Review Article

# Comparison of Organic Mulches with Various Weed Control Strategies for Weed Management in Maize

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**Abstract** |A field study was conducted to investigate and compare the performance of organic living mulches (legumes cover cropping) with conventional weed control practices in maize crop. The experiment was carried at the New Developmental Farm, the University of Agriculture, Peshawar during Rabi season 2021, using Randomized complete block (RCB) design with ten treatments, replicated three times. Data was recorded on days to 50 % tasseling, silking, and maturity, plant height, fresh weed biomass, dry weed biomass, weed species composition, biological yield, thousand grain weight, grain yield, harvest index and cost benefit ratio. The results showed that both the herbicides (Atrazine and Stomp 300 EC) were effective in weed control having lowest fresh weed biomass of 29.31 and 32.65 kg ha$^{-1}$, respectively. Maximum biological yield (8309.7 kg ha$^{-1}$) was recorded in cowpea as living mulch while minimum biological yield (5909 kg ha$^{-1}$) was recorded in control treatment. Similarly, maximum grain yield (2883.3 kg ha$^{-1}$) was recorded in mung-bean as living mulch and minimum grain yield (2364.7 kg ha$^{-1}$) was recorded in cucumber used as living mulch. Similarly maximum days to maturity (129.67) was noted in water melon, followed by cowpea as living mulch took (117.67). Maximum number of grains were recorded in cowpea (270.33), while minimum number of grains were recorded in control. Cost benefit ratio revealed that hand weeded treatment excelled among all the other applied treatments with a ratio of (1: 5.44) followed by water melon mulch having ratio of (1: 5.04) and Stomp 330 EC (1: 3.74). It is concluded that herbicides followed by living mulches of cowpea and mung-bean significantly improved growth and yield attributes of maize crop. Whereas, the cost-benefit analyses revealed that hand weeding and watermelon mulch were the most economical. However, for sustainable maize cultivation integration of hand-weeding and legume mulches is the best choice.

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**Keywords** | Organic mulches, Weed management, Weed biomass, Maize yield, Cost/Benefit analysis

## Introduction

Maize (*Zea mays* L.) stands as the third most widely cultivated crop globally after wheat and rice. Maize is contributing as a staple food in 94 developing countries (Shiferaw *et al*., 2011; Lan *et al*., 2020). Maize constitutes 30%, 38%, and 6.5% of the food source, across the America, Africa, and Asia, respectively, and play a significant role in global food security (FAOSTAT, 2019). Its adaptability to diverse agro-climatic conditions makes it an essential food for over 4.5 billion people in 94 low and medium income Countries (LMICs), providing at least 30% of the food calories (Anonymous, 2016). In Pakistan, maize ranks as the third major cereal crop and second in Khyber Pakhtunkhwa after wheat (PARC, 2007; Asim *et al*., 2012). In Pakistan maize is cultivated on an area of 1042 thousand hectares, yielding 3109.6 thousand tons with an average yield of 2984 kg $ha^{-1}$. Khyber Pakhtunkhwa, contributes significantly to these figures, where maize is cultivated over an area of 492.2 thousand hectares, producing 782.4 thousand tons with an average yield of 1590 kg $ha^{-1}$. The global maize production, reaching 1,124 million tons during 2018-19 (FAOSTAT, 2019), while maize contributes 6.4% to the total food grains in Pakistan (Rehman *et al*., 2008).

Despite its potential significance, maize cultivation faces several challenges, particularly weed infestations which causing substantial yield losses of 38% in Pakistan (Hassan and Marwat, 2001). Globally, weeds induce an average yield loss of 12.8% and 29.2% in the absence of weed control practices. Traditional weed management practices, particularly chemical applications, increase environmental concerns, therefore a shift towards sustainable alternatives is needed. Mulching, including the use of living mulches, emerges as a promising weed control strategy. Mulching involves covering the soil with crop materials to suppress weed growth, reduce erosion, enhance soil quality and regulate temperature. However, living mulches are considered as cover crops which compete for resources and suppress weed growth (Saudy *et al*., 2021). Whereas, organic mulches such as straw, hay, grass, or leaf matter, and cover crops offer numerous benefits for organic maize production. They suppress weeds, preserve soil moisture and increase nutrient availability (Shen *et al*., 2012; Jemal and Berhanu, 2020).

Moreover, the optimal growth conditions for maize, need warm soil, adequate space, sunlight, irrigation and well-drained soil with a pH between 6.0-6.8. Considering these factors, we need to explore sustainable practices for increase maize productivity. Maize being an exhaustive crop, particularly in its nitrogen requirements, necessitates attention to planting dates and spacing to ensure optimal development. Maize is a good nutritious crop the grains is rich in starch, protein, fiber, oil, and ash (Ahmad *et al*., 2020). However, the average yield of maize in Pakistan is hindered by various factors, where weed infestation is a major biotic constraint which substantially reduce maize yield. Despite the significance of maize cultivation and the challenges posed by weed infestations, there exists a research gap in understanding the potential of integrating living mulches with weed control strategies. Although conventional practices and chemical approaches have been explored, however, comprehensive investigation into the effectiveness of mulches and their economic implications in maize cultivation in Pakistan is lacking.

