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Impact of mulching materials on weeds dynamics, soil biological properties and lettuce (*Lactuca sativa* L.) productivity

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Abstract
Chemical control of weeds in lettuce crop brings damaging effects on soil microorganisms and reduces produce quality. It is therefore essential to explore effective and safe weed management approaches. Hence, a repeated field experiment was conducted to investigate the impact of black plastic mulch, wheat straw, rice husk, saw dust and manual weeding on weeds, soil health and lettuce yield. The minimum inhibitory effect on fresh and dry weight (gm^{-2}) of weeds was recorded by rice husk whereas highest was noted by the application of wheat straw. However, expensive hand weeding was found to be superior in managing weed infestation. Maximum lettuce plant height, number of leaves $plant^{-1}$, head diameter, fresh weight, dry weight and yield was obtained from manually weeded and wheat straw mulch treated plots. The application of wheat straw as mulch caused an increase of 1.59%, 12.35%, 14.02%, 4.13%, 7.56%, 6.39%, 14.33% and 18.6% in net return, soil dehydrogenase activity, β-glucosidase activity, urease activity, microbial biomass carbon, nitrogen, phosphorus and bacterial population, respectively over control. It is suggested that wheat straw mulch could be used to get better economic return, improve lettuce yield, inhibit weed growth and enhance soil biological functioning.

Keywords: benefit-cost ratio, lettuce, mulches, microorganisms, soil enzymes, weeds

1. Introduction

Weed control is a major constraint in profitable lettuce (*Lactuca sativa* L.) production, as it is expensive, time-consuming and causing severe yield losses when failing to ensure an adequate weed management (Kristiansen *et al*., 2008) [22]. Earlier growth stages of lettuce seedlings need to be kept weed free, as it is very sensitive to weed competition due to shallow root system (Isık *et al*., 2009). Weed management in conventional lettuce crop is normally based on effective combination of chemicals and cultivation practices, such as mechanical tillage, hoeing and hand weeding (Fennimore & Richard, 1999) [13]. Presence of intra-row weeds not targeted by usual cultivation practices and restricted use of herbicides makes weed management more difficult in lettuce, especially in organic crop production systems (Van Der Weide *et al*., 2008) [46].

In Pakistan average yield loss by weeds in many crops is much higher (11.5%) than global average (9.5%) (Rabbani *et al*., 2013) [28]. Yield and quality of vegetable crops is greatly reduced by weeds in hand-harvested crops, such as lettuce (Shem-Tov *et al*., 2006) [34]. In lettuce 20 to 40% yield loss occurred if weed cover of 25% is present and complete crop failure has been observed at 50% weed cover (Lanini & Le Strange, 1991) [24]. The cost of weed control in commercial lettuce is about 11% of the total production cost of lettuce (Tourte & Smith, 2001) [41]. Because of limited selective herbicides, the weed suppression costs for lettuce are very high (Bell *et al*., 2000) [5]. High market and quality values, small growth phases and concerns to damage caused by herbicides restrict the registration of new herbicides for lettuce (Ryder, 1999) [29]. Weeds result in more annual losses in crops as compared to insect, pest and diseases (Khan *et al*., 2008) [20]. Therefore, it is most important to control weeds population for better crop production.

