Effect of organic mulches on agronomic parameters – A case study of tomato crop (Lycopersicon esculentum Mill.)

Lalit Goel1*, Vijay Shankar1, R. K. Sharma1

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Abstract
Purpose The present study was conducted to investigate the effectiveness of locally available organic mulches on moisture retention, yield and irrigation water use efficiency in tomato crop.

Methods The crop was grown in a randomized complete block design using pine needle mulch, wheat straw mulch and rice straw mulch as treatments and no mulch serving as control.

Results Mulches were able to increase the soil moisture retention through 0.1 m to 0.5 m soil depth. Though mulches behaved differently in soil moisture retention at various depths, the average moisture retention observed for pine needle mulch, wheat straw mulch and no mulch was 22.18 %, 21.01 %, 18.52 % and 18.23 %, respectively. The mulches brought about a soil temperature reduction to an extent of 3.3 °C in maximum daily temperature and 1.4-1.8 °C in average soil temperature at 14:00 o’clock during the crop period. The positive effect produced on soil hydrothermal environment was directly reflected through increased leaf area index, plant height and yield. The trend of favourable effect produced by mulches on growth parameters was pine needle mulch > rice straw mulch > wheat straw mulch > no mulch. Mulching increased irrigation water use efficiency by 28.9%, 26.6 % and 12.5 % in pine needle mulch, rice straw mulch and wheat straw mulch, respectively over no mulch.

Conclusion Locally available organic materials can effectively be used to increase soil moisture retention, enhance yield and irrigation water use efficiency in tomato crop.

Keywords Irrigation water use efficiency, Mulching, Plant growth parameters, Soil moisture retention, Soil temperature, Yield

Introduction
Among the vegetable crops, tomato (Lycopersicon esculentum Mill.) stands second in economic importance after potato. Global annual production of tomato is 182.3 million tonnes from an acreage of 4.8 million ha (FAO 2018). India ranks second in tomato production, after China and 19.69 million metric tonnes of tomato fruits are produced from an area of 808,540 ha (DAC and FW 2017). Tomato production is highly sensitive to water stress, requiring continuous availability of water throughout the production cycle of the crop (Lopes et al. 2005). Irrigation helps to increase the yield of tomato in dry season (Bharath 1965). The focus of the crop water management practices is not merely to address the issue of increase in the yield but also to enhance water use efficiency in water limited environments. Promoting sustainable use of water through improved water use efficiency is the major challenge encountered in the rain fed and irrigated agriculture (Berihun 2011). It is imperative to utilize water efficiently through various soil moisture conservation practices. For successful agriculture, proper utilization of water is essential which can be achieved by adopting suitable water conservation measures (Shankar et al. 2017). Application of mulches on soil surface improves soil moisture retention, reduces temperature of soil and wind velocity at soil surface (Kay 1998; Jalota and Prihar 1998). Mulches can also increase water penetration in soil by preventing surface runoff and reducing the crusting of soil (Munshower 1994). Mulches restrict the transport of water vapours from soil to micro climate and help to check the losses though evaporation (Xie et al. 2006; Yuan et al. 2009), thereby the availability of soil water to the crops is increased (Fuchs and Hadas 2011). Thus, the use of organic and plastic mulches is gaining impetus in vegetable production. Plastic mulching has been recommended by several researchers as water saving technique in tomato crop. Plastic mulches promote growth, increase yield and improve the quality of to-
mato crop by readily warming the soil and conserving the moisture (Liu and Hu 2000), but the plastic mulches have a limitation to be used in summer months, which is also the growing period (April-October) of tomato crop in mid hills. In summers, use of polythene can harm the crop due to increase in temperature of soil and air (Pardo et al. 2005; Radics and Széné Bognár 2004). Furthermore, this plastic influences the environment negatively. Therefore, use of plastic mulches is likely to be limited or prohibited in future. Environment friendly crop production promotes clean technologies which reduce the production of waste and encourage the recycling and reuse of materials. Under such circumstances, availability of local low cost materials offers a good alternative to plastic mulch. Organic mulches, such as rice husk, wheat straw and rice straw also increase crop growth and yield (Mukherjee et al. 2012). In India a huge volume of crop residue is generated every season with each crop which is subjected to burning (Gupta and Dadlani 2012). Another waste material is pine needles which often become a cause of forest fires, adding to the environmental pollution. Use of these cheap and easily available organic wastes as a substitute to plastic mulch can be a good step towards clean cultivation. There are reports on the use of simple and low cost organic mulches to moderate the soil temperature and improve soil moisture retention, increase water use efficiency and enhance the growth and yield of tomato (Tindall et al. 1991; Agele et al. 1999; Ramalan and Nwokeocha 2000). Crop residues such as wheat straw and rice straw as well as pine needles are easily available in abundance. These organic materials are biodegradable and potential mulching materials but may vary in the effect produced in different environments and crops (Monks et al. 1997). This variation has been observed with regard to their differential effects produced on the hydrothermal properties of soil. Much information on the effect of these local mulch materials on soil temperature, moisture retention, plant growth and irrigation water use efficiency in tomato crop is not available for mid hills. Keeping in view the above background, present study was undertaken with the objective to investigate the effect of rice straw, wheat straw and pine needles mulch on soil hydrothermal regime, plant growth parameters and irrigation water use efficiency (IWUE) in tomato crop.