Considering the potential of living mulches in weed control, we hypothesize that integrating living mulches could reduce weed competition, resulting in increased maize yield. Whereas, the economic outcomes of living mulches in term of reduced herbicides, could be a sustainable weed control strategy for maize cultivation.

## Materials and Methods

*Experimental site description*

An experiment entitled "Comparison of living mulches with various weed control strategies for weed management in maize" was conducted in the New Developmental Farm UAP during Rabi Season 2021. Standard sowing procedures were followed and maize variety "Azam" was planted with various mulch treatments. District Peshawar lies between 34° North latitude and 71.52° East longitude. It is surrounded by a range of high mountains from three sides, with the fourth opening towards Punjab province consist of plains with extensive canal system for irrigation. The climate of Peshawar is hot and semi-arid characterized by very hot, long summer and short winters. District Peshawar does not fall in the Monsoon region. The valley lack irrigation water bot famous for its diverse agriculture.

*Experimental design and field layout*
The experiment was carried out in Randomized complete block RCBD design, having ten treatments replicated three times. Following treatments were used in the experiment.

*Herbicides*
T1= Stomp 330 EC as pre-emergence
T2= Atrazine as post-emergence),
Organic mulches
T3= weeds biomass as mulch),
*Living mulches*
T4= Wild melon (*Cucumis melo* var. *agrestis* L.)
T5= Water melon (*Citrullus lanatus* L.)
T6= Cucumber (*Cucumis sativus* L.)
T7= Mung bean (*Vigna radiata* L.),
T8= Cowpea (*Vigna unguiculata* L.),
T9= Weed free treatment (hand weeding)
T10= Weedy check (control).

*Data was recorded on the following parameters*

1. *Days of tasseling:* Data on days to tasseling was recorded when 50% plants developed tassels in each treatment on visual bases. Data were recorded from day of sowing till 50% tasseling.
2. *Days to silking:* Data on days to silking was recorded when 50% plant developed silks in each treatment. Days were counted from sowing till the completion of 50% silks on visual bases.
3. *Plant height (cm):* Plant height was measured at physiological maturity. Five representative plants were randomly selected from each experimental unit and their height was measured from the ground level or base to the top of the plant and was averaged.
4. *Fresh weed biomass (kg ha$^{-1}$):* To determine fresh weed biomass, all the existing weeds from individual treatments were pulled 8 weeks after sowing, weighed fresh and the data obtained was converted to kg ha$^{-1}$.
5. *Dry weed biomass:* To determine dry weed biomass, all the existing weeds pulled for fresh weight biomass data from individual treatments were dried, then weighed and data obtained was converted into kg ha$^{1}$.
6. *Days to maturity:* Days to maturity were calculated from date of sowing till 75 % of the plants got physiological maturity.
7. *Biological yield (kg ha$^{-1}$):* Biological yield includes cob weight (husks + grains) and Stover weight. Plant of two central rows of each sub-plots were harvested at maturity, air-dried and weighed by spring balance and the data obtained was converted kg ha$^{-1}$ by the formula:

$$Biological\ yield\ (kg\ ha^{-1}) = \frac{(Biological\ yield\ per\ unit\ area\ (kg)}{Area\ harvested\ (m)} \times 10000$$

8. *Number of cobs m$^{-2}$:* The number of cobs m$^{-2}$ were calculated by randomly selecting 1 m$^2$ area in each treatment and counting the number of cobs within it.
9. *Number of grains cob$^{-1}$:* From each sub-plot five cobs were randomly selected and their grains were counted after threshing each cob separately and then averaged.
10. *Thousand-grain weight (g):* Thousand grains were taken randomly from the grain lot of each subplot and weighed by using electronic digital balance. This process was repeated thrice to get average thousand grains weight.
11. *Grain yield (kg ha$^{-1}$):* The grains from two central rows in each treatment were weighed and converted to kg ha$^{-1}$ by the formula:

$$Grain\ yied\ kg\ ha^{-1} \frac{Grain\ weight\ (kg)}{Area\ harvested\ (m^{-2})} \times 100$$

12. *Harvest index (%):* Harvest index was calculated by using the formula;

$$Harvest\ index\ (HI\ \%) \frac{Grain\ yield\ (kg\ ha^{-1})}{Biological\ yield\ (kg\ ha^{-1})} \times 100$$

13. *Cost-Benefit Ratio (CBR):* Cost-Benefit Ratio (CBR) was determined by dividing the added income by adding cost. The added income and added cost were obtained from the added yield due to the use of mulches and hand weeding and their respective costs as compared to weedy check. The added cost were the cost of mulches and hand weeding. Cost-Benefit ratio was calculated by the formula:

$$Cost - Benefit\ Ratio\ (CBR) = \frac{Added\ income}{Added\ cost}$$

*Statistical analysis*
The data recorded individually for each parameter was statistically analyzed for analysis of variance (ANOVA) techniques suitable for Randomized Complete Block Design (RCBD) by using Statistix 8.1 statistical software. Where the F-values were significant, means were compared by using LSD test at 0.05 level of probability, (Steel and Torrie, 1960).

