R-2243
[1-5]

REVIEW ARTICLE Agricultural Reviews,

Effect of Mulches on Crop, Soil and Water Productivity: A Review

Sudhanshu Verma[1], Swati Swayamprabha Pradhan[1]

10.18805/ag.R-2243

ABSTRACT

A mulch is a layer of material applied to the surface of an area of soil. Mulches are used for various reasons in agriculture but water conservation and erosion control are the most important objectives particularly in arid and semi-arid regions. Other reasons for use of mulching include soil temperature modification, weed control, soil conservation and after decomposition of organic mulch add plant nutrients, improvement in soil structure, increase crop quality and yield. Conservation of soil moisture by application of mulches becomes essential for profitable cultivation of the crop under rainfed condition of semi-arid ecosystem. In spite of no assured irrigation in these regions, the moisture conservation technique is not in practice. Mulches not only conserve soil moisture but also impart manifold beneficial effects, like suppression of extreme fluctuation of soil temperature and reduction of water loss through evaporation, resulting in more stored soil moisture, maintenance of soil fertility, suppression of weed growth, improvement in growth and yield. The requirement of water through mulch can further be reduced by using locally available organic materials as mulches which not only save irrigation water but also conserves soil moisture.

Key words: Crop productivity, Growth, Mulches, Soil productivity, Water productivity, Yield attributes, Yield.

In India the vast majority of the agrarian land is under rainfed condition and to increase water availability for rainfed or arid area, mulches are a possibility for soil moisture conservation that helps in water accessibility, increase infiltration, impedes soil erosion and decreases surface runoff (Adekalu *et al.,* 2007). Mulching is a viable strategy of manipulating the crop-growing environment by controlling soil temperature, retaining soil moisture and reducing evaporation (Ghosh *et al.*, 2006 and Chakraborty *et al.*, 2008), which ultimately enhances plant growth, development and yield. However, the effect may vary with soils, climate and used mulch material and the amount of application to increase the output of the production. Surface mulching increase the soil temperature in winter and decreases during summer, which reduced loss of soil moisture, check the weed emergence and their growth, (Ramakrishna *et al.,* 2006). Straw mulch applied at 4-6 t ha^{-1} was effective in improving soil physical conditions including protection of the top soil from erosion. If top soil temperature is excessive, mulching reduces temperature for more optimal germination and root development (Guo *et al.*, 2014). The surface mulch favorably influences the soil moisture regime by controlling evaporation from the soil surface, improves infiltration, soil water retention, decreases bulk density and facilitates condensation of soil water at night due to temperature reversals (Tisdall *et al.*, 1991). Mulching have favorable effect on soil nutrients. Naeni and Cook (2000) was reported improvement in soil temperature, maintenance of soil moisture, soil N and K due to the organic waste of mulches that boosted crop yield. It not only alters the physico-chemical properties but also the biological properties of soil (Thakur and Kumar 2020).

Effect of mulches on growth

Application of paddy straw mulch recorded 14.4% higher yield of maize as compared to no mulch (Priya and Shashidhara, 2016). Choudhay and Kumar (2014) showed that the crop productivity of sequential crops was 18-35% higher with mulch application than no mulch. The growth parameters were highest with paddy straw mulch (Sharma and Bhardwaj 2017). Paddy straw mulch recorded significantly higher plant height dry matter accumulation $plant^{-1}$ and number of leave $plant^{-1}$ over the dust mulch and no mulch respectively, Rajput *et al.* (2014). Din *et al.* (2013) found that maximum plant height of maize was recorded under wheat mulch followed by berseem mulch and minimum in no-mulch. Ram *et al.* (2013) reported that application of rice straw @ 6 t ha^{-1} recorded significantly highest leaf area index, effective tillers m^{-2}, spike length (cm), grains $spike^{-1}$, 1000-grain weight (g) of wheat as compared to rice straw @ 4 t ha^{-1}, rice straw @ 2 t $ha^{-1}$and no mulch. Pervaiz *et al.* (2009) Maximum plant height was obtained in wheat straw @14 Mg ha^{-1} (2.53 m), followed by wheat straw @ 7 Mg ha^{-1} and minimum in no mulch. Khurshid *et al.* (2006) recorded significantly highest growth parameters, number of cobs per plant, number of grains per cob and 1000-grain weight of maize with 12 Mg mulch ha^{-1} as compared to the

[1]Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh, India.