Now a day, people prefer to consume vegetables which are produced without inorganic fertilizer because they are suffering from severe diseases as a result of residual toxicity of plant protection chemicals (Asao *et al*., 2014) [3]. It is well known fact in salad farming that the use of mulch improves the value of crops (Verdial *et al*., 2001) [45]. Mulch is a natural (straw, sawdust, herbage and other materials) or synthetic (polyethylene) material which is used for protection of plant from chilling, drought and other stresses like weeds. Also, it is considered as an agro technique which can significantly modify micro-environment of plants (Siwek *et al*. 2007) [35]. Mulching is one of the management practices for increasing water use efficiency and weed control in crop fields (Unger & Jones, 1981) [43]. Different types of materials such as wheat straw, rice straw or husk, plastic film, grass, wood, sand, oil layer etc. are used as mulch (Khurshid *et al*., 2006; Seyfi & Rashidi, 2007) [21,. 33]. Previous researchers (Tolk *et al*., 1999) [40] reported that mulch application caused an increase of 19% in above ground biomass and grain water use efficiency was enhanced by 14% as compared to un-mulched soil. Water saving of more than 50% was achieved with the use of plastic cover over the naked soil and the importance of soil coverage is further enhanced under water limited conditions. Mulch provides a better soil environment, moderates soil temperature, increases soil porosity and water infiltration rate during intensive rain as a result of better runoff, erosion and weed control (Bhatt & Kheral, 2006; Anikwe *et al.*, 2007; Glab & Kulig, 2008) [7, 2, 14]. Organic mulches perform additional functions of increasing soil organic matter content, CEC, enhancing biological activity, improving soil structure and boosting plant nutrients after decomposition (Tian *et al.*, 1994; Lal, 1995) [39, 23].

A lot of work has been done on different methods of weed control in lettuce but work on weed control by natural and synthetic mulches is scanty and non-systemic. Therefore, the current research trial was intended to achieve the following objectives: (i) To compare which mulching material prolonged weed control in lettuce crop (ii) To find out which mulching material is conducive for maximizing the lettuce yield and soil biological properties (iii) To determine which mulch material is cost effective.

2. Materials and Methods

Field experiment was conducted in Research Area, College of Agriculture, University of Sargodha situated in sub-tropical (32.08° N latitude, 72.67° E longitude) semi-arid climate of the central Punjab, Pakistan during 2016-2017. The experiment was conducted on sandy loam soil (Table 1). Daily precipitation, relative humidity, minimum and maximum temperature during the crop growth period were recorded from the weather station of Punjab Agriculture Department (In-service agricultural training Institute, Sargodha) situated near the experimental field (Figure 1). The experiment was laid out in a randomized complete block design (RCBD) with four replications having a net plot size of 6 m × 1.8 m. The experiment comprised black plastic mulch (0.05 mm), wheat straw mulch, rice husk mulch and saw dust mulch each at 2 tha^{-1}, along with a weed free treatment.

Lettuce nursery was planted on 8th of December, 2016 and transplanted to field on 3rd January, 2017 in 30 cm apart rows maintaining a plant spacing of 30 cm. The mulches were applied in the field just after transplanting as per treatment. Manual hoeing was done at regular intervals to keep the plots free of weeds in weed free treatment. Ten plants were selected at random to record data on number of leaves plant^{-1}, plant height (cm), head diameter (cm) and fresh weight following standard procedure. The lattuce yield was recorded on per plot basis and was converted to tha^{-1}. The data on density and biomass of weed was recorded from two quadrates of 1m^2 randomly from each plot.

Soil samples were collected from root zone at suitable time after application of treatments and analysed for soil dehydrogenase activity (Tabatabai, 1994) [37], β-glucosidase activity (Eivazi and Tabatabai, 1994) [37], urease activity (Kandeler and Gerber 1988) [19], microbial biomass C (Vance *et al*., 1987) [44], microbial biomass N (Vance *et al*., 1987) [44], microbial biomass P (Brookes *et al*., 1982, 1985) [9, 8], fungal biomass (Ergosterol) (Djajakirana *et al*.,1996) [11] and bacterial population (Azmi and Chatterjee 2016) [4].

Net income was calculated as:

$$Net\ income = \text{Gross income} - \text{Gross investment}$$

(CIMMYT, 1988).

The recorded data was analyzed by using Fischer's analysis of variance technique and treatment means were compared at 5% significance level by using least significant difference test (Steel *et al*., 1997) [36]. The Sigma Plot 2009 (Version 11.0) software was used for graphical representation of the data.