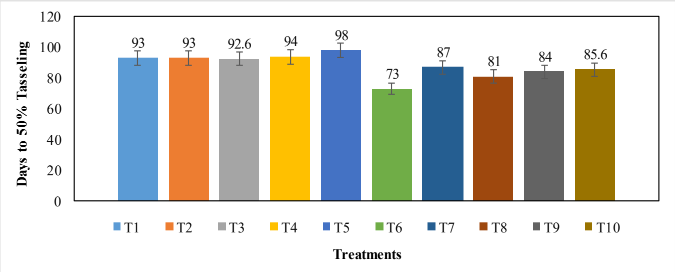


**Figure 1:** *Effect of different treatments on days to 50% tasseling in maize.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check*

## Results and Discussion

*Days to 50% Tasseling*

Statistical analysis of data regarding days to 50% tasseling revealed significant differences among the treatments tested (Figure 1). Maximum days to 50% tasseling were recorded for T5 (water melon as living mulch), which took 98 days for 50% tasseling, followed by T4 (melon as living mulch) by taking 94.33 days to 50 % tasselling. Minimum days for 50% tasseling was recorded for T6 (cucumber as living mulch) by taking 73 days to 50% tasseling in maize crop. The variation in days to 50% tasseling observed for the different treatments indicate that the living mulch considerably affect maize crop development. Increased time to tasseling obtained in T5 and T4, with watermelon and melon used as living mulch respectively, which may be attributed to their growth patterns related with maize plants. These types of mulch may build a more shaded or competitive environment, thereby influencing the maize plant's growth rate and developmental timeline. Contrary, the cucumber mulch (T6) had a shorter period to 50% tasseling, which may suggest that cucumbers do not inhibit or even promote maize development which could be due to lesser competitions for resources or varied shading compared to watermelon and melon. Variations of the tasseling time describe the high effect of the choice of living mulch on growth and other development stages of maize, apparently for differences in light interception, nutrient availability, or competition or soil moisture resulting from such different mulch types. Marahatta (2020) reported that plastic mulched showed the lowest days to for tasseling as compared to straw mulch and no-mulch treatments.

*Days to 50% Silking*

Statistical analysis for data for days to 50% silking showed significant differences among the treatments at $p < 0.05$ (Figure 2). the data shows that maximum days to silking (50%) in maize was recorded for water melon as living mulch, which took 104 days to reach 50% silking, followed by two statistically similar treatments i.e. Stomp 330 EC (100.33) and melon as living mulch (100.33) while minimum days to silking were recorded in cowpea as living mulch (87.33). The data shows significant differences in days to 50% silking of maize among mulching treatments. Apparently, watermelon as a living mulch induced the longest time to silking, which can be due to its influence on temperature conditions, moisture, and nutrient availability in the soil. Cowpea is a legume; therefore, it showed the shortest time to silking by improving soil fertility and reducing competition. Stomp 330 EC and living mulch from melon exhibited similar times to silking, thus their effects on the maize crop were alike. The findings align with Aung and Zar (2023), confirmed that the number of days to silking considerably reduced with the application of mulching, which was attributed to improved soil moisture and temperature. Improvements of such factors favor a quick crop growth, hence accelerating the silking process in maize plants.

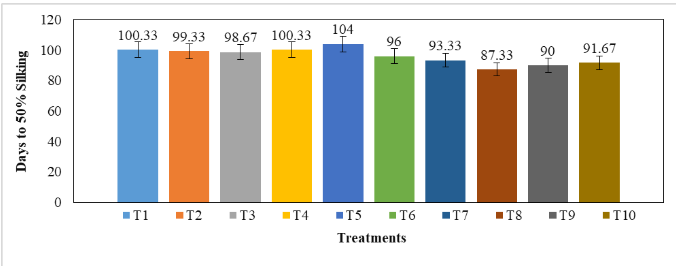


**Figure 2:** *Effect of different treatments on days to 50% silking in maize.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Plant Height (cm)*

Statistical analysis of data showed significant differences at $p<0.05$ among the mean of various treatments tested (Figure 3). Maximum plant height was recorded in cowpea as living mulch (161.8 cm) followed by hand weeding (150.9 cm) while the minimum plant height was recorded in weedy check (103.15 cm). Currently investigation have revealed relationships between plant height and other agronomic factors, including lodging resistance and utilization of advanced technologies for accurate estimation. Stubbs *et al.* (2023) assessed the effect of plant height on the resistance to stalk lodging in maize and found that, there is linear relationship between plant height and lodging resistance; therefore, taller plants may become more susceptible to lodging under such unfavorable conditions as strong winds. Regardless of improving the height of maize, the cowpea mulch treatment may also have a benefit for the physical support of maize plants through improved soil health and nutrient availability for the maize crop and thus reducing lodging risks.