Materials and methods

Experimental site

The present investigation was undertaken to evaluate the moisture conserving ability of various biodegradable organic mulches in tomato crop at National Institute of Technology, Hamirpur, Himachal Pradesh, India in the year 2018. The study area is located in the Western Himalayas at an altitude of 738 m above mean sea level and 31°42’40” N latitude; 76°31’33” E longitude. This region falls under sub-humid mid hills of Western Himalayas. It is warm there and the average annual temperature is 21.6 °C in Hamirpur. June is the warmest month of the year with an average temperature of 30.3 °C and coldest month is January with an average temperature of 11.7 °C. The mean daily maximum temperature is 36.6 °C in June and 17.1 °C in January. The mean daily minimum temperature is 6.4 °C in January and 24.6 °C in June. The area receives an average annual rainfall of 1572 mm, 80 percent of which is received during June to September due to southwest monsoons. The amount of rainfall received during the growing period of the crop (21st June 2018 to 9th October, 2018) was 1059.25 mm. The soil of the experimental site was sandy loam with sand, silt and clay content of 77.32%, 14.44% and 8.24%, respectively.

Experimental design and crop management

Field trial was laid in a randomized complete block design (RCBD) with three soil surface mulch treatments: wheat straw mulch (WM), rice straw mulch (RM) and pine needle mulch (PM) applied at 10 tonnes per hectare each and no mulch (NM) serving as control. Three replications were maintained for each treatment. The plots for tomato seedling transplanting were prepared by soil tillage and formation of 1m wide and 3 m long raised beds spaced at 1.2 m distance. Seedlings of tomato hybrid US 920 were transplanted on June 21st, 2018 in rows 0.60 m away from each other with a plant to plant distance of 0.45 m. Each plot had two rows with tomato plants (7 plants per row and 14 plants per plot). The mulches were spread one week after the planting of tomato seedlings on the raised beds so that the mulches did not damage the newly transplanted seedlings. All the seedlings were watered every day with measured amount of half litre water till 2nd of July, 2018. Heavy rains due to monsoons started from July 3rd, 2018 and continued till September 25th, 2018. Two uniform irrigations of 30 mm each were also applied on September 17th, 2018 (due to period of poor rainfall w.e.f. September 1st to September 22nd, 2018) and October 5th, 2018 (due to no rains after September 25th, 2019) during the crop period. During the crop season 0.264 m$^3$ of irrigation water was supplied to each plot.

Determination of soil moisture and temperature

The soil moisture and temperature were determined using the methods described by Goel et al. (2019). The soil moisture probe - Diviner 2000 (Sentek Pty Ltd. Stepney, South Australia) was used to measure soil moisture content. For determination of soil moisture at different depths the pipes of 0.05 m diameter were inserted in the middle of each plot to a depth of 0.5 m. The soil moisture data were measured at depths starting
Crop parameters

Investigations on plant growth characteristics like leaf area index (LAI), plant height and yield were carried out in present study as described by Mukherjee et al. (2012). One plant from each replication under every treatment was selected randomly for the measurement of LAI. Sampling technique involved uprooting of one plant from each plot at each occasion. The tomato produce was harvested at regular intervals from each plot when fruits turned yellowish red. Six pluckings were done during the entire crop period. The total yield was calculated by summing up the yields from all pluckings and expressed as tonnes per hectare.