3. Results & Disscussions

Effect of mulching on growth and yield of lettuce

The impact of different mulching practices on number of leaves plant^{-1} was significant (Figure 2). The highest number of leaves plant^{-1} (19.9) was recorded in weed free plots which were statistically similar to wheat straw mulch. The lowest number of leaves plant^{-1} (13.9) was recorded with saw dust mulch. The increase in number of leaves plant^{-1} of lettuce observed in manual weeding and wheat straw mulch treated plots might be due to lower competition between lettuce plant and weeds (Figure 8&9). The lettuce plant might have utilized available resources at more efficiently due to reduced weed interference. These results are in line with Bhatt *et al*. (2004) [6] and Khurshid *et al*. (2006) [21] who reported that organic mulches improved the number of leaves plant^{-1} of lettuce. An increase in the number of lettuce leaves plant^{-1} with the application of organic and inorganic mulches as compared to un-weeded control has also been reported by Jenni *et al*. (2004) [17].

The height of lettuce was affected by different mulching treatments (Figure 3). The highest value was recorded with weed free (85.1 cm) which however, was statistically at par with wheat straw and plastic mulch. As weeds were not allowed to compete with lettuce in weed free treatment, more resources were available for lettuce plants which ultimately attained greater height. A significant increase in plant height of pea with the application of organic mulches has also been reported by Sajid *et al*. (2013) [30]. Weed free treatment resulted in highest head diameter (67.3 cm) of lettuce, which was statistically similar with plastic and wheat straw mulch treatments. However, lowest (48.6 cm) head diameter of lettuce was observed in plot where saw dust was used as a mulching material (Figure 4). The higher lettuce head diameter with manual weeding might be due to the maximum weed control that enhanced the photosynthetic rate and chlorophyll contents by providing optimum nutrients, space, light and water to lettuce plant. Our results are supported by the findings of Salehi *et al*. (2013) [31] who found a significant positive effect of mulches on lettuce head diameter. Fontanetti-Verdial *et al*. (2001) [45] studied the impact of mulch on Iceberg lettuce and identified that plastic mulch significantly enhanced the chlorophyll, head weight and dry matter of lettuce plant as compared to un-mulched plots. Our results are also supported by Jenni *et al*. (2004) [17] who reported that plastic and organic mulch reduced weed growth which in turn resulted in significantly heavier heads as compared to un-mulched plots.

The fresh and dry weight of lettuce varied significantly due to different mulching practices (Figure 5&6). The weed free treatment resulted in highest fresh and dry weight and was statistically similar to wheat straw mulch. Similarly, rice husk and saw dust mulches produced lower lettuce fresh and dry weights than all other mulching treatments. It was probably due to poor soil moisture retention and weed suppression by these mulching materials. The higher lettuce fresh and dry weight in case of manual weeding and wheat straw mulch was probably due to the greater number of leaves, plant height and head diameter. The results are in agreement with the findings of Salehi *et al*. (2013) [31] who reported a significant increase in lettuce fresh weight with the application of mulches. Fontanetti-Verdial *et al*. (2001) [45] also reported an increment in lettuce dry weight due to mulching which was the result of better nutrients availability, optimum soil temperature and moisture. Different mulch treatments significantly influenced total yield of lettuce (Figure 7). The highest lettuce yield (16.7 t ha^{-1}) was recorded in plots where manual weeding was done and it was statistically at par with straw mulch and plastic mulch treated plots. The differences between plastic mulch and rice husk mulch could not reach to the level of significance. The lowest lettuce yield (12.7 t ha^{-1}) was obtained from plots where saw dust was used as mulching material and it was statistically at par with plots where rice husk was used as mulch. The superior performance in term of total lettuce yield presented by manual weeding, wheat straw and plastic mulch treatments when compared to others can be explained by maximum suppression of weeds and improvement in soil biological health which resultantly improved the availability of water and minerals to lettuce plants. The better growth of plants grown in plots where plastic mulch was applied is in line with the findings of Iqbal *et al*. (2009) [16] who reported a significantly higher vegetative growth as well as fruit yield of hot pepper hybrids mulched with black plastic. Our results are also in agreement with the findings of Salehi *et al*. (2013) [31] who reported a significant increase in lettuce yield with the application of organic mulch. However, our results are contradictory to the findings of Mulvaney *et al*. (2011) [16] who reported that collard yield was not affected by any mulch treatment which may be due to variable response of different species to mulching.

