avoid splashing soil borne diseases on tomato leaves during watering, mulching of the plant is advised. The findings are consistent with those of Caroline et al. (2013) in tomato. The unmulched plots stayed more saturated for a long period without any improvement in the drainage system, which might have resulted in increased disease incidence/severity (Khurshid *et al*. 2006). In our opinion, improved soil drainage through black plastic mulching could be the reason for less disease incidence/severity. Bala (2012) also observed that the black polyethylene mulch proved to be most effective to lowest incidence of buckeye rot and minimum *Alternaria* blight severity Lyimo et al. (1998) also investigated the effects of mulching and staking on the development of tomato leaf blight caused by Alternaria solani and Phytophthora infestans, respectively. Mulching and staking were found to reduce the incidence of early and late blight by 5 to 20% when compared to unmulched and unstaked controls. The apparent rate of infection of the two pathogen was also significantly lower in mulched and staked tomato.

Mulching was more effective than staking in suppressing early and late blight diseases in tomato. In two stem training system, incidence of the disease was low because the plants were more erect as compared to three stem training system and foliage and fruits up to a height of 15-20 cm were removed which could avoid the moist and stagnant air conditions for the pathogen to perpetuate. This might be the suitable reason for less buckeye rot incidence in two stem trained plants. More incidence/severity of different diseases in three stem training system might be due to more number of branches/laterals which could have created suffocative conditions which are desirable for the development of the disease. On the other hand, less number of branches will provides more passage of air and sunlight towards the soil and less suffocative conditions might have resulted into less disease spread. Mehta et al. (2010) revealed similar findings on several illnesses in the tomato crop.

Conclusion

In the present study, various aspects of plant growth, yield and diseases were assessed for tomato cultivation. The importance of raised-bed planting systems for sustainability of soils suitable for cultural practices was revealed by this study. It was also proved that due to the improved soil physical and chemical properties with raised-bed planting systems the production and productivity of tomato could be enhanced in mid hills conditions of Himachal Pradesh. In addition, it was determined that fruit yield did not increase in flat planting method in short term even though the same agro-techniques were followed. Such a case was probably because the soils were not able to create suitable conditions for microorganism's activity due to reduced mineralization which could add organic matter in the soil probably. In unsuitable soil conditions, enzymatic activity of microorganisms decreases and nutrient quantities mineralized from the organic matter decreases as well. In the study, the highest values for all parameters were obtained from raised-bed planting systems, black mulch application along with two stem training system. Therefore, from the present findings it was revealed that raised-bed planting system improved mainly the plant growth and yield parameters. Therefore, raised-bed planting system was found to be superior over the flat planting system. Planting on raised beds when used singly and in combination with other cultural methods produced good disease control and higher yield that compared favorably to the conventional methods. Based upon present results, it can also be concluded that use of black and silver/black shaded color synthetic mulch significantly increased the growth, yield and yield contributing characters as compared to the un mulched treatments in tomato in the open field conditions. Results of this study showed that different training levels influence plant developmental characteristics and yield of the indeterminate tomato variety. Therefore, taking into consideration all the aspects it is concluded that plants trained to double stem performed best for all the plant growth and yield characters as well as. Based upon the present results it could be revealed that raised bed planting method along with black polythene mulch produced the significantly higher yield due to the favorable soil temperature conditions achieved in that particular treatment.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

Abhivyakti, Kumari, P., Ojha, R. K., & Job, M. (2016). Effect of plastic mulches on soil temperature and tomato yield inside and outside the polyhouse. *Agricultural Science Digest, 36*, 333-336.

Ahmad, I. M., Qubal, B., Ahmad, G., & Shah, N. H. (2009). Maize yield, plant tissue and residual soil N as affected by nitrogen management and tillage system. *Journal of Agricultural and Biological Science, 1*(1), 19-29.

