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Research Article

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Assessing Potential of Maize Hybrids under Varying Tillage Practices

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ABSTRACT

Changing tillage practices can affect soil characteristics and conditions for seed germination along with effecting crop production drastically. Therefore, a field experiment was conducted to find out the effect of different tillage practices on the potential of maize hybrids at Agronomic Research farm, University of Agriculture, Faisalabad during the 2nd week of March 2019. Two hybrids of maize (H1=YH-1898 and H2=DK-9108) were sown under four tillage practices (T0=Zero Tillage, T1=Minimum Tillage, T2=Conventional Tillage and T3=Deep Tillage. Data regarding leaf area index, leaf area duration, total dry matter, crop growth rate, plant height, cob length, yield per cob, 1000-grain weight, number of grain rows per cob, grain yield, cob height and cob girth were recorded using standard procedures. The collected data were analyzed statistically by using Fisher's analysis of variance technique and honestly significant difference at 5% probability was used to compare the differences among treatments means. Maximum crop productivity was achieved with minimum tillage with DK-9108 hybrid in comparison to other tillage practices. An increase of 11.7% in thousand grain weight, 3.4% increase in cob girth and 17.7% increase in grain yield was observed by changing the hybrid. Whereas 34% yield increment was noticed with deep tillage in comparison to traditional practices providing 34% more profit to the farmers. However, interaction of both hybrid and tillage practices could not increase maize yield significantly.

Keywords: Tillage, maize, hybrid, effect and yield

INTRODUCTION

Agricultural intensification and rising human population have accelerated soil degradation over time [1]. Maize is the leading cereal worldwide in terms of total production, but it is the third leading cereal in Pakistan. Maize is the cereal that is cultivated by household labor on limited lands [2]. It is cultivated for great income return and has numerous cultivars with high yielding potential [3, 4]. It is growing on an area of 1.6 million hectares in the country with contributing 0.7% to GDP [5].

Hybrid maize production and its food and feed appraisal certainly attract the economist for fulfillment of the basic nutritional and dietary requirements of the human population [6]. Maize is used for livestock feed due to its high carbohydrates proportion and low gluten prevalence and is composed of 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3% sugar and 1.7% ash [7].

Tillage is the mechanical manipulation of soil for proper seed germination. Various factors affect maize yield, but tillage appears to be the most important factor [8].

Tilth, the physical condition of the soil helps the seed to have extensive seed surface to soil contact that results in better moisture and air availability as well as nutrient uptake for improved germination and better emergence, leading to short crop stand. In addition, root proliferation is more effectively done under tillage-based seed-bed preparation [9]. Minimum tillage practice refers to the least manipulation of soil. Additional benefits of no tillage and minimum tillage are often counted in the form of prolonged nutrient availability in the form of previous crop residues and the opportunity for microbes to contribute to the crop growth and yield [10]. No-till soils have diverse plant biomass that results in moistening of soil and lowering of temperature with efficient micro-organisms

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activity, good aggregation structure and improvement in soil properties particularly in respect of nitrogen contents, soil organic matter, cation exchangeable capacity and decreased C:N ratio [11]. Agriculture results in a reduction of the soil's bulk density in the upper sheet of soil compared with traditional tillage soils [12].

Various tillage practices adversely affected the surface hydrologic properties leading to increased infiltration rate and reduced runoff [13]. Recently, zero or minimum tillage practices have been used to mitigate soil erosion and to increase soil organic matter [14]. Minimum tillage has been proposed to improve soil fertility for the purpose of increasing crop yield [15]. Lu, Lu [16] proposed that numerous tillage practices have significant impact on soil organic carbon. Tillage practices are directly related to soil conditions, climatic condition and type of crop [17]. More organic matter of soil has good impact on soil physical as well as chemical properties and improves crop yield [18]. Nitrogen contents, organic matter and exchangeable cations were highly influenced by various tillage practices [19].

Tillage practices greatly affected the soil physical, biological and chemical properties thus influenced crop as well as straw yields [20]. Rigorous tillage practices and residue removal for crop cultivation have been the cause of lower soil fertility with leaving the soil surface more susceptible to erosion problems [21]. Decline in soil fertility due to soil degradation in Kenya has been reported to be a serious threat to food security [22]. Rapid soil degradation in the world is mainly due to the ever increasing human population and agronomic interventions with soil [23].

Soil health improvement and increasing soil organic carbon are inevitable for sustainable crop production [24]. Agricultural management strategies can play a significant role in increasing crop production [25]. Reducing tillage can be a fruitful way to improve crop production along with reducing the soil degradation and increasing soil quality [26]. Minimum tillage improves soil quality by increasing microbial population and activities and root biomass [27, 28]. Reduced or minimum tillage practice augments the soil organic matter [29], reduces soil erosion [30], decreases soil compaction and increase microbial activities [31]. Minimum tillage may have initial drawbacks such as yield reduction [32] but yield increases with passage of time [33]. Yield reduction at initial level may be due to short duration of experiments [34]. The drastic problem of soil erosion can also be minimized by zero tillage [35].

Additional benefits of no tillage and minimum tillage are often counted for prolonged nutrient availability [10]. Reduced carbon foot prints under different tillage practices increased the yield of wheat and maize in China [17].