Effect of mulching on fresh and dry weight of weeds

Effect of different mulching materials on fresh and dry weight of weeds is presented in figure 8 and 9. A significant reduction in weeds fresh and dry weight was observed with all mulch treatments. The maximum fresh and dry weight of weeds 399.24 gm^{-2} and 58.29 gm^{-2} respectively, was recorded in plots where rice husk was applied as mulch material. All other mulching treatments resulted in significantly lower weed biomass compared with rice husk mulch, however the differences among plastic, wheat and saw dust mulch could not reah to the level of significance (Figure 8, 9). Among various mulching materials, rice husk showed poor weed inhibition. This might be due to inability of rice husk to block the light availability to weeds. Broad leaves and grass weeds were found in the experimental plots. Essien *et al*. (2009) [12] reported that different organic mulches have different ability to suppress the weed growth. These results are in accordance with the findings of Thayalaseelan *et al*. (2017) [38] who observed variability in weeds control efficacy of different mulches. Our results are also in conformity with the findings of Seigler (1996) [32] who revealed that organic mulches reduced weed growth by decreasing the soil temperature and act as a physical obstacle that hinder the light needed for weed seed germination that ultimately decreased fresh weight of weeds. Sajid *et al*. (2013) [30] also stated that organic mulches significantly decreased the weeds biomass in pea crop. Awodoying & Ogunyemi (2005) also supporting our finding by observing that weed control efficiency of different types of mulches ranged from 27 to 97%. The weeds were able to emerge through the rice husk and produced greater biomass as compared to other mulches. A similar difference in weed dry weight due to the application of rice straw, saw dust, clover weed and cogen grass was recorded by Abouziena *et al*. (2015) [1]. Our observations are also in line with the findings of Thayalaselan *et al*. (2017) who reported that weed composition and biomass were lowest in live mulched plots.

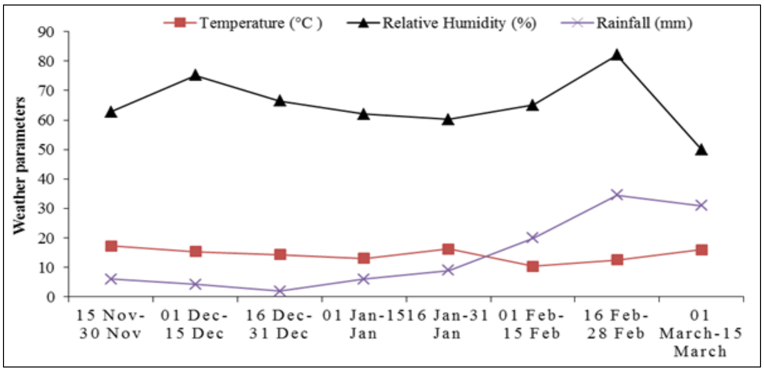

Fig 1: Rainfall, temperature and relative humidity for the growing period of lettuce during 2016-2017

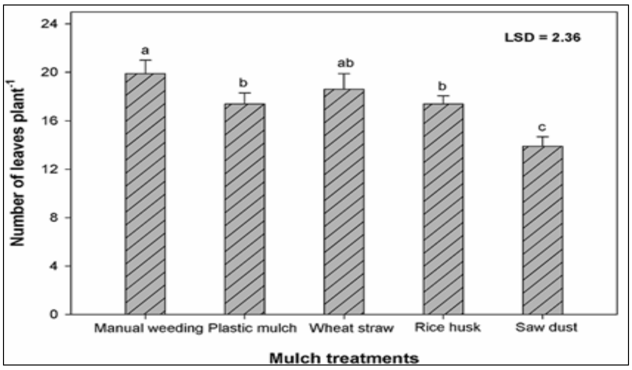

Fig 2: Effect of different mulching materials on lettuce number of leaves per plant