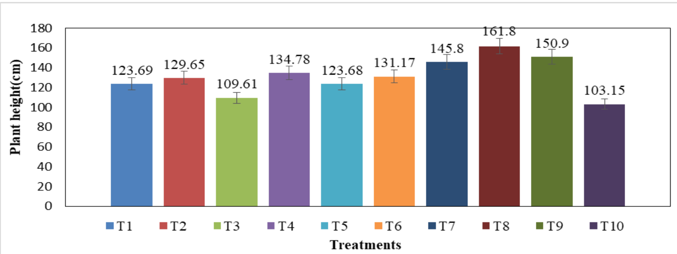


**Figure 3:** *Effect of different treatments on plant height (cm) of maize.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata)), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Fresh weed biomass (kg ha$^{-1}$)*

Statistical analysis of the data revealed significant differences at $p<0.05$ among the means of the treatments tested (Figure 4). Highest fresh weed biomass was recorded for control treatment (500.96 kg ha$^{-1}$). Lowest weed fresh biomass was recorded for Atrazine applied as post-emergence herbicide (29.31 kg ha$^{-1}$). In the present experiment, highest weed was observed in the control plots as compared with the treatments applied. Apparently, the highest weed biomass in the control plot was due to the limited weed management practices which lead to increase in weed biomass. Contrary, the weed biomass in Atrazine treated plot was effectively reduced, thus exposing its potent efficacy. High reduction in weed biomass under Atrazine treatment shows its activity to inhibiting weed growth and competition (Fluttert *et al.*, 2022).

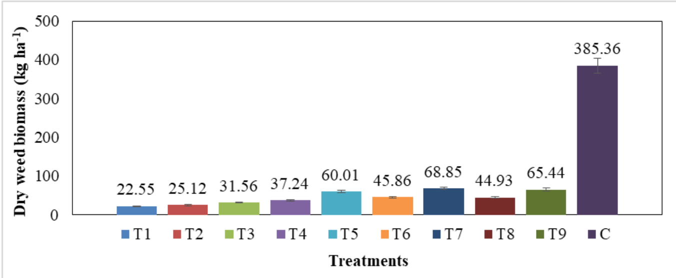


**Figure 4:** *Effect of different treatments on dry weed biomass (kg ha$^{-1}$).*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata)), T9= Weed free treatment as hand weeding and T10= Weedy check.*

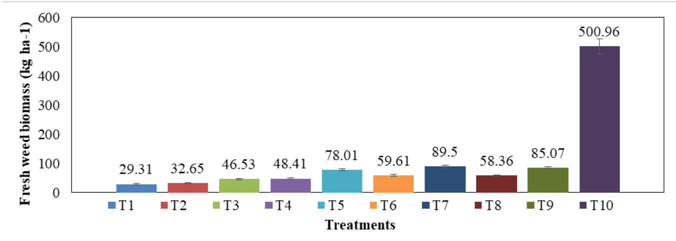


**Figure 5:** *Effect of different treatments on fresh weed biomass (kg ha$^{-1}$).*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata)), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Dry Weed Biomass (Kg ha$^{-1}$)*

Analysis of the data showed that dry weed biomass was significantly ($p<0.05$) affected by various treatments applied. The data presented in Figure 5 showed that maximum dry weight was recorded in weedy check (385.36) followed by mung bean as living mulch (68.85) while minimum data was recorded in Stomp 330 EC (22.55). Highest weed insurgence was observed in the control treatment as compared to the treatments applied. The results show that weedy check has the higher weed biomass because of the higher weed populations. living mulches, such as mung bean, does not completely suppress weeds population, but it can improve soil fertility. However, integrating man-


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ual weeding and legume mulching as well as hand weeding can be reduce weed biomass and improved crop yield (Nwosisi *et al*., 2019).

*Days to Maturity*

Analysis of data shows significant differences at ($p<0.05$) among the means of various treatments tested (Figure 6). The highest number of days to maturity was recorded in water melon as living mulch (129.67 days) followed by melon (128.3) while the lowest number of days to maturity was recorded in cowpea as living mulch (117.67). For instance, days to full maturity was randomly varied from treatment to treatment, with minimum lifespan period being observed was for the mungbean and control treated groups. This may be attributed to full sunlight exposure of the soil leading to minimum or higher soil temperature. Studies have shown that the tasseling and silking stages could be increased by 6 to 8 days while grain maturity could be shortened by about 8 days with the use of mulches such as water hyacinth and rice straw, and earlier with the ash mulch by 5 days. Probably this is due to the temperature regulation in the soil by the mulches themselves, their enhancement for metabolic activities and speeding of other growth processes amounted to. The improved micro-environment in this zone, created by the mulches, is important in maintaining the right temperatures of the soil and other moisture levels and encouraging proper use of water and nutrient uptake by the plant, hence enhancing earliness and better performance of the crop (Awal and Khan, 2000; Jemal and Berhanu, 2020).