Alagoz, G., & Ozer, H. (2019). The effects of planting systems on soil biology and quality attributes of Tomatoes. *Archives of Agronomy and Soil Science, 65*(3), 421-433.

Angmo, S., Bhatt, R. P., Paljor, E., Dolkar, P., Kumar, B., Chaurasia, O. P., & Stobdan, T. (2018). Black polyethylene mulch doubled tomato yield in a low-input system in arid trans-himalayan ladakh region. *Defence Life Science Journal, 3*(1), 80-84.

Ansari, G., Lal, M., Kanwar, H. S., Kanwar, R., & Verma, R. (2017). Effect of planting geometry and training on growth and seed yield of tomato (*Solanum lycopersicum* L.). *Journal of Applied and Natural Science, 9*(2), 1146-1150.

Ara, N., Bashar, M. K., Begum, S., & Kakon, S. S. (2007). Effect of spacing and stem pruning on the growth and yield of tomato. *International Journal of Sustainable Crop Production,* ***2,*** 35-39.

Bahadur, A., Singh, A. K., & Singh, K. P. (2013). Effect of planting systems and mulching on soil hydrothermal regime, plant physiology, yield and water use efficiency in tomato. *Indian Journal of Horticulture, 70,* 48-53.

Bakker, D., Hamilton, M., Hetherington, G. J., & Spann, R. (2010). Salinity dynamics and the potential for improvement of water logged and saline land in a Mediterranean climate using permanent raised beds. *Soil Tillage Research*, *110*(1), 8-24.

Bala Rajni. (2012). Effect of mulch, spacing and training system on yield and quality of tomato. Ph D Thesis Dr. Y S Parmar University of Horticulture and Forestry Nauni Solan India. 79 p.

Berle, D., & Westerfield, R. (2013). Raised beds vs. in-ground gardens. *The university of Georgia*. **In:** Cooperative Extension.

Bhattarai, P., Kaushik, R. A., Ameta, K. D., Jain, H. K., Kaushik, M. K., & Sharma, F. L. (2015). Effect of plant geometry and fertigation on growth and yield of cherry tomato (*Solanum lycopersicon* var. *cerasiforme*) under zero energy poly house conditions. *Indian Journal of Horticulture, 72*(2), 297-301.

Bhujbal, P. D., Tambe, T. B., & Ulemale, P. H. (2015). Effects of mulches on flowering, fruiting, yield and pest-disease incidence of tomato (*Lycopersicon esculentum* mill.). *The Bioscan*, *10*(1), 465-468.

Bracy, R. P., Parish, R. L., Bergeron, P. E., & Constantin, R. J. (1993). Comparison of flat and rounded planting bed for vegetable crops. *Applied Engineering Agriculture, 9*, 271-275.

Caroline, F. A., & Olubukola, O. B. (2013). Integrated management strategies for tomato *Fusarium* wilt. *Biocontrol Science, 18*(3), 117-127.

Cebula, S. (1995). Optimization of plant and shoot spacing in glasshouse production of sweet pepper. *Acta Horticulture,* ***412***, 321-329.

Choudhary, M. R., Munir, A., & Mahmood, S. (2008). Field soil salinity distribution under furrow-bed and furrow-ridge during wheat production in irrigated environment. *Pakistan Journal of Water Resource*, *12*(2), 33-40.

Decoteau, D. R., Kasperbauer, M. J., Daniels, D. D., & Hunt, P. G. (1988). Plastic mulch colour effect on reflected light and tomato plant growth. *Scientia Horticulturae,* 34, 169-175.

Frank, F. (2000). Pruning Tomato. Suggested Cultural Practices for Tomato – AVRDC, no. 213.

Guo, F. C., Fujime, Y., Hirose, T., & Kato, T. (1991). Effects of the number of training shoots, raising period of seedlings and planting density in growth, fruiting and yields of sweet pepper. *Journal of the Japanese Society for Horticultural Science*, *59*, 763-770.