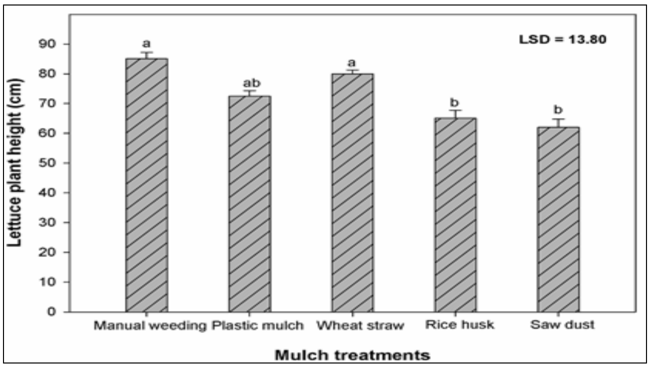

Fig 3: Effect of different mulching materials on lettuce plant height (cm)

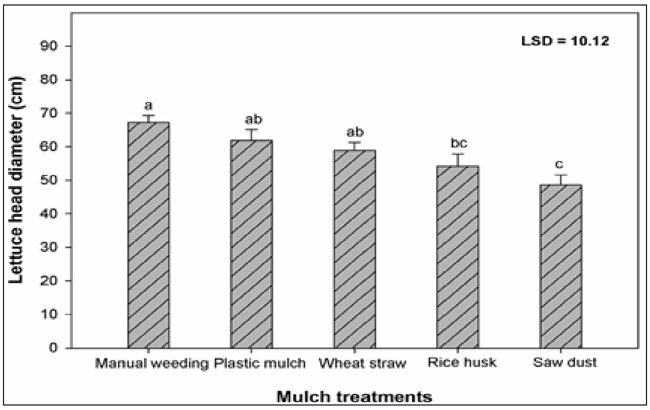

Fig 4: Effect of different mulching materials on lettuce head diameter (cm)

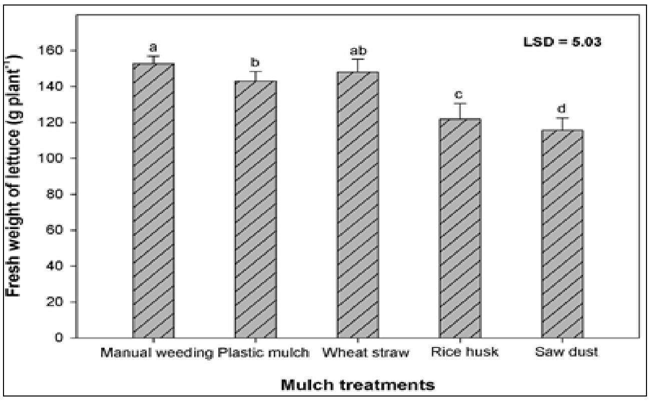

Fig 5: Effect of different mulching materials on fresh weight of lettuce (g plant^{-1})

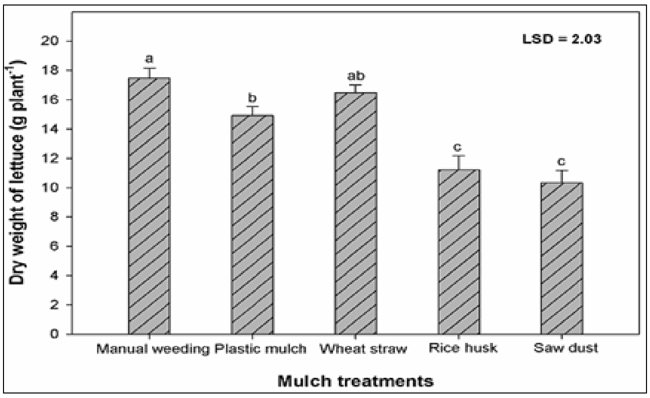

Fig 6: Effect of different mulching materials on dry weight of lettuce (g plant^{-1})