Concerning the environment and surging the charges of crop cultivation in recent years, a focus on zero tillage and no tillage has been a major part of agronomic research worldwide. There is no such recommendation for the farmers in Pakistan and they are the traditional tillage equipment and methods which are reasons of less profitable agriculture. Therefore, research was planned with the objective to investigate the impacts of different tillage systems on growth, development and yield of maize hybrids in Pakistan.

MATERIALS AND METHODS

Experimental Details and Soil Analysis

The trial was laid out during 2nd week of March, 2019 at Agronomic research area, University of Agriculture, Faisalabad. Randomized Complete Block Design was used with split plot arrangement and replicated thrice with plot size of 3 m x 4 m. Soil samples from the depth of 0-30 cm were collected prepared for analysis. Mean values for soil characteristics are given in Table 2.

Factors and Treatments

The experiment consisted of two factors, tillage and maize hybrids. Tillage practices included were Zero Tillage (Least manipulation of soil with hand drill), Minimum Tillage (One ploughing followed by planking), Conventional Tillage (Two cultivations followed by planking) and Deep Tillage (One deep ploughing (Chisel plough) + one transverse ploughing followed by planking). Hybrids used were YH-1898 and DK-9108.Treatment combinations were H1T0 (YH-1898 with zero tillage), H1T1 (YH-1898 with deep tillage), H1T2 (YH-1898 with conventional tillage), H1T3 (YH-1898 with minimum tillage), H2T0 (DK-9108 with zero tillage), H2T1 (DK-9108 with deep tillage), H2T2 (DK-9108 with conventional tillage), H1T3 (YH-1898 with minimum tillage).

Table 1. Description of treatments

Treatments	Tillage Implement (No. of Operations)				Seed Implement
	Ploughing +Planking	Cultivator	Rotavator	Chisel Plough	Hand Drill
Zero Tillage	NA	NA	NA	NA	1
Deep Tillage	1	1	1	1	NA
Conventional Tillage	1	2	1	NA	NA
Minimum Tillage	NA	1	1	NA	NA

Crop Sowing and Seed Rate

Seeds were taken from Punjab Seed Corporation. Sowing was done manually on flat surface by maintaining line to line distance at 75cm with seed rate of 25 kg ha-1 while distance of plant to plant was maintained at 25 cm. Crop protection practices were used to keep the crop free from diseases and insect pests.

Data Collection and Analysis

Data for weather conditions during the experiment was taken from Meteorological observatory, University of Agriculture, Faisalabad and is represented in figure 1. Data regarding leaf area index (LAI), leaf area duration (LAD), total dry matter (TDM), crop growth rate (CGR), height of plant, length of cob, grains per cob, 1000-grain weight, No. of grain rows per cob, economic yield, cob height and cob girth were measured. The sample which was collected from experimental observations was evaluated using the HSD test at 5% level of significance to compare the variation between treatments' means. Formulae used for the mentioned parameters are given as

LAI = (Leaf area)/(Land area covered) [36]

LAD = (L1+L2)/2× t2-t1 [37]

CGR = (W1-W2)/(P(t2-t1)) [38]

Table 2. Soil properties of the experimental site.

Parameters	Values		Status
	0-15 (cm)	15-30 (cm)	
Soil texture	Sandy clay loam		
pH	8.0	8.2	Alkaline
EC (dSm^{-1})	3.8	4.0	Saline
N (%)	0.061	0.058	Medium
P_2O_5(ppm)	18.5	14.7	High
K_2O (ppm)	280	240	High
OM	1.26	1.19	Medium
Sand (%)	20	19	
Silt (%)	17	16	
Clay (%)	63	65	

EC = electrical conductivity, OM = organic matter and pH = negative logarithm of hydrogen ions concentration.

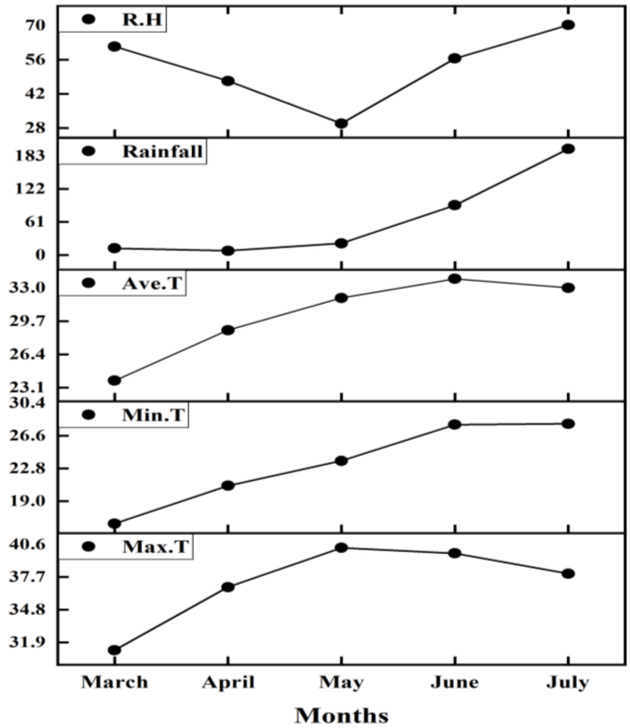

Figure 1. Weather analysis of during experimental.