Corresponding Author: Sudhanshu Verma, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh, India.
Email: sudhanshubcn@gmail.com

How to cite this article: Verma, S. and Pradhan, S.S. (2024). Effect of Mulches on Crop, Soil and Water Productivity: A Review. Agricultural Reviews. doi: 10.18805/ag.R-2243.

Submitted: 19-04-2021 **Accepted:** 19-01-2022 **Online:** 14-03-2024

rest of the treatment. Rahman *et al.* (2005) rice straw mulch recorded significantly higher plant density, spike density m^{-2}, grains $spike^{-1}$ and 1000 grain weight of wheat as compared to non-mulch plots.

Bhatt *et al.* (2004) conducted a field experiment on maize and reported that dry matter production with paddy straw mulch was higher by 138% than the dry matter production from no mulch plots.

Effect of mulches on yield attribute and yield

Maize yields with plastic film and rice straw mulch were significantly increased by 26.20% and 9.50%, respectively, while water use efficiency increased by 21.58% and 7.20%, compared with unmulched plot (Tang *et al.*, 2016). Mulched treatments recorded significantly higher maize grain yield as compared to maize grown without mulch. The extent of per cent increase with mulched plot was 20.68% over non-mulched plots, Priya and Shashidhara (2016). Kumar *et al.* (2016) reported that application of mulch recorded higher maize yield as compare to no mulch treatment. Bhardwaj (2013) also reported beneficial effects of mulch on earliness, yield and quality of the crop. Rajput *et al.* (2014) was recorded highest grain yield with the application of paddy straw mulching and followed by green weed mulch and dust mulch. All the mulching treatments produced significantly higher grain yield than control, however dust mulch and no mulch at par with each other. Shah *et al.* (2013) concluded that mulching materials improved the soil physical condition and consequently yield of maize and wheat straw mulch showed the highest yield of maize under bed sowing system. Din *et al.* (2013) recorded maximum grains cob^{-1} and test weight under wheat straw mulch which over no-mulch applied under non-irrigated condition. Singh *et al.* (2011) concluded that mulch improved crop growth and yield determining attributes, however this only led to significantly higher yield when there was prolonged water deficit stress prior to anthesis. Singh *et al.* (2011) concluded that live mulching of sunhemp improved yield of maize compared with the no mulch. Chakraborty *et al.* (2010) recorded an increase in grain yield with mulching and attributed this to the better soil water status and improved plant canopy. Sharma *et al.* (2010) observed that live mulching with sunnhemp or *Leucaena* was about same in their beneficial effect (12.3-14.7%) but their combined application enhance the maize yield by 19.1% over control. Khan and Parvej (2010) reported that mulching practices enhanced grain yield nearly double (8.73 t ha^{-1}) with water hyacinth than unmulched plants (4.93 t ha^{-1}). Pervaiz *et al.* (2009) reported that mulch significantly increased maize grain yield. Maximum yield was observed in wheat straw @14 Mg ha^{-1}, followed bywheat straw @ 7 Mg ha^{-1} and minimum in no mulch. Shittu and Fasina (2006) reported that dry cob weight was recorded significantly higher under residue management, where the surface mulching residue seems to have better for maize production. Khurshid *et al.* (2006) reported that application of mulch@ 8 Mg ha^{-1} recorded significantly highest grain yield as compared to control. Gosavi (2006) conducting an experiment on sweet corn reported significantly maximum weight of cob, length of cob and kernels cob^{-1}under mulching than no mulch treatments. Bhatt *et al.* (2004) trial conducted at Punjab Agriculture University, Ludhiana on maize reported that straw mulch increased the cob yield by 60.5% as compared to un-mulched treatment.