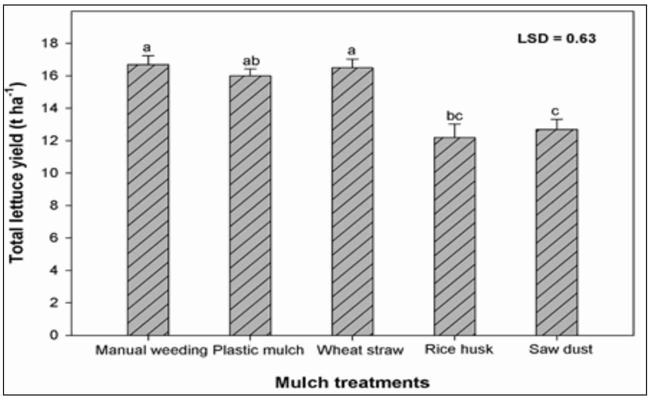

Fig 7: Effect of different mulching materials on lettuce yield (t ha^{-1})

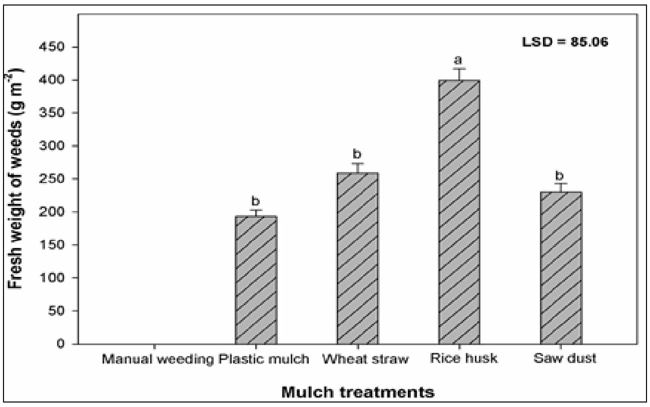

Fig 8: Effect of different mulching materials on fresh weight of weeds (g m^{-2})

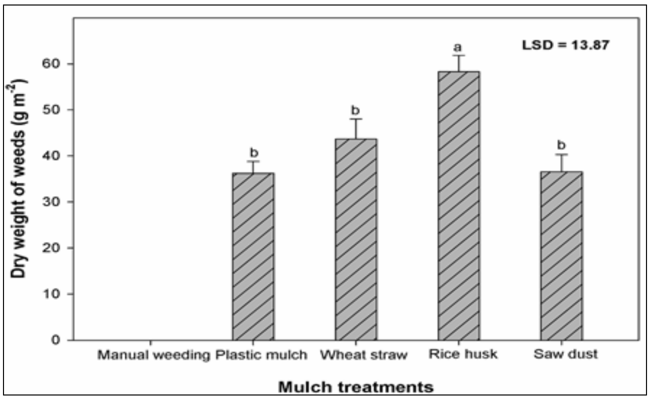

Fig 9: Effect of different mulching materials on dry weight of weeds (g m^{-2})