Irrigation water use efficiency

The effect of mulching produced on yield was worked out in terms of Irrigation Water Use Efficiency (IWUE). IWUE is defined as crop yield per unit of irrigation water used to produce the yield (Howell et al. 2001). This was calculated as fresh fruit weight (kg) obtained per unit volume of irrigation water (m³) applied as described by Mahadeen et al. (2011) for tomato crop.

Results and discussion

Soil moisture

The data on soil moisture was obtained from 0.1 m to 0.5 m soil depths. Data regarding daily soil moisture at 0.1 m, 0.2 m, 0.3 m, 0.4 m and 0.5 m are graphically shown in Figs. 1, 2, 3, 4 and 5, respectively. At 0.1 m soil depth (Fig. 1), the soil moisture was more in all the mulch treatments over NM and the order of soil moisture in various treatments was WM> PM> RM> NM. It was observed that during the early months of the crop, i.e. July to August, moisture retention in all the mulch treatments was high at 0.1 m soil depth as compared to NM and no significant difference in soil moisture content could be observed among WM, PM and RM. However, in September and October when the rains receded, significant differences in soil moisture were observed among various treatments with WM retaining maximum soil moisture followed by PM and RM in which soil moisture content was at par, as compared to NM. This trend is justified by the fact that during July and August, there were heavy rains due to monsoons and the mulches kept the soil in the uppermost layer quite wet resulting in high and almost same moisture at 0.1 m soil depth in all the mulch treatments; whereas the moisture was low in NM as there was no covering on the top of soil to retain the moisture. With the withdrawal of rains in September and October, soil moisture content reduced in all treatments at 0.1 m depth.
and ranking of soil moisture retention was in the order WM> PM> RM> NM. The soil moisture was more by 36.6 %, 30.7 % and 29 %, respectively for WM, PM and RM as compared to NM. Again at 0.2 m depth (Fig. 2), the trend of soil moisture retention by various mulches was same as observed at 0.1 m soil depth, but the increase observed at this depth was 23.5%, 10.3 % and 9.3 % in WM, PM and RM, respectively with reference to NM. At 0.3 m, a change in the trend of soil moisture for various treatments was observed, which was PM> RM> WM> NM with an increase of 32.5 %, 9.8 % and 7.0 %, respectively as compared to NM. At 0.4 m and 0.5 m soil depth, the order of soil moisture content was PM> RM> NM> WM. At these depths the soil moisture observed in WM as compared to NM was lower by 31.5 % and 24.1 %, respectively at 0.4 m and 0.5 m soil depths. This observation indicated that wheat straw absorbed more water, which resulted in lesser moisture content at lower depths in WM as compared to NM. The high moisture retaining ability of wheat mulch has also been reported earlier in our previous study on the effectiveness of WM and RM on moisture retention in potato crop (Goel et al. 2019).

![Fig. 2 Soil moisture at 0.2 m depth](image)

![Fig. 3 Soil moisture at 0.3 m depth](image)
The data on average soil moisture are presented in Table 1. Analysis of this moisture data from 0.1 m to 0.5 m depth averaged for the five soil depths showed that the soil moisture increase over NM with the applied mulches was 1.59%, 21.72% and 15.3% in WM, PM and RM, respectively. The results were in agreement with previous studies where increase in soil moisture in response to mulching has been observed by various researchers in tomato crop (Agele et al. 1999; Monks et al. 1997; Tu et al. 2006).
Soil temperature