RESULTS AND DISCUSSION

Growth and Physiological Traits

Leaf Area Index (LAI): Both tillage practices and hybrids were significant in influencing LAI in maize crop during the experiment, while their interaction was non-significant. Among the tillage practices, deep tillage was the best suited in increasing LAI, while the lowest values for LAI were noticed in minimum tillage (Figure 2). Changing tillage practices might have influenced the nutrient availability status in the soil as nutrient availability affects LAI accordingly [39]. The Maximum LAI from deep tillage was due to exploration of deep soil profile by plant roots and supporting the enlargement of leaves. Moisture and nutrient availability from deep tillage promoted seed germination and stand establishment. Similar approaches were reported by Anjum, Ashraf [40] who stated that maximum LAI in deep tillage treatment might be due to good seed germination and better crop stand as compared to other tillage practices. Hybrid H2 performed comparatively better than H1 in producing LAI (4.44). [41] found higher leave area index in sunflowers under tillage practices rather than no tills. [42] also reported increase leaf area index of maize in contemporary tillage practices in comparison to traditional practices.

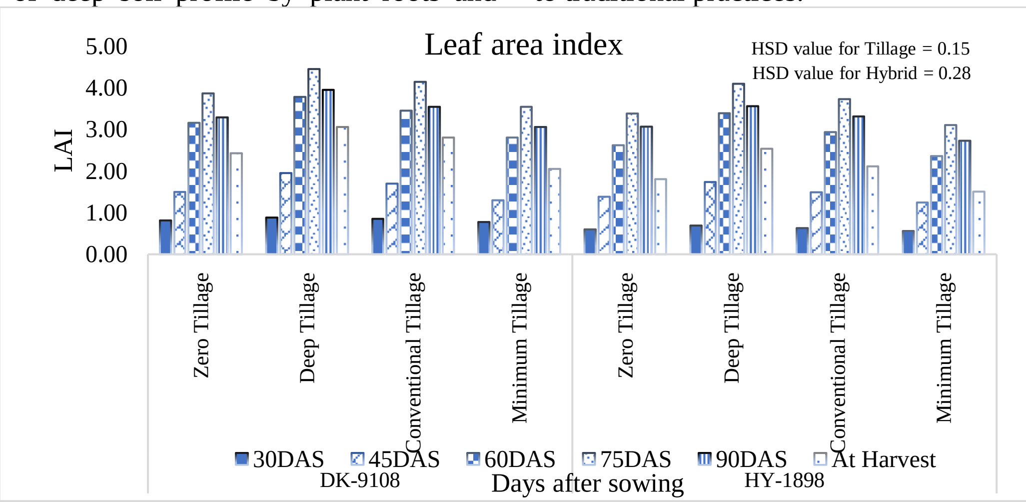

Figure 2. Leaf area index of maize hybrids as influenced by different tillage practices.

Leaf Area Duration (LAD) (days): The recorded data (Figure 3) indicates positive effects of different tillage practices on LAD of maize hybrids. Hybrids were also significantly different from each other for LAD, whereas interaction of both was non-significant. Among tillage practices, maximum LAD was recorded from deep tillage and from hybrids, H2 attained more LAD than H1. Deep tillage is a productive approach to pulverizing compacted subsoil layers [43, 44]. Genetic makeup may influence the germination of hybrids and their potential. Besides this, their growth is also dependent on resource availability which can be increased through deep tillage as it provides more moisture and aeration in root zone to support root elongation and thus ensure that the crop remains green and healthy for a longer time [45].

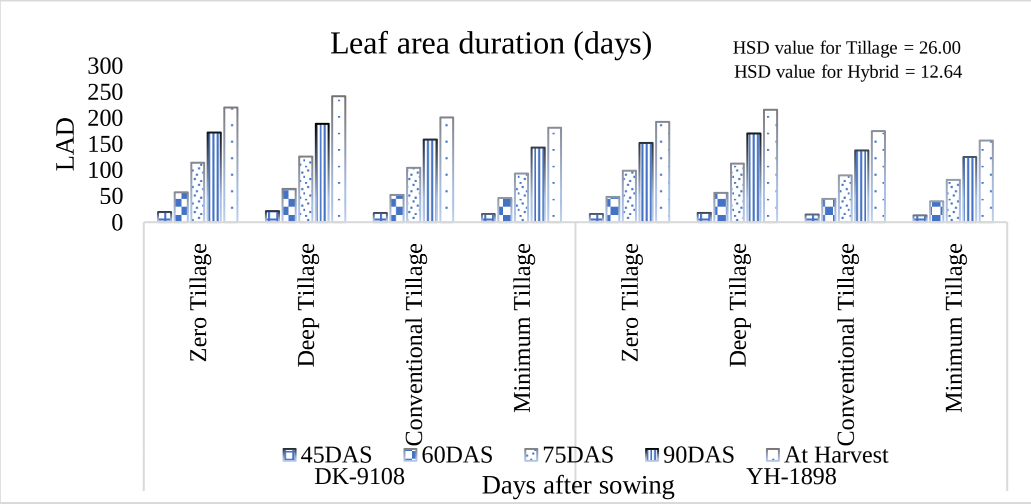

Figure 3. Leaf area duration of maize hybrids as influenced by different tillage practices.

Total Dry Matter (TDM) (g m-2)

Hybrids used and tillage practices followed performed significantly in TDM augmentation of maize. Data regarding TDM (Figure 4) also illustrated non-significant interactive effective of both hybrids and tillage practices.