Effect of mulching on soil biological Properties

Dehydrogenase activity of soil was affected significantly by mulching treatments (Table 2). The maximum dehydrogenase activity (20 µg TPF g^{-1} soil h^{-1}) was observed where mulching of wheat straw was used which was followed by manual weeding (17.8 µg TPF g^{-1} soil h^{-1}) which was probably due to improved aeration and moisture conservation However, the minimum dehydrogenase activity (15.3 µg TPF g^{-1} soil h^{-1}) was recorded where saw dust mulch was used. A significant increase in β-Glucosidase activity of soil was observed with all mulch treatments (Table 2) over weed free which was due to higher quantity of organic matter in mulched soil. While, the plots covered with wheat straw recorded highest activity of β-Glucosidase (34.22 µg PNP g$_{-1}$soil h$_{-1}$) in soil which however was statistically similar to manual hoeing. The β-Glucosidase activity in plots treated with plastic mulch, rice husk and saw dust was statistically similar. The urease activity ranged from 3.70 to 5.29 µg NH4+g^{-1} soil h^{-1} (Table2). The activity of the urease enzyme in wheat straw mulched plots was the highest when compared with plastic mulch, rice husk and saw dust. The minimum value of urease activity was observed in saw dust mulch which however, did not differ significantly from plastic mulch treatment. The increase in dehydrogenase and β-Glucosidase activity of soil by wheat straw might be due to the rapid decomposition of wheat straw that added more organic matter into the soil. Coolong (2012) [10] stated that straw mulching increase soil health by improving soil structure, soil organic matter, mineral nutrient availability and enhanced soil bioactivity. Yang *et al*. (2003) [48] also reported increased soil dehydrogenase activity in grass mulch treated plots than no mulch plots. A minor influence on the soil β-Glucosidase activity by the application of wheat straw mulch was also reported by Lombao *et al*. (2015) [25]. Increase in urease activity due to application of wheat straw mulch is in accordance with the results of study conducted by Lombao *et al*. (2015) [25] who reported higher values of urease activity in the soil with the application of straw mulch. These results are also supported by the findings of Zhang *et al*. (1992) [49] who studied the effect of straw mulching on maize and rhizosphere soil micro-ecological environment and found that straw mulching significantly improved soil urease enzyme.

Microbial biomass C was significantly influenced by all mulch treatments (Table 3). The highest microbial biomass C (81.05 µg g-1 soil) was noted with organic mulch of wheat straw. Mulch materials namely saw dust, rice husk and plastic mulch showed lower microbial biomass C as compared to wheat straw (Table 3). The perusal of data presented in table 3 also indicated that maximum (15.30 µg g-1 soil) microbial biomass N was recorded in plots where mulch of wheat straw was applied and it was followed by the manual weeding. Plastic and saw dust mulch resulted in statistically similar microbial biomass N. However, minimum (9.90 µg g-1 soil) microbial biomass N was recorded in plots where saw dust mulch was applied. In case of microbial biomass P, wheat straw, rice husk and manual weeding produced statistically similar results. However, maximum microbial biomass P (6.70µgg-1soil) was recorded where wheat straw mulch was applied. Whereas, minimum microbial biomass P (5.11µgg-1soil) was recorded in plots where saw dust was used as a mulch material (Table 3). Among all the treatments, highest bacterial population (7.19 x105 $CFUg_{-1}$ soil) was obtained in plots where mulching of wheat straw was used. Minimum soil bacterial population was recorded in saw dust mulched plots which was statistically similar to plots covered with plastic mulch (Table 3). Bacterial population in manually weeded and rice husk mulch plots were intermediate and statistically similar. The decrease in the soil microbial biomass C, N and P with saw dust might have been due to less aeration and concomitant poor decomposition of saw dust mulch that reduced the availability of these minerals in the soil. The observed increase in microbial biomass C, N and P in plots treated with wheat straw mulch might be due to rapid decomposition of wheat straw in the soil. These results are in agreement with Goyal *et al*. (1999) [15] who revealed that mulching of wheat straw significantly enhanced the microbial biomass C and microbial activity. These findings are in agreement with previous report (Lombao *et al*., 2015) [25] who indicates that the application of wheat straw mulch brought a slight improvement in soil microbial biomass C. Our results are in accordance with the findings of Tu *et al*. (2005) [42] who found that application of wheat straw mulch enhanced the microbial biomass N by 30% as compared to non-mulched soils. The findings of Jodavgiene *et al*. (2010) also support our results as they reported that C: N ratio of grass mulch was more favorable for increasing microbial biomass N than saw dust mulch. These results are in accordance with the findings of Goyal *et al*. (1999) [15] who stated that organic mulches such as wheat straw imparted significant effect on soil health and enhanced the soil microbial activity as compared to inorganic mulches. Our findings are also in conformity with the results of Munoz *et al*. (2017) who revealed that application of wheat straw mulch enhanced the microbial biomass in soil as compared to plastic mulch treatment. In our experiment all mulch treatments improved the bacterial population in soil except saw dust. The results are in conformity with the findings of Yang *et al*. (2003) [48] who revealed that soil bacterial population was improved significantly in the grass mulch treated plots as compared to control. The similar results are also reported by Jodaugiene *et al*. (2010) who stated that as compared to no mulch treated plots bacterial population in the soil improved significantly where straw mulch was applied. Xishi *et al*. (1998) [47] also reported 22.6% increase in soil bacterial population with the application of mulch over no mulch plots.