Hassan, I., Hussain, Z., & Akbar, G. (2005). Effect of permanent raised beds on water productivity for irrigated maize-wheat cropping system. Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico edited by C.H. Roth, R.A. Fischer and C.A. Meisner ACIAR Proceedings. 121: 59-65.

Khurshid, K., Iqbal, M., Arif, M. S., & Nawaz, A. (2006). Effect of tillage and mulch on soil physical properties and growth of maize. *International Journal of Agriculture and Biology*. *8*(5), 593- 596.

Kumar, S. D., & Lal BR. (2012). Effect of mulching on crop production under rainfed condition: A Review. *International Journal of Research Chemistry and Environment*, *2*(2), 8-20.

Kumari, C., Kumar, B., & Kumar, M. (2018). Utilization of polythene mulching under protected cultivation of tomato: A method to minimize amount of irrigation under semi arid ecosystem of Jharkhand, India. *International Journal of Current Microbiology and Applied Sciences, 7*(08), 4315-4320.

Lamont, Jr. W.J. (2005). Plastics: Modifying the microclimate for the production of vegetable crops. *Horticulture Technology,* 15, 477-481.

Locher, J., Ombodi, A., Kassai, T., & Dimeny, J. (2005). Influence of coloured mulches on soil temperature and yield of sweet pepper. *European Journal of Horticulture Sciences,* 70(3), 135-141.

Locher, J, Ombodi A, Kassai T, Tornyai T and Dimeny J. (2003). Effect of black plastic mulch and raised bed on soil temperature and yield of sweet pepper. *International Journal of Horticultural Science, 9*(3-4), 107-110.

Lyimo, H. F. J., Tiluhongelwa, T. D. M., Maerere, A. P., & Njau, P. (1998). The effect of mulching and staking on the development of early and late blights of tomato. *Tanzania Journal of Agricultural Sciences, 1*(2), 167-172.

Ma, Y. O., & Han, Q. H. (1995). Effect of wheat straw mulch on the growth, development and yield of maize. *Acta Agriculture Boreali-Sinica*, *10*(1), 106-111.

Mahadeen, A. Y. (2014). Effect of polyethylene black plastic mulch on growth and yield of two summer vegetable crops under rain-fed conditions under semi-arid region conditions. *American Journal of Agriculture and Biological Sciences, 9*(2), 202-207.

Malik, R. K., Yadav, A., & Singh, S. (2005). Resource conservation technologies in ricewheat cropping system of Indo-Gangetic plains. In: Abrol, I.P., Gupta, R.K., Malik, R.K. (Eds.), Conservation agriculture: Status and prospects Centre for advancement of sustainable agriculture, New Delhi. Pp. 13-23.

Mbonihankuye, C., Kusolwa, P., & Msogoya, T. J. (2013). Assessment of the effect of pruning system on plant developmental cycle-yield and quality of selected indeterminate tomato lines. Proc. 2nd All Africa Horticulture Congress Eds: K. Hannweg and M. Penter. *Acta Horticulture.* 1007, ISHS

Mehta, D. K., Kaith, N. S., & Kanwar, H. S. (2010). Effect of training methods and mulching on growth, yield and fruit rot incidence in tomato (*Solanum lycopersicum*). *Indian Journal of Agricultural Sciences,* 80(9), 829-831.

Muhammad, A., Singh, A., Gambo, A. B., & Kwaifa, N. M. (2014). Growth of tomato (*Lycopersicon lycopersicum* Mill.) as influenced by training and pruning at Sokoto Fadama, Nigeria. *Journal of Biology, Agriculture and Healthcare, 4,* 2224-3208.

Mukherjee, A., Kundu, M., & Sarkar, S. (2010). Role of irrigation and mulch on yield, evapotranspiration rate and water use pattern of tomato (*Lycopersicon esculentum* L.). *Agricultural Water Management*, *98*, 182-189.