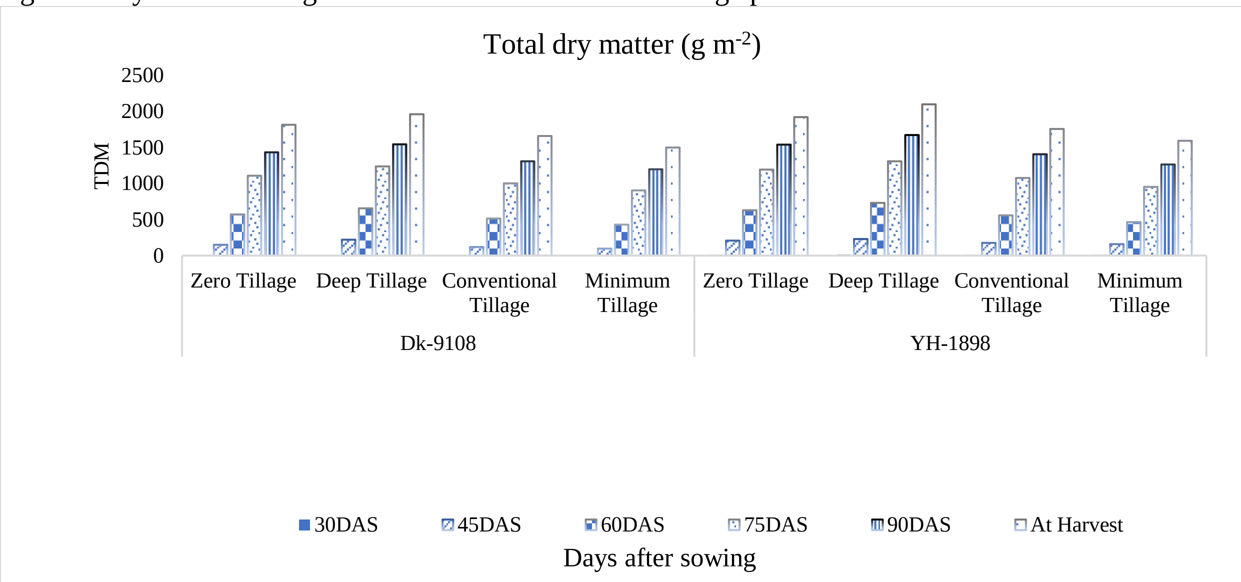

Figure 4. Total dry matter of maize hybrids as influenced by different tillage practices.

Crop Growth Rate (CGR) (g m-2 day-1)

Data recorded for CGR is given in figure 5 which shows significant individual factors but non-significant interaction of both in increasing CGR for maize. The highest CGR was obtained in deep tillage followed by zero and conventional tillage. The least CGR was recorded in the minimum tillage.

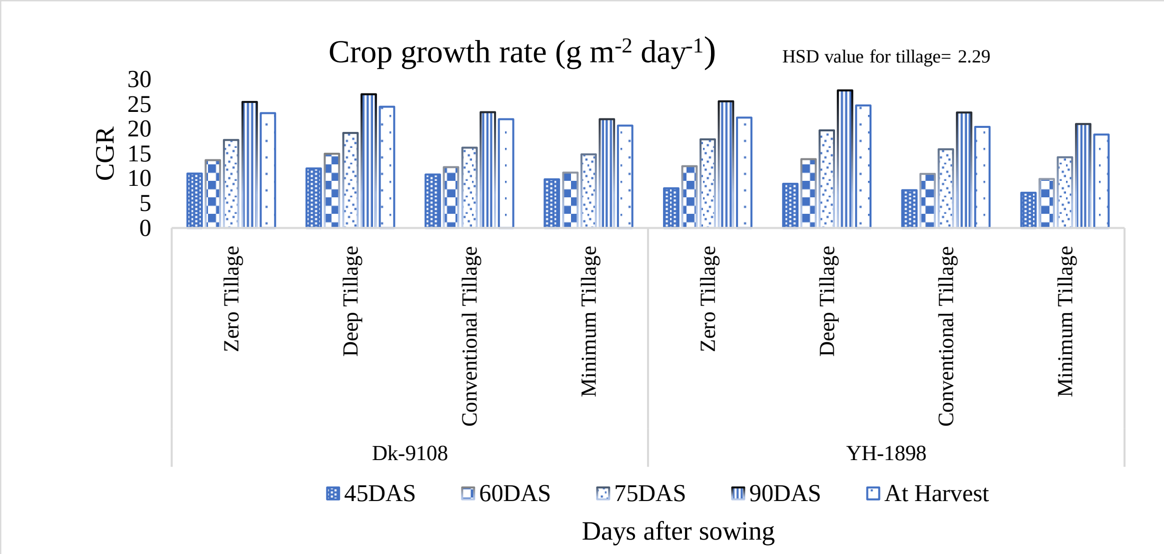

Figure 5. Crop growth rate of maize hybrids as influenced by different tillage practices.