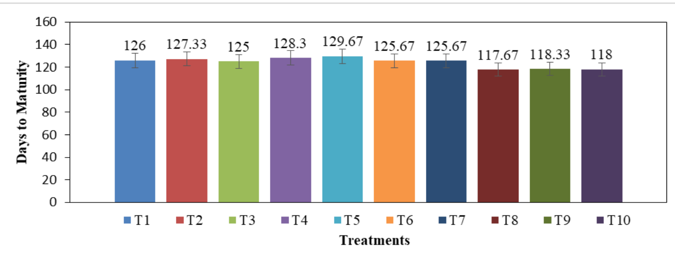


**Figure 6:** *Effect of different treatments on days to maturity.*

*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata)), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Biological yield (kg ha$^{-1}$)*

Statistical analysis of data revealed significant differences at ($p<0.05$) among the means of various treatments (Figure 7). The highest biological yield was recorded in cowpea as living mulch (8309.7 kg ha$^{-1}$) followed by water melon as living mulch (8200 kg ha$^{-1}$) while the lowest biological yield was recorded in weedy check (5909 kg ha$^{-1}$). Biological yield in the present study was noted to be higher under the living mulches. This could be due to the longer root system of Maize vs. the shallow root system of the mulches. The presence of living mulches improved the water holding capacity, infiltration rate and cumulative might have substantially influenced the soil functioning and nutrient supplying capacity thereby contributing to the productivity of Maize crop. Our results are in line with the study of Das and Ghosh (2020) who reported that living mulches positively influences the productivity of summer Maize cropping system.

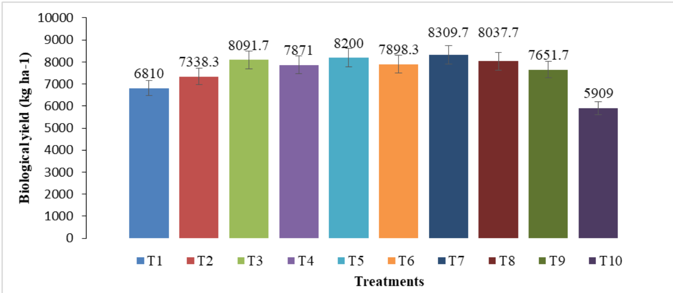


**Figure 7:** *Effect of different treatments on biological yield (kg ha$^{-1}$) of maize crop.*

*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Number of Cobs m$^{-2}$*

Analysis of data shows that significant differences at ($p<0.05$) among various means of different treatments were recorded (Figure 8). Highest number of cobs m$^{-2}$ were recorded in Mung bean as living mulch (5.7) followed by cowpea as living mulch (5.5) while lowest number of Cobs m$^{-2}$ were recorded in herbicide Stomp 330 EC as pre-emergence (3.7). Number of cobs$^{-2}$ amongst the treatment were observed as positively correlated with application of living mulches as compared with the other treatments, with slight range of variance. Cover crop can help to alter prevalence of weed interference by denying weeds the opportunity to use water, light, nutrients as well as soil. Living mulches of legumes effectively suppress weed growth and increase crop productivity. Interestingly, living mulches compete with the weeds for water, light, and other essential resources. However, their efficiency may vary under different conditions or according to management practices (Abdul Rahman *et al*., 2022).

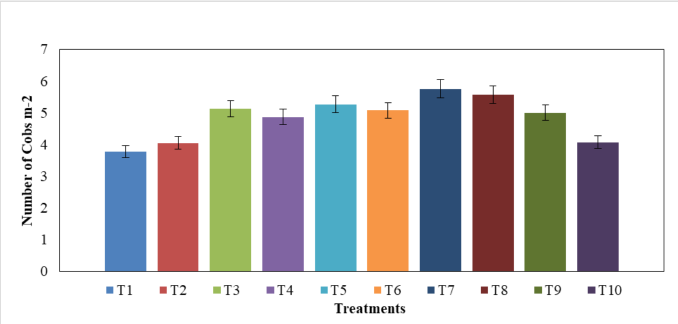


**Figure 8:** *Effect of different treatments on number of cob* $m^{-2}$ *of maize crop.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Number of grains cob*$^{-1}$
Statistical analysis of data shows significant differences at ($p<0.05$) among various means of treatments (Figure 9). Highest number of grains cob$^{-1}$ were recorded in cowpea as living mulch (270.33) followed by hand weeding (262.67) while the lowest number of grains cob$^{-1}$ were recorded in weedy check (197). In our experiment, higher frequency of grains cob$^{-1}$ were noted for living mulches treated plots as compared with the other treatments tested. Yadav *et al*. (2021) also reported corresponding results that living mulches positively enriches the number of grains in summer maize cropping.