Effect of mulches on nutrient uptake

Paddy straw mulch recorded significantly highest total nitrogen and phosphorus and potassium uptake by maize followed by green weed mulch, dust mulch and no mulch, respectively (Rajput *et al.*, 2014). Shaheen *et al.* (2010) reported that mulching along with recommended dose of N+P fertilizer recorded significantly higher total N and P uptake over no mulch. Pervaiz *et al.* (2009) reported that maximum N concentration in maize shoots was observed in wheat straw @14 Mg ha^{-1}, followed by wheat straw @ 7 Mg ha^{-1} and minimum in no mulch at 45 days after sowing. Similar trend was observed at harvest. Pervaiz *et al.* (2009) observed that mulched treatments show significantly superiority in total uptake of N, P and K than un mulched treatments.

Effect of mulches on quality

Application of mulch did not influence the protein content in peanut kernels. But protein yield was found significantly higher in mulched peanut by 1.31 fold over non-mulched peanut. Further, mulched peanut recorded 1.2% higher oil content over non-mulched peanut. Higher oil yield is a function of oil content and kernel yield, which was found under mulched treatment as compared to control (Jain *et al.*, 2017). Sarkar and Sarkar (2017) was reported that the mulched plants produced higher oil content in seed over no mulched and the maximum was with black polythene followed by straw mulch @ 5 t ha^{-1}. Ram *et al.* (2013) was conducted a field experiment for three years and reported that the straw mulching did not have any significant effect on protein content of wheat grains. Pinjari (2007) revealed that the sugar content, protein content and fiber content were significantly superior under mulch than no mulch. Gosavi (2006) conducted a field trial on sweet corn reported that significantly highest sugar content (12.26) in sweet corn under mulch than the remaining treatments.

Effect of mulches on water use

Polythene mulch recorded significantly higher water-use efficiency over non-mulched treatment. It was due to reduction in the evaporation and of weeds population under polythene mulch that conserved the soil moisture (Jain *et al.*, 2017), (Lalitha *et al.*, 2010). Sarkar and Sarkar (2017) observed that the highest WUE and WEE were recorded with black polythene mulch fallowed by dry straw mulch @ 5 t ha^{-1} and water hyacinth @ 5 t ha^{-1}. However, lowest WUE and WEE were obtained in no mulch treatment. Jimenez *et al.* (2017) concluded that three year field experiment demonstrates the application of straw mulches changed the spatial and temporal soil-moisture distribution pattern

throughout the soil profile. This was especially true for straw mulch, which favored water infiltration and their storage inside the soil surface. Keesstra *et al.* (2016) reported that mulch to conserve soil moisture is commonly used in semiarid regions, as well as sub humid and humid regions, mainly due to its positive effect on soil temperature and infiltration and its reduction of soil evaporation by breaking the capillarity. Priya and Shashidhara (2016) observed that the increase in yield with mulch treatment was due to the increase in availability of soil moisture for longer period than non-mulched plot. Kumar *et al.* (2015) reported that moisture-conservation practices resulted in marked improvement in grain yield of maize, kaolin 6%+organic mulch having maximum numerical value in respect of grain yields. Zhao *et al.* (2014) was found that straw mulches have significant effects on soil moisture improvement as compared to control. Kadu *et al.* (2014) stated that mulching with paddy straw @ 5 t ha^{-1}along with kaolin (6%) spray was recorded highest water use efficiency over control. Ram *et al.* (2013) stated that rice straw mulching (6 t ha^{-1}) decreased the water use and increased the WUE as compared to no mulch. Singh *et al.* (2011) reported that the mulch treatment found to be significantly increased biomass and grain water productivity over non mulch treatment. Singh *et al.* (2011) concluded that mulch conserved soil water and reduced the number of irrigations while maintaining yield and increasing irrigation water productivity, in comparison with the recommended practice of scheduling according to cumulative pan evaporation. Jordan *et al.* (2010) reported that mulch to the improved soil porosity, aggregate stability, more abundant organic matter, lower bulk density and thus enhanced infiltration and available water capacity. Sharma *et al.* (2010) revealed that mulching is very effective in improving the soil water content (2.1-2.3%), grain yield (15.1%) and WUE over no-mulching treatments. Khan and Parvej (2010) found that the water retentive capacity of the water hyacinth and rice straw mulched soil under zero tillage condition was higher at all the stages of plant growth. Pervaiz *et al.* (2009) concluded that wheat straw as mulch in conjunction with deep tillage improves soil physical health, crop growth and increased soil moisture contents (17%) compared to control.