Naresh, R. K., Singh, B., Singh, S. P., Singh, P. K., Arvind, K., & Amit, K. (2012). Furrow irrigated raised bed (FIRB) planting technique for diversification of rice-wheat system for western IGP region. *International Journal of Life Sciences Biotechnology and Pharma Research,* 3(1), 1-11

Patil, V. K., Gupta, P. K., & Tombre, P. G. (1973). Influence of pruning, mulching and nitrogenous fertilizer on the growth, yield and quality of staked plants of 'Sioux' variety of tomato. *Vegetable grower,* 8: 4-9.

Pavlovic, R., Mladenovic, J., Pavlovic, N., Zdravkovic, M., Josic, D., & Zdravkovic, J. (2017). Antioxidant nutritional quality and the effect of thermal treatments on selected processing tomato lines. *Acta Scientarium Polonorum Hortorum Cultus*, *16*(3), 119-128.

Prakash, P. O., Kumar, G. P., Rajesh, L., Jairam, P., & Rajesh, J. (2017). Effect of different mulches on growth, yield and its attributing characters of chilli (*Capsicum annuum* L.) *cv.* Kalipeeth. *International Journal of Agriculture Sciences, 9*(1), 3599-3602.

Rahman, M. J., Quamruzzaman, M., & Samsuddin, M. (2016). Effect of different mulch materials on growth and yield of tomato. *Bangladesh Horticulture, 2*(2), 29-37.

Razzak, H. A., Ibrahim, A., Wahb-Allah, M., & Alsadon, A. (2013). Response of cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) to pruning systems and irrigation rates under greenhouse condition. *Asian Journal of Crop Science,* 64**,** 321-332.

Seyfi, K., & Rashidi, M. (2007). Effect of drip irrigation and plastic mulch on crop yield and yield components of cantaloupe. *International Journal Agriculture Biology*. *9*, 247- 249.

Sharma, D., Kumar, S. & Rana, K. S. (2016). Integrated management of collar rot of bell pepper. *International Journal of Agricultural Sciences, 8*(6): 3468-3470.

Singh, B., & Kumar, M. (2005). Effect of plant spacing and stem pruning on growth and yield of cherry tomato in greenhouse. *Haryana Journal of Horticultural Sciences, 34*(1-2): 179-180.

Singh, H., Sharma, P., Kumar, P. & Dhillon, N. S. (2017a). Influence of spacing and pruning on growth characteristics, yield and economics of tomato (*Solanum lycopersicum* L.) grown under protected environment. *International Journal of Current Microbiology and Applied Sciences, 6*(9), 1833-1838.

Sowinska, A. K., & Turczuk, J. (2018). Effects of plastic and biodegradable mulch films in field tomato cultivation. *Acta Scientarium Polonorum Hortorum Cultus*, *17*(5), 123-133.

Suresh, B. V., Roy, R., Sahu, K., Misra, G., & Chattopadhyay, D. (2014). Tomato genomic resources database: An integrated repository of useful tomato genomic information for basic and applied research. *PLoS One*. *9*(1), e86387.

Tarara, J. M. (2000). Microclimate modification with plastic mulch. *Horticulture Science,* 35, 169-180.

Toor, R.K., & Savage, G.P. (2005). Antioxidant activity in different fractions of tomatoes. Food Research International, *38*(5), 487-494.

Wilkes, L. H., & Hobgood P. (1969). A new approach to field crop production. *Trans American Society of Agriculture Engineering, 12*, 529-532.

Yadav, S., Ameta, K. D., Sharma, S. K., Dubey, R. B., Rathore, R. S., Hareram, K. & Kapuriya V. K. (2017). Effect of spacing and training on vegetative growth characteristics and yield of tomato (*Solanum lycopersicum* L.) grown in polyhouse. *International Journal of Current Microbiology and Applied Sciences, 6*(5), 1969-1976.

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