*Grain Yield kg ha*$^{-1}$
Table shows that significant differences at ($p<0.05$) were recorded among various means of treatments tested (Figure 10). Highest grain yield ha$^{-1}$ was recorded in mung bean as living mulch (2883.3) followed by cowpea as living mulch (2808) while lowest grain yield ha$^{-1}$ was recorded in cucumber as living mulch (2364.7). The living mulch Cowpea and Mung bean were the greater contributor of the grain yield in the present study, which may be attributed to their leguminous nature that enriches the soil by fixing Nitrogen and Phosphorus in the root zone, weed biomass as mulch treatment also responded positively to grain yield in Maize crop. The findings of the study are aligning with Yadav *et al*. (2021) who reported that cowpea as living mulch enhances the grain yield in summer Maize cropping system.

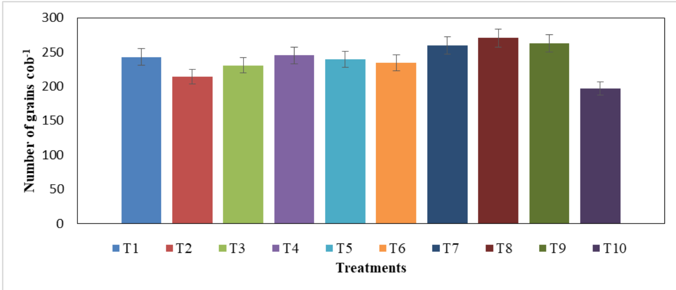


**Figure 9:** *Effect of different treatments on number of grain cob*$^{-1}$ *of maize crop.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check.*

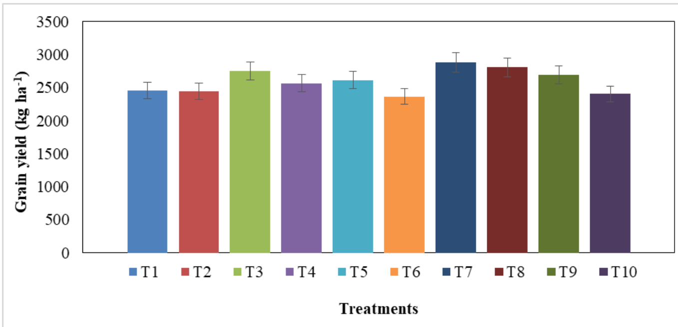


**Figure 10:** *Effect of different treatments on grain yield (kg ha*$^{-1}$*) of maize crop.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Harvest Index (%)*
Statistical analysis of data revealed that significant difference at ($p<0.05$) among various means of different treatments (Figure 11). Highest harvest Index was recorded in mung bean as living mulch (43.703) followed by weedy check (40.91) while the lowest

harvest index was recorded in cucumber as living mulch (29.61). In the present experiment maximum harvest index was observed for Cowpea living mulch treatment. Increase in harvest index and yield attributes in maize crops due to the presence of living mulches of legumes have been reported by Das *et al.* (2020). Living legume mulches, therefore, strongly enhance the harvest index of maize through improvement in soil quality, weed control, and optimization of resource use. Being living mulches, legumes increase the organic matter and nutrient availability in the soil, especially nitrogen, which is important for maize growth. A few studies have estimated that living legume mulches could enhance maize grain yield. Reports indicate that under certain conditions, this increase could be as high as 37%. In addition, living legume mulches are said to suppress weeds, reducing competition for light, water, and nutrients. This means promoting maize productivity. Legumes can enhance soil water-holding capacity and hence promote microbial activity, making the soil more hospitable to maize roots.

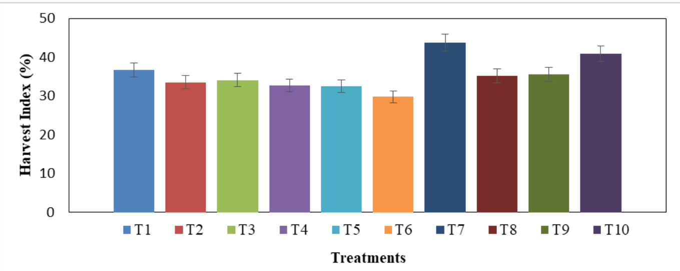


**Figure 11:** *Effect of different treatments on harvest index (%) of maize crop.*
*T1= Stomp 330 EC as pre-emergence and T2= Atrazine as post-emergence), organic mulches (T3= weeds biomass as mulch), Living mulches (T4= melon (Cucumis melo), T5= water melon (Citrullus lanatus), T6= cucumber (Cucumis sativus), T7= mung bean (Vigna radiata), T8= cowpea (Vigna unguiculata), T9= Weed free treatment as hand weeding and T10= Weedy check.*

*Cost-Benefit Ratio (CBR)*

It is the ratio between added cost and added income of weed management practices. The enumerated data shown in the Table 1 showed the cost benefit ratio of the weed management practices i.e. herbicides, mulches and hand weeding. The results showed that all the applied treatments considerably increased crop yield and similarly varied in terms of cost. Highest cost benefit ratio (1:5.44) was recorded for hand weeding followed by watermelon (1:5.04) and weed biomass (1:4.67) while the least cost benefit ratio was recorded for Stomp 330 EC (1:3.74) and Cucumber (3.77). The cost benefit ratio further revealed that hand weeding and living mulch (watermelon) significantly increased the net income. Among the herbicide, Atrazine enhanced crop yield but due to environmental concern as compared to hand weeding and mulch treatments, it should be discouraged.