Effect of mulches on soil property

Mulching improved soil hydrologic characteristics that affect the soil physical and chemical properties. The mulches also reduces deterioration of soil quality by preventing runoff and reducing soil loss that improves soil aeration, soil structure, organic matter content and physical properties of the soil (Kadera *et al.*, 2017). Mulching treatment adds organic acids to the soil leads to lower soil pH (Sharma and Bhardwaj 2017) also reduces soil EC as compared to un-mulched treatment and soil EC fluctuated between observation and it tended to increase as soil moisture decreased, (Taufiq *et al.*, 2017). Zhang *et al.* (2016) reported that in an arid environment, the application of straw mulch significantly increased soil organic matter to the top soil layers (0-15 cm) and the stratification ratio of soil organic matter also increased. Saha (2013) reported that SOC was recorded higher with maize straw mulch followed by paddy straw mulch; while no mulch treatment resulted in reduction of SOC. Mulching with thatch grass resulted in more soil moisture content followed by paddy straw mulch. Straw mulching significantly influenced the soil moisture content and concentration of nitrate-N, K, Ca and Mg in the soil solution (Jordan *et al.*, 2011). Javeed *et al.* (2013) stated that maximum soil bulk density was recorded in the control treatment followed by the wheat straw mulch and grass mulch respectively and higher total soil porosity was obtained with wheat straw mulch followed by grass mulch treatment and lowest with control.

Combination of wheat straw mulch+bed sowing system showed the lowest bulk density of 15 cm surface layer while the highest bulk density was obtained with flat sowing without mulch was reported by Shah *et al.* (2013). Ram *et al.* (2013) stated that application of rice straw @ 6 t ha^{-1} recorded significantly highest soil organic carbon and lowest bulk density as compared to rice straw @ 4 t ha^{-1}, rice straw @ 2 t ha^{-1} and no mulch in surface soil (0-15 cm) layer. Mitra and Mandal (2012) reported that incorporation of paddy straw improved available NPK and soil physico-chemical properties as compared with non-mulched plots. Jordan *et al.* (2011) reported that mulching improves the soil physical properties, such as bulk density, porosity and aggregate stability, while increasing infiltration and decreasing runoff rates, as well as reducing soil-moisture loss from evaporation. Jordan *et al.* (2010) observed that application of wheat straw mulch significantly improved soil fertility and physical properties with mulching rate. Saha *et al.* (2010) found that residue incorporation significantly decreases the bulk density of surface (0-15 cm) soil layer, whereas, zero tillage with residue retention recorded significantly higher mean weight diameter and geometric mean diameter of soil aggregates. Pervaiz *et al.* (2009) concluded that wheat straw as mulch in conjunction with deep tillage mulch decreases bulk density (1.35 Mg m^{-3}) compared to control. Shashidhar *et al.* (2009) reported that higher organic carbon content of soil was recorded with sunhemp mulch (0.71%) followed by silkworm bed waste (0.68%), paddy straw (0.66%) mulched plots and least organic carbon content (0.48%) in non mulched plot. Singh *et al.* (2009) reported that residue application improved the soil physio-chemical and biological environment in the soil through addition of nutrients, enhanced microbial activity.