Development Parameter

Days to Physiological Maturity

The data provided in (Table 3) showed the significant impact of various tillage practices and maize hybrids cultivated on days to physiological maturity. Minimum tillage took maximum (117.67) days, while the lowest (98.00) days were taken in cases of deep tillage to reach physiological maturity. Maximum average mean days to physiological maturity (108.00) were observed from H1, whereas, H1 reached physiological maturity in 105.09 days, in the case of hybrids cultivated. Significant effects of tillage practices on days to physiological maturity in different crops have also been reported recently [46-48]

Days to 50% Tasseling

Days to 50% tasseling were not much affected by tillage practices and varying hybrids. Only deep tillage took least days (64.17) to reach 50% tasseling, however, all the other tillage practices under consideration were statistically similar to each other table 3. Hybrids were significant with H1 reaching late (67.67 days) to 50% tasseling in comparison to H2 with 64.25 days. Interaction of both tillage practices and hybrids remained non-significant for days to 50% tasseling.

Days to 50% Silking

Days to 50% silking were only significantly affected by hybrids sown table 3. The tillage practices and interaction of tillage practices and hybrids did not affect significantly on days to 50% silking. Hybrid H1 took 68.67 days to reach 50% silking, while 64.42 days were taken by H2 to reach the similar stage.

Table 3. Influence of various tillage practices and maize hybrid on phenology

Treatments	Physiological Maturity	Days to 50% Tasseling	Days to 50% Silking
H_1-Hybrid YH-1898	105.09B	67.67A	68.67A
H_2-Hybrid DK-9108	108.00A	64.25B	64.42B
HSD value	2.35*	1.59**	1.20**
T_0= Zero tillage	110.69B	66.83A	67.83A
T_1= Deep tillage	98.00C	64.17B	65.50B
T_2= Conventional tillage	99.82C	66.33A	66.17AB
T_3= Minimum tillage	117.67A	66.50A	66.67AB
HSD value	2.82**	2.06*	2.29*

$H_1 \times T_0$	109.09	68.33	70.00
$H_1 \times T_1$	96.67	65.67	67.67
$H_1 \times T_2$	97.30	68.00	68.33
$H_1 \times T_3$	117.30	68.67	68.67
$H_2 \times T_0$	112.30	64.67	65.67
$H_2 \times T_1$	99.33	62.67	63.33
$H_2 \times T_2$	102.33	64.67	64.00
$H_2 \times T_3$	118.09	65.00	64.67
HSD value	NS	NS	NS

Note: level with various letters is statistically significant at α=0.05, *= Significant, NS= Non-significant, **= Highly significant

Yield Components

Plant Height (cm)

Based on the data presented in table 4, it can be concluded that the plant height of maize is significantly affected by the hybrid used. The maximum plant height (188.38 cm) was recorded in H2, while the minimum (168.57) was recorded in H1. However, there was no significant effect of tillage or interaction between tillage and hybrids on plant height.

Additionally, genotypes that are tolerant of abiotic and biotic stress are expected to have improved yield stability [49], which means they can consistently produce good yields under varying environmental conditions. This information suggests that in addition to plant height, other traits such as stress tolerance should also be considered when selecting maize hybrids for optimal crop performance. Properly tilled seed beds ensured weed control and promoted germination of seeds with increased aeration in soil to promote plant growth [50, 51].

Cob Length (cm)

The data presented in Table 4 indicates that cob length in maize crops is directly related to grain yield. This is because a longer cob means more space for grains to develop, resulting in a greater number of grains per cob. Tillage practices had a similar impact on cob length, with minor differences observed. However, the effect of hybrids on cob length was statistically significant, and there was no significant interaction between tillage and hybrid practices. In terms of tillage practices, the maximum mean cob length (21.28 cm) was recorded in deep tillage, while zero tillage practices had the minimum mean value for cob length (17.25 cm). These findings contradict the results of [52], who found no significant effect of various tillage practices on cob length.The impact of tillage on cob length is complex and can be influenced by several factors, including soil structure, moisture levels, and weed competition.

1000-Grain Weight (g)

The 1000-grain weight is an important parameter that is directly related to grain yield in maize crops. The data presented in Table 4 shows that tillage practices did not have a significant effect on 1000-grain weight, while hybrids showed a significant effect. There was no significant interaction observed between tillage and hybrid practices.

Anjum, Raza [19] found similar results, indicating that deep tillage had better results compared to other tillage practices in terms of 1000-grain weight. This is likely due to the fact that deep tillage can improve soil structure, leading to better root growth and nutrient uptake, which ultimately results in larger and heavier grains.

No. of Grain Rows Per Cob

The number of grain rows per cob is an important parameter for determining maize crop yield. The data presented in Table 4 shows that the highest number of grains (16.33) per cob was found in H2, while the minimum (13.33) was found in H1. The results for all four treatments of H2 were similar with minor differences, and the same was true for the H1 treatments. Tillage practices did not have a significant effect on the number of grain rows per cob, and the interaction between tillage and hybrid practices was also non-significant.

The genetic potential of maize varieties is an important factor in determining their yield potential, and open-pollinated varieties (OPVs) may have lower yields compared to hybrid varieties due to their lower genetic potential. Additionally, high weed intensity can also negatively impact maize yields. Therefore, selecting appropriate high-yielding hybrid varieties and implementing effective weed management practices can help to improve maize crop yields [53].