Economic analysis

The net income of organic weed control practices was recorded as Rs. 596700, 587350, 558400, 459500 and 432500 with wheat straw mulch, manual weeding, plastic mulch, rice husk mulch and saw dust mulch, respectively (Table4). Wheat straw mulch had maximum net return followed by manual weeding. Higher net return in wheat straw mulched plots was due to less cost of production as compared to expensive manual weeding. The highest (5.40) benefit-cost ratio was obtained in case of wheat straw treated plots which was followed by plastic mulch (4,74). However, minimum benefit-cost ratio was recorded when weeds were controlled by using saw dust mulch.

Table 1: Pre-sowing soil properties

Parameter	Values	Status
EC (1:2.5) d Sm-1	0.23	Non Saline
Total soluble salts	12.12%	Medium
pH	7.9	Medium alkaline
Organic matter (%)	0.89	Medium
Total Nitrogen (%)	0.58	Medium
Available P (ppm)	11	Medium
Extractable K (ppm)	118	Medium
Extractable Na (ppm)	0.9	Medium
Olsen's P (ppm)	16.8	High

Table 2: Influence of different mulching material on Dehydrogenase, β-Glucosidase and urease activity of soil

Treatments	Dehydrogenase activity (µg TPF g-1 soil h-1)	β-Glucosidase activity (µg PNP g-1 soil h-1)	Urease activity (µg NH_4+ g-1 soil h-1)
Manual weeding	17.8 ab	30.01 ab	5.08 b
Plastic mulch	15.7 b	26.55 b	3.79 d
Wheat straw	20.0 a	34.22 a	5.29 a
Rice husk	16.9 b	28.63 b	4.84 c
Saw dust	15.3 b	25.85 b	3.70 d
LSD (0.05)	2.95	5.42	0.19

Means not sharing same letter in a column differ significantly at $p \leq 0.05$, LSD = Least significant difference

Table 3: Influence of different mulching materials on microbial biomass C, N, P and

Treatments	MBC (µg g-1 soil)	MBN (µg g-1 soil)	MBP (µg g-1 soil)	Bacterial population (x10^5 CFU g-1)
Manual weeding	75.35 b	14.38 ab	5.86 ab	6.09 b
Plastic mulch	60.70 d	10.93 c	5.15 b	4.83 c
Wheat straw	81.05 a	15.30 a	6.70 a	7.19 a
Rice husk	73.77 c	13.26 b	6.40 a	5.98 b
Saw dust	58.82 e	9.90 c	5.11 b	4.40 c
LSD (0.05)	1.54	1.67	1.24	0.97

MBC: Microbial biomass - C, MBN: Microbial biomass - N, Microbial biomass – P, CFU: Colony forming unit, Means not sharing same letter in a column differ significantly at $p \leq 0.05$, LSD = Least significant difference

Table 4: Economic analysis of lettuce production as influenced by different mulch treatments

Treatments	Yield (t ha^{-1})	Gross income	Total cost (Rs. ha^{-1})	Net return (Rs. ha-1)	Benefit cost ratio
Manual weeding	16.72	752400	165050	587350	4.56
Plastic Mulch	15.73	707850	149450	558400	4.74
Wheat straw	16.27	732150	135450	596700	5.40
Rice husk	13.31	598950	139450	459500	4.29
Saw dust	12.71	571950	139450	432500	4.10

Green lettuce price = Rs. 45 kg-1

4. Conclusions
From the results of this experiment it can be concluded that among all the mulching treatments, wheat straw mulch has the potential to give better economic return by improving lettuce yield through inhibiting weed growth and enhancing soil biological functioning.

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