Mulching exerted a significance influence on soil temperature. The daily soil temperature during the crop period under different mulching materials (WM, PM, RM and NM) measured at 0.1 m depth at 9:00, 14:00 and 17:00 o’clock are shown in Figs. 6, 7 and 8, respectively. At 9:00 o’clock, similar soil temperature was experienced in all the treatments which ranged from 18.1°C to 25.2°C during the crop season (Fig. 6). The difference in soil temperature among mulched plots and plot without mulch became evident at 14:00 o’clock (Fig. 7). During the crop season, the highest soil temperature was observed on July 10th, 2018, where the soil temperature observed was 30.2°C in NM at 14:00 o’clock, where the corresponding temperatures observed in mulched plots were 26.9°C, 27.1°C and 27.8°C in WM, PM and RM, respectively. This showed that mulching could reduce the soil temperature up to 3.3°C. The average soil temperatures observed at 14:00 o’clock during the crop season were 24.9°C, 25.1°C, 25.3°C and 26.1°C in WM, PM, RM and NM, respectively. Thus reduction in soil temperature at 14:00 o’clock averaged over the entire cropping season was around 1.4°C - 1.8°C (Fig. 7). Though WM, PM and RM showed a significant reduction in soil temperature in comparison to NM, no significant variation was observed among the mulch materials on the effect produced on soil temperature. At 17:00 o’clock also the average soil temperature in mulched plots was lower by 1.3°C to 1.7°C. It is interesting to point that all the mulches significantly decreased the soil temperature and variation among the mulching materials under study which was found insignificant. The results are in agreement with the findings of Agele et al. (1999) who reported that mulching reduced soil temperature at 0.05 m soil depth. The results of this study were also in conformity with the results of Schonbeck and Evanylo (1998) who found that organic mulches

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean soil moisture %</th>
<th>Average soil moisture %</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>10cm</td>
<td>20cm</td>
</tr>
<tr>
<td>WM</td>
<td>22.65</td>
<td>22.15</td>
</tr>
<tr>
<td>PM</td>
<td>21.67</td>
<td>19.78</td>
</tr>
<tr>
<td>RM</td>
<td>21.4</td>
<td>19.6</td>
</tr>
<tr>
<td>NM</td>
<td>16.58</td>
<td>17.94</td>
</tr>
</tbody>
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WM- Wheat straw mulch, PM- Pine needle mulch, RM – Rice straw mulch and NM- No mulch

![Effect of mulching on soil temperature at 9:00 hours](image-url)
reduced maximum soil temperature in tomato. Crop growth and development is greatly affected by soil temperature. The temperature of root zone influences the root growth, development, plant nutrients uptake and translocation (Cooper 1973). Role of soil and root zone temperature in tomato crop has been reported by several researchers. Tindall et al. (1990) reported 25 °C to be the optimum temperature for plant growth and nutrient uptake. Rey and Costes (1965) found that optimal soil temperature ranges between 20 – 30 °C for plant root growth in tomato. Similarly Díaz-Pérez and Batal (2002) reported that the optimum soil temperature for tomato fruit number and yield harvested is about 26 °C and if the mean seasonal root-zone temperature rises above 27 °C, it causes plant stress and adversely affects the plant vigour and fruit yield (Díaz-Pérez et al. 2007). Soil temperature optimization effect of mulches has been observed by Monks et al. (1997) who reported that wheat straw was able to maintain the soil temperature between 21°C - 26 °C. In present study also the mulches were able to maintain soil temperature in the optimal range and prevented the soil temperature from shooting up beyond 27.1 °C (Fig. 6-8). The cooling effect of the mulches produced on soil could be explained from the fact that mulches reduced the evaporation and shaded the soil surface from incoming solar radiation (Ham et al. 1993). The soil temperature reduction is always achieved under the biodegradable mulches because these materials have a higher permeability which allows for good gas exchange with the open air (Chandra and Rustgi 1998). In present study also the cooling effect was reached due the use of organic mulches which are biodegradable, produce shading effect and check soil water evaporation.

![Fig. 7 Effect of mulching on soil temperature at 14:00 hours](image1)

![Fig. 8 Effect of mulching on soil temperature at 17:00 hours](image2)
Crop growth parameters

Plant height and LAI were observed as crop growth parameters in response to mulching. Effect of mulches on plant height is depicted in Fig. 9. At the time of transplanting, the average seedling height varied from 0.11 m to 0.13 m and there was not much difference in the plant height under various treatments. With the application of mulches, the difference in the rate of growth for various treatments became visible and the order of height attainment by tomato plants under various treatments was PM>RM>WM>NM. At the time of final harvest, i.e. at 135 days after transplanting (DAT), the plants under PM attained an average height of 1.58 m whereas the maximum plant height reached in NM was 1.3 m. There are several reports on increase in plant growth parameters in tomato as a result of mulching (Agele et al. 1999; Monks et al. 1997; Tu et al. 2006). Increase in plant height of tomato as a result of local mulch materials has also been reported by Kayum et al. (2008).