Cob Girth (cm): Cob girth is an important parameter related to the yield of the maize crop. It can be increased by adapting suitable varieties and providing climatic conditions to which the plant is subjected for its development and the growth. The cob diameter is important because the number of grains and the grain rows mainly depend on the diameter of the cob. All the treatments of tillage related to H1 and H2 had significantly the same values with minor differences. Among all treatments the maximum value (4.55 cm) was observed in table 4. Tillage practices non-significantly affect the cob girth in both hybrids. Minimum cob girth (4.40 cm) was founded in H1. Main effect of hybrids was significant. Tillage was statistically non-significant but interaction was also be non-significant. All the treatments having minor differences between their cob girth values. Production of hybrid maize is more as compared to conventional verities. Hybrids maize has long silk, more grain rows per ear, better cob girth and more grain yield than conventional cultivars [54].

Grain Yield (t ha-1)

It is important to note that the effect of tillage practices on grain yield can vary depending on the specific environmental conditions and crop management practices. However, the results presented in Table 4 suggest that in the conditions of this study, deep tillage resulted in the highest grain yield. Additionally, the data indicate that the hybrid H2 produced a higher grain yield than H1. The main effects of both hybrids and tillage were statistically significant, but their interaction was not significant. These findings are consistent with previous studies, such as Wasaya, Tahir [55], who reported that deep tillage resulted in maximum grains per cob, and [56], who found that deep tillage resulted in higher grain yields. Overall, the results suggest that careful selection of both hybrid varieties and tillage practices can significantly impact grain yield in maize crops.

Biological Yield (t ha-1) The results presented in Table 4 suggests that the tillage practices had a significant effect on the biological yield of maize. The highest biological yield (37.70 t ha-1) was obtained in H1T2, while the lowest biological yield (28.50 t ha-1) was observed in minimal tillage activities. The effect of hybrids on the number of grains per cob was not statistically significant, and the interaction between tillage practices and hybrids was also not significant for this parameter.

These findings are consistent with the results reported by [7], who found that various tillage practices led to higher plant biological yields compared to no tillage. Similarly, [57] reported that deep tilling resulted in a higher biomass production compared to no-till practices.

Harvesting Index (%)

Tillage practices have a significant impact on the harvest index, while the hybrid effects are negligible. The maximum harvest index was recorded in the deep tillage treatment, with a value of 35.02%, and the minimum harvest index was observed in the minimum tillage practices, with a value of 24.42%. These results are consistent with the findings of [58], who reported that deep tilled plots gave the maximum harvest index.

Table 4. Influence of different tillage practices and hybrid on yield of Spring planted maize.

Treatments	Plant Height	Cob Length	1000 Grain Weight	Number of Rows	Cob Girth	Yield Per Cob	Yield	Biological Yield	Harvesting Index
H_1-Hybrid YH-1898	168.57B	19.17A	348.10B	13.33B	4.40B	205.73B	7.63A	31.93	28.36
H=-Hybrid DK-9108	188.38A	19.83A	389.08A	16.33A	4.55A	222.30A	8.28A	33.15	32.34
HSD Value	**9.93****	**0.67***	**41.75***	**1.01****	**0.15***	**4.32****	**0.66****	**NS**	**NS**
T_0=Zero tillage	175.83	17.25C	361.48	14.89	4.44	216.18B	7.27B	31.00B	28.37B
T_1=Deep tillage	185.85	21.28A	355.93	15.00	4.48	241.66A	9.15A	36.70A	35.02A
T_2=Conventional tillage	184.88	20.61AB	371.83	15.00	4.60	200.16C	8.85A	33.95AB	33.61A
T_3=Minimum tillage	167.36	18.86BC	355.68	14.44	4.38	198.04C	6.83B	28.50B	24.42B
HSD Value	**NS**	**1.81****	**NS**	**NS**	**NS**	**14.64****	**1.27***	**1.49****	**4.99****
$H_1 \times T_0$	178.70	20.67	397.62	13.33	4.41	206.69c	7.17	33.00	31.95
$H_1 \times T_1$	174.98	21.22	368.50	13.33	4.39	228.00b	8.65	37.70	32.19
$H_1 \times T_2$	165.38	20.78	401.01	13.78	4.45	195.66cd	8.04	30.00	27.04
$H_1 \times T_3$	155.22	20.78	384.36	12.89	4.34	192.56d	6.65	27.00	22.26
$H_2 \times T_0$	186.27	20.67	325.34	16.44	4.46	225.66b	7.37	34.90	35.26
$H_2 \times T_1$	196.71	20.56	343.36	16.67	4.57	255.33a	9.15	35.70	37.84
$H_2 \times T_2$	191.06	20.89	342.66	16.22	4.75	204.66c	9.11	32.00	29.69
$H_2 \times T_3$	179.49	20.00	327.01	16.00	4.41	203.53c	6.99	30.00	26.57
HSD Value	**NS**	**NS**	**NS**	**NS**	**NS**	**8.63***	**NS**	**NS**	**NS**

Note: level with different letters are statistically significant at α=0.05 *= Significant, NS= Non -significant, **= Highly significant.

Conclusions:

Extensive agricultural practices have resulted in soil degradation and environmental pollution. Reducing tillage benefits farmers with more profit from less input. Results from the current experiment depicted that deep tillage was the most beneficial method of tillage for maize production in Faisalabad region of Pakistan. However, minimum tillage has resulted in higher gross returns as compared to other tillage practices. Therefore, farmers are suggested to consider using deep tillage practices to increase their net benefits. However, it is important to note that the selection of tillage practices should be based on several factors such as soil type, climatic conditions, crop variety, and labor availability, among others.