Effect of mulches on economics

Jain *et al.* (2017) reported higher returns from peanut grown under mulch treatment over non-mulched treatments. Sarkar and Sarkar (2017) stated that the maximum net returns and B:C ratio were found with black polythene mulch followed by straw mulch @ 5 t ha^{-1}. However, no mulch recorded minimum net returns and B:C ratio due to lower seed and straw yield. Rajput *et al.* (2014) reported that dust mulch recorded higher gross returns (63119 Rs ha^{-1}), net returns (50536 Rs ha^{-1}) and B:C ratio (4.01) as compared to rice

straw, wheat straw and legume straw mulch. Ghosh *et al.* (2006) stated that combined use of wheat straw (WS)+black polythene (BP) recorded significantly higher gross returns than other mulch treatments. However, net returns were the highest with WS mulch, which was statistically similar to net returns with WS+BP. The lowest net returns were recorded with transparent polythene mulch. Gosavi (2006) conducted a field trial on sweet corn observed that the gross return, net profit and B:C ratio were higher under mulched treatments. Dutta *et al.* (2005) resulted that the maximum grass returns, net returns and B:C ratio was recorded under paddy straw mulch (5 t ha^{-1}) as compared to no-mulched treatment.

CONCLUSION

Under this changing climatic conditions in arid and semi-arid zones of the tropics and subtropics, moisture, temperature, precipitation and other soil factors are the limiting factors in crop production. On the basis of above findings conclusions may be drawn, mulch is most effective for enhancing growth parameters, yield attributes, yield, harvest index, quality parameters, gross returns and maximum nutrients uptake by crop than no mulch. By modification of soil microclimate, mulches increase plant growth, development, quality and yield of most crops.

Conflict of interest

All authors declared that there is no conflict of interest.

REFERENCES

Adekalu, K.O., Olorunfemi, I.A. and Osunbitan, J.A. (2007). Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. Bioresource Technology. 98: 912-917.

Bhardwaj, R.L. (2013). Effect of mulching on crop production under rainfed condition-A review. Agricultural Reviews. 34(3): 188-197.

Bhatt, R., Khera, K.L., and Arora, S. (2004). Effect of tillage and mulching on yield of corn in the submontaneous rainfed region of Punjab, India. International Journal of Agriculture and Biology. 6(1): 126-128.

Chakraborty, D., Garg, R.N., Tomar, R.K., Singh, R., Sharma, S.K., Singh, R.K. and Kamble, K.H. (2010). Synthetic and organic mulching and nitrogen effect on winter wheat (*Triticum aestivum* L.) in a semi-arid environment. Agricultural Water Management. 97(5): 738-748.

Chakraborty, D., Nagarajan, A., Aggarwal, P., Gupta, V.K., Tomar, R.K., Garg, R.N., Sahoo, R.N., Sarkar, A., Chopra, U.K., Sharma, K.S. and Kalra, N. (2008). Effect of mulching on soil and plant water status and the growth and yield of wheat in a semi-arid environment. Agricultural Water Management. 95: 1323-1334.

Choudhary, V.K., and Kumar, P.S. (2014). Influence of mulching on productivity, root growth and weed dynamics of maize (*Zea mays*)-based cropping systems. Indian Journal of Agronomy. 59(3): 364-370.

Din, S., Ramzan, M., Khan, R., Rahman, M.U., Haroon, M., Khan, T.A. and Samad, A. (2013). Impact of tillage and mulching practices on weed biomass and yield components of maize under rainfed condition. Pakistan Journal of Weed Science Research. 19(2).

Dutta, D., Bandyopadhyaya, P. and Banerjee, P. (2005). Effect of tillage systems and mulching on summer groundnut. Annals of Agricultural Research. 26(3): 375-377.

Ghosh, P.K., Dayal, D., Bandyopadhyay, K.K., and Mohanty, M. (2006). Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. Field Crops Research. 99(2-3): 76-86.

Gosavi (2006). Effect of mulches, fertilizer and levels of organic manure on the performance of rabi sweet corn M.Sc. (Agri.) Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.).

Guo, S.Y.C., Jian, H.X.Y., Wang, J.X.C. and Ru, Y.C. (2014). Effects of different mulches on growth development and yield of peanut. Journal of Southern Agriculture. 45(8): 1363-1368.

Jain, N.K., Meena, H.N. and Bhaduri, D. (2017). Improvement in productivity, water-use efficiency and soil nutrient dynamics of summer peanut through use of polythene mulch, hydrogel and nutrient management. Communications in Soil Science and Plant Analysis. 4(5): 549-564.