**Table1:** *Cost-benefit ratio of various treatments.*

| Treatments | Added Income | Added Cost | Net Profit (Rs.) | Cost Benefit Ratio |
|---|---|---|---|---|
| Atrazine | 83100 | 19450 | 64614 | 4.27 |
| Stomp 330 EC | 76700 | 20500 | 56745 | 3.74 |
| Weed Biomass | 81400 | 17430 | 64407 | 4.67 |
| Melon | 75900 | 17250 | 59308 | 4.41 |
| Watermelon | 85810 | 17000 | 69830 | 5.04 |
| Cucumber | 71050 | 18800 | 50569 | 3.77 |
| Cowpea | 66825 | 17040 | 50845 | 3.92 |
| Mung bean | 84579 | 21500 | 63499 | 3.93 |
| Hand weeding | 86400 | 15880 | 71914 | 5.44 |
| Control | - | - | - | - |

## Conclusions and Recommendations

In the light of results, it is concluded that hand weeding and herbicides effectively suppress weeds growth, however concerning the limitation and adverse effects of herbicides on crop quality and soil health it should be discouraged. Contrary, the positive highest maize yield was observed with living mulches particularly water melon, followed by cowpea and mung bean. Living mulches have a significant impact on weed suppression in maize crop. Therefore, integrating living mulches with hand weeding could be a feasible and sustainable approach to enhance maize yield. Considering the economic aspect of different treatments, the highest net returns from maize crops were achieved through a combination of hand weeding and living mulch (watermelon). This shows not only the efficacy but also the economic viability of adopting these practices for additional profit in farming operations. It is recommended to farmers to consider the integration of hand weeding and living mulches, particularly watermelon, for optimizing both yield and economic returns. Moreover, herbicide application may be considered feasible for larger cultivating areas due to the labor-intensive nature of hand weeding and mulches. However, for smaller-scale maize cultivation, hand weeding and mulches is suggested as best option.

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## Novelty Statement

Living/organic mulches particularly cover cropping of legumes in maize crop in combination with conventional weed control practices considerably suppress weed population and improve maize productivity. Contrary to the previous studies that only focused on a single type of mulch or weed control approach. In the present study we have investigated and compares a variety of organic mulches, including legumes and other cover crops for weed suppression in maize crop. It is further reveal that legume cover cropping significantly improve soil fertility, suppress weed growth and utilization of inter-row space with multiple economic benefits. Our findings suggest that living mulches of legume cover crop particularly, cowpeas and mung beans, considerably suppress weed population and improve maize growth and yield. However, watermelon mulch and hand weeding were shown to be the most cost-effective and sustainable practice.

## Author's Contribution

**Huzaifa Hammad:** Performed research work, data collection, data entry and write-up.
**Bakhtiar Gul:** Research Conceptualization, Methodology Supervision Funding acquisition.
**Haroon Khan:** Investigation, visualization, Manuscript writing, review, editing.
**Muhammad Fawad:** Original draft preparation review, editing and Proofreading.
**Hafizullah:** Data validation.
**Haidar Ali:** Review and editing.
**Tamana Bakht:** Statistical analysis.

*Conflict of interest*
The author has declare there is no conflict of interest.

## References

Abdul Rahman, N., Larbi, A., Berdjour, A., Kizito, F., and Hoeschle-Zeledon, I. 2022. Cowpea living mulch effect on soil quality and grain yield in smallholder maize-based cropping system of Northern Ghana. J. Soil Sci. Plant Nutr., 22(3): 3925-3940. https://doi.org/10.1007/s42729-022-00942-5

Ahmad, I., Ahmad, B., Boote, K., and Hoogenboom, G. 2020. Adaptation strategies for maize production under climate change for semi-arid environments. Eur. J. Agron., 115: 126040. https://doi.org/10.1016/j.eja.2020.126040

Anonymous. CGIAR Annual Report 2016. Innovations for Global Food Security. Accessed from https://cgspace.cgiar.org/items/523e4a7f-7b80-4d8e-aff8-cd60b7ee9e70. Accessed on Feb 22, 2024.

Asim, M., Akmal,M., Farhatullah, A.K., and Razi-ud-din. 2012. Rate of nitrogen application influences yield of maize at low and high population in Khyber Pakhtunkhwa, Pakistan. Pak. J. Bot., 44(1): 289-296.