REFERENCES

1. Pradhan, A., et al., *Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: A transdisciplinary approach.* Agricultural Systems, 2018. 163: p. 27-35.
2. Bedeke, S., et al., *Adoption of climate change adaptation strategies by maize-dependent smallholders in Ethiopia.* NJAS - Wageningen Journal of Life Sciences, 2019. 88: p. 96-104.
3. Adimassu, Z., A. Kessler, and L. Stroosnijder, *Farmers' strategies to perceived trends of rainfall and crop productivity in the Central Rift Valley of Ethiopia.* Environmental Development, 2014. 11: p. 123-140.
4. Abate, T., et al., *Factors that transformed maize productivity in Ethiopia.* Food Security, 2015. 7(5): p. 965-981.
5. Govt. of Pakistan, *Economic survey of Pakistan 2021-22. Ministry of Fianance*. 2022: Islamabad. p. 17-40.

6. Lobell, D.B., K.G. Cassman, and C.B. Field, *Crop yield gaps: their importance, magnitudes, and causes.* Annual review of environment and resources, 2009. 34: p. 179-204.
7. Khan, A., et al., *Organic and inorganic nitrogen treatments effects on plant and yield attributes of maize in a different tillage systems.* Pak. J. Bot, 2009. 41(1): p. 99-108.
8. Rosner, J., et al., *Conservation tillage systems–soil–nutrient–and herbicide loss in lower Austria and the mycotoxin problem.* substance, 2008. 2(1.0): p. 0-6.
9. Hodge, A., *Plastic plants and patchy soils.* Journal of experimental botany, 2006. 57(2): p. 401-411.
10. Ngoma, H., N.M. Mason, and N.J. Sitko, *Does minimum tillage with planting basins or ripping raise maize yields? Meso-panel data evidence from Zambia.* Agriculture, Ecosystems & Environment, 2015. 212: p. 21-29.
11. Álvaro-Fuentes, J., et al., *Modelling tillage and nitrogen fertilization effects on soil organic carbon dynamics.* Soil and Tillage Research, 2012. 120: p. 32-39.
12. Jina, B., et al., *Soil characteristics in oak and pine forests of Indian Central Himalaya.* E-International Scientific Research Journal, 2011. 3(1): p. 19-22.
13. Van Wie, J., J. Adam, and J. Ullman, *Conservation tillage in dryland agriculture impacts watershed hydrology.* Journal of hydrology, 2013. 483: p. 26-38.
14. Hailin, Z. and G. Wangsheng, *Prospects and present situation of conservation tillage.* Zhongguo Nongye Daxue Xuebao (China), 2005.
15. Githongo, M., et al., *The effect of minimum tillage and animal manure on maize yields and soil organic carbon in sub-Saharan Africa: A meta-analysis.* Environmental Challenges, 2021. 5: p. 100340.
16. Lu, X., et al., *Effects of tillage management on soil CO2 emission and wheat yield under rain-fed conditions.* Soil Research, 2015. 54(1): p. 38-48.
17. He, L., et al., *Effects of different tillage practices on the carbon footprint of wheat and maize production in the Loess Plateau of China.* Journal of Cleaner Production, 2019. 234: p. 297-305.
18. Thomas, G., R. Dalal, and J. Standley, *No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics.* Soil and Tillage Research, 2007. 94(2): p. 295-304.
19. Anjum, S.A., et al., *Influence of different tillage practices on yield of autumn planted maize (Zea mays L.).* Pakistan Journal of Agricultural Research, 2019. 32(2): p. 293-301.
20. Zhang, Y., et al., *Crop yield and soil properties of dryland winter wheat-spring maize rotation in response to 10-year fertilization and conservation tillage practices on the Loess Plateau.* Field Crops Research, 2018. 225: p. 170-179.
21. Cerdà, A., et al., *Soil erosion and agriculture.* Soil and Tillage Research, 2009. 106(1): p. 107-108.
22. Karaya, H., et al., *Determination of levels of Striga germination stimulants for maize gene bank accessions and elite inbred lines.* 2012.
23. Di Falco, S., *Adaptation to climate change in Sub-Saharan agriculture: assessing the evidence and rethinking the drivers.* European Review of Agricultural Economics, 2014. 41(3): p. 405-430.
24. Jarecki, M., et al., *Long-term trends in corn yields and soil carbon under diversified crop rotations.* Journal of environmental quality, 2018. 47(4): p. 635-643.
25. Adamtey, N., et al., *Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya.* Agriculture, Ecosystems & Environment, 2016. 235: p. 61-79.
26. Kiboi, M.N., et al., *Soil fertility inputs and tillage influence on maize crop performance and soil water content in the Central Highlands of Kenya.* Agricultural Water Management, 2019. 217: p. 316-331.
27. Franzluebbers, A., *Integrated crop–livestock systems in the southeastern USA.* 2007, Wiley Online Library.
28. Ghimire, R., J.B. Norton, and E. Pendall, *Alfalfa-grass biomass, soil organic carbon, and total nitrogen under different management approaches in an irrigated agroecosystem.* Plant and soil, 2014. 374: p. 173-184.
29. Bescansa, P., et al., *Soil water retention capacity as affected by tillage systems under semiarid conditions in Navarra (NE Spain).* Soil Tillage Res, 2006. 87: p. 19-27.
30. Cardoso, E.J.B.N., et al., *Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health?* Scientia Agricola, 2013. 70: p. 274-289.