Javeed, H.M.R., Zamir, M.S.I., Tanveer, A. and Yaseen, M. (2013). Soil physical properties and grain yield of spring maize (*Zea mays* L.) as influence by tillage practices and mulch treatments. Cercetari Agronomice in Moldova. 46(1): 69-75.

Jiménez, M.N., Pinto, J.R., Ripoll, M.A., Sanchez-Miranda, A. and Navarro, F.B. (2017). Impact of straw and rock-fragment mulches on soil moisture and early growth of halm oaks in a semiarid area. Catena. 152: 198-206.

Jordan, A., Zavala, L.M., Gil, J. (2010). Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. Catena. 81: 77-85.

Jordan, A., Zavala, L.M., Munoz-Rojas, M. (2011). Mulching Effects on Soil Physical Properties, In: Encyclopedia of Agrophysics, Springer, Dordrecht. [Glinski, J., Horabik, J., Lipiec, J. (Eds.)], 492-496.

Kadera, M.A., Sengeb, M., Mojidc, M.A. and Itob, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. Soil and Tillage Research. 168: 155-166.

Kadu, S.P., Patel, D.B., Patel, R.B. and Patel, A.P. (2014). Effect of moisture stress and evapo-trasnpiration suppressants on growth and yield of summer groundnut. Trends in Biosciences. 7(22): 3628-3632.

Keesstra, S., Pereira, P., Novara, A., Brevik, E.C., Azorín-Molina, C., Parras-Alcántara, L., Jordán, A., Cerdà, A. (2016). Effects of soil management techniques on soil water erosion in apricot orchards, Science Total Environment. 551: 357-366.

Khan, M.A.H. and Parvej, M.R. (2010). Impact of conservation tillage under organic mulches on the reproductive efficacy and yield of quality protein maize. The Journal of Agricultural Sciences. 5(2): 52-63.

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

Kumar, A., Kumar, J., Mahajan, A., Sharma, N. and Stanzen, L. (2015). Weed management in maize-based cropping system. Indian Journal of Weed Science. 47(3): 254-266.

Kumar, V., Kumar, M., and Rai, A.P. (2016). Mulching in fruit and vegetable crop production under rainfed conditions: A Review. Journal of Soil and Water Conservation. 15(4): 313-317.

Lalitha, M., Thilagam, V.K., Balakrishnan, N., and Mansour, M. (2010). Effect of plastic mulch on soil properties and crop growth-A review. Agricultural Reviews. 31(2): 145-149.

Mitra, B., and Mandal, B. (2012). Effect of nutrient management and straw mulching on crop yield, uptake and soil fertility in rapeseed (*Brassica campestris*)-greengram (*Vigna radiata*)-rice (*Oryza sativa*) cropping system under Gangetic plains of India. Archives of Agronomy and Soil Science. 58(2): 213-222.

Naeni, M.S.A.R. and Cook, H.F. (2000). Influence of compost on temperature, water, nutrient status and the yield of maize in a temperate soil. Soil Use and Management. 16: 215-221.

Pervaiz, M.A., Iqbal, M., Shahzad, K. and Hassan A.U. (2009). Effect of mulch on soil physical properties and n, p, k concentration in maize shoots under two tillage systems. International Journal of Agriculture and Biology. 11: 119-124.

Priya, H.R. and Shashidhara, G.B. (2016). Effect of crop residues as mulching on maize-based cropping systems in conservation agriculture. Research on Crops. 17(2): 219-225.

Rahman, M.A., Chikushi, J., Saifizzaman, M., and Lauren, J.G. (2005). Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. Field Crops Research. 91(1): 71-81.

Rajput, B.S., Shukla, N.N., Sen, A. and Singh, R.K. (2014). Row spacing and mulching effect on growth and nutrient uptake of maize under Guava based agri-horti system. Online International Interdisciplinary Research Journal. 4(3): 131-138.

Ram, H., Dadhwal, V., Vashist, K.K. and Kaur, H. (2013). Grain yield and water use efficiency of wheat in relation to irrigation levels and rice straw mulching in North West India. Agricultural Water Management. 128: 92-101.

Ramakrishna, A., Tamb, H.M., Wani, S.P. and Long, T.D. (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crops Research. 95: 115-125.