Aung, Z.M., and Zar, T. 2023. Effects of different mulching materials on yield and yield components of maize (*Zea mays L.*). J. Agric. Appl. Biology, 4(1): 1-10. https://doi.org/10.11594/jaab.04.01.01

Awal, M.A., and Khan, M.A.H. 2000. Mulch induced eco-physiological growth and yield of maize. Pak. J. Biol. Sci., 3(1): 61-64. https://doi.org/10.3923/pjbs.2000.61.64

Das, S.K., Ghosh, G.K., and Avasthe, R. 2020. Evaluating biomass-derived biochar on seed germination and early seedling growth of maize and black gram. Biomass Conversion and Biorefinery, 1-1: 4. https://doi.org/10.1007/s13399-020-00887-8

FAOSTAT. 2019. Food balance sheets. Retrieved from http://www.fao.org/faostat/en/#data/ (accessed on 13$^{th}$ August, 2024)

Fluttert, J.C., Soltani, N., Galla, M., Hooker, D.C., Robinson, D.E., and Sikkema, P.H. 2022. Effective dose of atrazine required to complement tolpyralate for annual weed control in corn. Weed Technol., 36(4): 523-530. https://doi.org/10.1017/wet.2022.45

Hassan, G., and Marwat, K. B. 2001. Integrated weed management (IWM) in agricultural crops. In Technologies for Sustainable Agriculture, Eds. Faooq-e-Azam, M. M. I. Chaudhry, I. Kauser, and A. Malik. Nuclear Institute for Agriculture and Biology, Faisalabad, pp. 27-34.

Jemal, K., and Berhanu, S. 2020. Effect of water application methods in furrow irrigation along with different types of mulches on yield and water productivity of maize (*Zea mays* L.) at Hawassa, Ethiop. Ethiop. J. Nat. Sci. Res., 10: 1-14.

Lan, X., Chai, S., Coulter, J.A., Cheng, H., Chang, L., Huang, C., and Li, L. 2020. Maize Straw Strip Mulching as a Replacement for Plastic Film Mulching in Maize Production in a Semi-arid Region. Sustainability, 12(15): 6273. https://doi.org/10.3390/su12156273

Liebman, M., and Davis, A.S. 2000. Integration of soil, crop and weed management in low-external-input farming systems. Weed Res., 40: 27-47. https://doi.org/10.1046/j.1365-3180.2000.00164.x

Marahatta, S. 2020. Effect of Nitrogen Levels on Spring Maize in Relation to Mulching Materials in Central Inner Tarai of Nepal. J. Insti. Agri. Ani. Sci., 115-125. https://doi.org/10.3126/jiaas.v36i1.48390

Nwosisi, S., Nandwani, D., and Hui, D. 2019. Mulch treatment effect on weed biomass and yields of organic sweetpotato cultivars. Agronomy, 9(4): 190. https://doi.org/10.3390/agronomy9040190

PARC. 2007. http://www.pakistan.com,allabout/crops/maize. Pakistan Agricultural Research Council, Islamabad.,

PlantVillage. Maize (Description). Website link: https://plantvillage.psu.edu/topics/corn-maize/infos. (Accessed date: 12-04-2021).

Rehman, A., Saleem, M.F., Malik, M.A., Ali, A., and Asghar, H.N. 2008. Maize (*Zea mays* L.) productivity under varying plant density and nutrient levels. Pakistan J. Agric. Res., 21(1-4): 7-14.

Saudy, H.S., El-Bially, M., Ramadan, K.A., Abo El-Nasr, E.K., and Abd El-Samad, G.A. 2021. Potentiality of soil mulch and sorghum extract to reduce the biotic stress of weeds with enhancing yield and nutrient uptake of maize crop. Gesunde Pflanzen, 73(4): 555-564. https://doi.org/10.1007/s10343-021-00577-z

Shen, J.Y., Zhou, D.D., Han, H.F., Zhou, X.B., and Li, Q.Q. 2012. Effects of straw mulching on water consumption characteristics and yield of different types of summer maize plants. Plant Soil Environ., 58(4): 161-166. https://doi.org/10.17221/404/2011-PSE

Shiferaw, B., Prasanna, B.M., Hellin, J., and Bänziger, M. 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Security, 3(3): 307-327. https://doi.org/10.1007/s12571-011-0140-5

Steel, R.G.D., and Torrie, J.H. 1960. Principles and procedures of statistics.

Stubbs, C.J., Kunduru, B., Bokros, N., Verges, V., Porter, J., Cook, D.D., and Robertson, D.J. 2023. Moving toward short stature maize: the effect of plant height on maize stalk lodging resistance. Field Crops Res., 300: 109008. https://doi.org/10.1016/j.fcr.2023.109008

Yadav, G.S., Babu, S., Das, A., Datta, M., Mohapatra, K.P., Singh, R., and Chakraborty, 2021. M. Productivity, soil health, and carbon management index of Indian Himalayan intensified maize-based cropping systems under live mulch based conservation tillage practices. Field Crops Res., 264: 108080. https://doi.org/10.1016/j.fcr.2021.108080\