![Effect of mulching on plant height](image)

The effect of different mulch treatments on LAI is shown in Fig. 10. The LAI values at transplanting ranged from 0.113 to 0.116 m²/m² for various treatments. The LAI increased as the growth of plants picked up. The order of increase in LAI for various mulch treatments was PM> RM> WM> NM and the maximum LAI was observed at 105 DAT, which was 2.93, 2.87, 2.84 and 2.52 m²/m², respectively in PM, RM, WM and NM, respectively. On the attainment of maximum LAI at 105 DAT, PM, RM and WM showed an increase of 28.26 %, 23.31 % and 20.63 %, respectively in LAI as compared to NM.

The effect of lowered soil temperature and increased soil moisture was reflected in the higher LAI of tomato plants in mulched plots. Nandan and Prasad (1988) explained that high moisture availability resulted in enormous increase in LAI due to high rate of cell division and cell size enlargement. Similarly, in this study, high moisture was available under mulches resulting in higher LAI under various treatments which was in the order of PM> RM> WM> NM which showed a trend similar to increase in soil moisture retention.

Crop yield and irrigation water use efficiency (IWUE)

Mulching resulted in a significant increase in total yield which was calculated as fresh fruit harvested obtained during the crop season from all the pluckings and expressed as tonnes per hectare. The yield obtained under various mulch treatments is presented in Table 2. The trend of yield was same as was for plant height and LAI. The increase in yield with mulches was 27.9 %, 25.6 % and 11.6 %, respectively in PM, RM and WM as compared to NM. The yield enhancing effect of mulching has also been observed by Mukherjee et al. (2018) and Aliabadi et al. (2019) who have respectively reported 23-58 % and 12-46 % increase in fruit yield under mulch over no mulch. In present study a yield increase of 5, 11 and 12 tonnes per hectare, respectively was observed in WM, RM and PM as compared to NM. The results are also in agreement with the study of Ramalan and Nwokeocha (2000), who reported that application of straw mulch enhanced the yield by 5.2 tonnes per hectare.
These results indicated that the positive effect of mulching on soil temperature and soil moisture was directly translated into increased plant growth parameters observed for tomato crop. Improved hydrothermal regime led to luxurious foliage development throughout crop growth. Good plant growth and canopy development is necessary for an efficient height interception and higher assimilation rates (Gupta and Gupta 1983; Zaman and Choudhuri 1995) and dry matter accumulation (Olasantan 1985; Ojeniyi and Adetoro 1993). These effects are responsible for increasing plant height and LAI under mulches which resulted in higher yield in the present study.

Mulching not only increased the crop harvest, but also significantly increased the IWUE (Table 2). The IWUE was enhanced by 28.9 %, 26.6 % and 12.4 % in PM, RM and WM, respectively as compared to NM. The increase in IWUE was as a resultant effect of enhanced soil moisture and optimum soil temperature for plant growth. Mukherjee et al. (2012) reported an increase in the IWUE by 113 % under rice straw mulch. Ramalan and Nwokeocha (2000) observed that application of straw mulch resulted in an increased water use efficiency and fruit yields because in unmulched plots high evapo-transpiration losses were responsible for more crop water use as compared to mulched plots where evapo-transpiration losses were minimized and water use efficiency was enhanced.

**Conclusion**

Present study pointed out that the locally available organic mulches have a potential to positively influence soil moisture retention, optimize soil temperature for crop growth, increase crop yield and improve irrigation water use efficiency in tomato crop in sub humid mid
hills of Western Himalayas possessing warm and temperate climate. All the mulch materials under investigation helped to increase the soil moisture retention, optimize the soil temperature and create a conducive soil hydrothermal environment for crop growth resulting in increased yield. The increased yield was accompanied with enhanced IWUE. Among the various mulch materials used, pine needle mulch was observed to be the best followed by rice straw and wheat straw. It can be said with conformity that environment friendly locally available organic materials can effectively be used as mulches to increase soil moisture retention, enhance yields and IWUE in tomato crop.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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