Saha, S., Chakraborty, D., Sharma, A.R., Tomar, R.K., Bhadraray, S., Sen, U., Behera, U.K., Purakayastha, T.J., Garg, R.N. and Kalra, N. (2010). Effect of tillage and residue management on soil physical properties and crop productivity in maize-Indian mustard system. Indian Journal of Agriculture Science. 80(8): 679.

Sarkar, S. and Sarkar, A. (2017). Improving growth and productivity of linseed using mulches under different levels of irrigation. Journal of Crop and Weed. 13(1): 1-6.

Shah, S.S.H., Hassan, A., Ghafoor, A. and Bakhsh, A. (2013). Soil physical characteristics and yield of wheat and maize as affected by mulching materials and sowing methods. Soil and Environment. 32(1): 14-21.

Shaheen, A., Ali, S., Stewart, B.A., Naeem, M.A., and Jilani, G. (2010). Mulching and synergistic use of organic and chemical fertilizers enhances the yield, nutrient uptake and water use efficiency of sorghum. African Journal of Agricultural Research. 5(16): 2178-2183.

Sharma, A. and Kumar, A. (2009). Effect of organics and integrated nutrient management on productivity and economics of *rabi* sorghum. Karnataka Journal of Agricultural Sciences. 22(1): 11-14.

Sharma, A.R., Singh, R., Dhyani, S.K., and Dube, R.K. (2010). Tillage and legume mulching effects on moisture conservation and productivity of rainfed maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. Indian Journal of Agronomy. 55(4): 245-252.

Sharma, R., and Bhardwaj, S. (2017). Effect of mulching on soil and water conservation-A Review. Agricultural Reviews. 38(4): 311-315.

Shashidhar, K.R., Bhaskar, R.N., Priyadharshini, P. and Chandrakumar, H.L. (2009). Effect of different organic mulches on pH, organic carbon content and microbial status of soil and its influence on leaf yield of M-5 mulberry under rainfed condition. Current Biotica. 2: 405-412.

Shittu, O.S., Fasina, A.S. (2006). Comparative effect of different residue management on maize yield at Ado-Ekiti, Nigeria. Journal of Sustainable Agriculture. 28(2): 41-54.

Singh, B., Humphreys, E., Eberbach, P.L., Katupitiya, A. and Kukal, S.S. (2011). Growth, yield and water productivity of zero till wheat as affected by rice straw mulch and irrigation schedule. Field Crops Research. 121(2): 209-225.

Singh, G., Marwaha, T.S. and Kumar, D. (2009). Effect of resource conserving techniques on soil microbiological parameters under long-term maize-wheat crop rotation. Indian Journal of Agricultural Sciences. 79(2): 94-100.

Tang, H., Xiao, X., Tang, W., Guo, L., and Wang, K. (2016). Effects of different mulching models on soil temperature, moisture and yield of maize (*Zea mays* L.) in hilly red soil upland in Southern China. Romanian Agricultural Research. 33: 169-177.

Taufiq, A., Wijanarko, A. and Kristiono, A. (2017). Effect of mulching and amelioration on growth and yield of groundnut on saline soil. Journal of Degraded and Mining Lands Management. 4(4): 945-954.

Thakur, M., and Kumar, R. (2020). Mulching: Boosting crop productivity and improving soil environment in herbal plants. Journal of Applied Research on Medicinal and Aromatic Plants. 100287.

Tisdall, J.A., Baverly, R.D. and Radcliffe, D.E. (1991). Mulch effect on soil properties and tomato growth using micro-irrigation. Agronomy Journal. 83: 1028-1034.

Zhang, D., Yao, P., Na, Z., Cao, W., Zhang, S., Li, Y., and Gao, Y. (2016). Soil water balance and water use efficiency of dryland wheat in different precipitation years in response to green manure approach. Scientific Reports. 6(1): 1-12.

Zhao, Y., Pang, H., Wang, J., Huo, L., Li, Y. (2014). Effects of straw mulch and buried straw on soil moisture and salinity in relation to sunflower growth and yield. Field Crops Research. 161: 16-25.