31. Sauvadet, M., et al., *High carbon use efficiency and low priming effect promote soil C stabilization under reduced tillage.* Soil Biology and Biochemistry, 2018. 123: p. 64-73.
32. Das, R. and S. Bauer, *Bio-economic analysis of soil conservation technologies in the mid-hill region of Nepal.* Soil and Tillage Research, 2012. 121: p. 38-48.
33. Pittelkow, C.M., et al., *Productivity limits and potentials of the principles of conservation agriculture.* Nature, 2015. 517(7534): p. 365-368.
34. Lechenet, M., et al., *Profiling farming management strategies with contrasting pesticide use in France.* Agricultural Systems, 2016. 149: p. 40-53.
35. Cavalieri, K.M.V., et al., *Long-term effects of no-tillage on dynamic soil physical properties in a Rhodic Ferrasol in Paraná, Brazil.* Soil and Tillage Research, 2009. 103(1): p. 158-164.
36. Williams, R., *The physiology of plant growth with special reference to the concept of net assimilation rate.* Annals of Botany, 1946. 10(37): p. 41-72.
37. Power, J., et al., *Effect of soil temperature, phosphorus, and plant age on growth analysis of barley 1.* Agronomy Journal, 1967. 59(3): p. 231-234.
38. Watson, D. and J. Wilson, *An analysis of the effects of infection with leaf-roll virus on the growth and yield of potato plants, and of its interactions with nutrient supply and shading.* Annals of Applied Biology, 1956. 44(3): p. 390-409.
39. Saleem, M.A., et al., *Foliar application of boron improved the yield and quality of wheat (Triticum aestivum L.) in a calcareous field.* Soil & Environment, 2020. 39(1): p. 59-66.
40. Anjum, S.A., et al., *Morphological and phenological attributes of maize affected by different tillage practices and varied sowing methods.* American Journal of Plant Sciences, 2014. 2014.
41. Mourad, A. and A.I. Nawar, *Sunflower growth performance under tillage or no tillage practice, irrigation intervals and nitrogen fertilization rates.* Alexandria Journal of Agricultural Sciences, 2020. 65(3): p. 223-232.
42. Otieno, H.M.O., et al., *Maize (Zea mays L.) growth and yield response to tillage methods and fertilizer combinations in the midland agro-ecological zones of Kenya.* Turkish Journal of Agriculture-Food Science and Technology, 2020. 8(3): p. 616-624.
43. Jin, H., et al., *The adoption of annual subsoiling as conservation tillage in dryland maize and wheat cultivation in northern China.* Soil and Tillage Research, 2007. 94(2): p. 493-502.
44. Hou, X., et al., *Effects of rotational tillage practices on soil properties, winter wheat yields and water-use efficiency in semi-arid areas of north-west China.* Field crops research, 2012. 129: p. 7-13.
45. Tsimba, R., et al., *The effect of planting date on maize grain yields and yield components.* Field Crops Research, 2013. 150: p. 135-144.
46. Kan, Z.-R., et al., *Effects of conservation tillage on wheat growth duration and grain yield in the North China Plain.* Archives of Agronomy and Soil Science, 2022. 68(8): p. 1019-1033.
47. Khan, A., et al., *Optimizing nitrogen sources and tillage practices for wheat crop stand and phenology.* Sarhad Journal of Agriculture, 2021. 37(2): p. 340-347.
48. Arjun, B., et al., *Growth, phenology, yield and yield attributes of rice as influenced by tillage, residue and nitrogen management practice in Chitwan, Nepal.* African Journal of Agricultural Research, 2021. 17(1): p. 128-136.
49. Sarkar, D., B. Mandal, and M.C. Kundu, *Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India.* Plant and soil, 2007. 301: p. 77-85.
50. Rakesh, S., *Textbook on Fundamentals of Agronomy: Principles and practices*. 2022: Shashwat Publication.
51. Sun, H., et al., *Biomaterials technology for agrofood resilience.* Advanced Functional Materials, 2022. 32(30): p. 2201930.
52. Pabin, J., et al., *Maize response to different straw management and tillage systems under cereal crop rotation.* International Agrophysics, 2006. 20(2): p. 141-146.
53. Fazli, S., A. Abdul, and S. Zubair, *Response of maize crop to various herbicides.* Pakistan Journal of Weed Science Research, 2007. 13(1/2): p. 9-15.
54. John Milton, P. and S. David Allen, *Breeding field crops*. 2006: Wiley-Blackwell; 5th edition. 433.
55. Wasaya, A., et al., *Improving maize productivity through tillage and nitrogen management.* African journal of

Biotechnology, 2011. 10(82): p. 19025-19034.

56. Memon, S.Q., et al., *Effect of tillage methods and fertilizer levels on maize production.* Pak. J. Agri. Sci, 2011. 48(2): p. 115-117.

57. Patil, S. and M. Sheelavantar, *Soil water conservation and yield of winter sorghum (Sorghum bicolor L. Moench) as influenced by tillage, organic materials and nitrogen fertilizer in semi-arid tropical India.* Soil and Tillage Research, 2006. 89(2): p. 246-257.

58. Ahadiyat, Y.R. and S. Ranamukhaarachchi, *Effect of soil tillage and maize-grass intercropping followed by grass management on soil properties and yield of rainfed maize.* Int. J. Agric. Biol, 2007. 9: p. 791-799.