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Influence of different tillage practices and herbicide application on physical properties of soil and yield of maize crop

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Abstract

A field experiment was executed to investigate the influence of different tillage practices and herbicide application on the physical properties of soil and yield of maize crop at the research farm of the University of Agriculture, Peshawar, Pakistan during 2018 and 2019. In this experiment four tillage practices (viz., mould board plough followed by rotavator, disc harrow twice, rotavator twice and cultivator twice followed by planking) and three times of herbicides application (viz., pre-emergence, post emergence and control) were arranged in a RCB design with split plot arrangements. Tillage practices were kept in main plots and herbicide application in sub-plots. Statistical analysis of the data revealed that tillage practices had shown significant effect on soil bulk density (g cm^{-3}), moisture contents (%), penetration resistance (N cm^{-2}), biological yield (kg ha^{-1}) and grain yield (kg ha^{-1}) of maize crop. The use of mould board plough and rotavator were better for improving the physical properties of soil at 0-20 cm depth. The bulk density and penetration resistance of the soil were lowest and moisture retention was highest with the application of mould board plough, and vice versa with the use of cultivator twice followed by planking. The same trend was obtained for biological and grain yield of maize in response to corresponding tillage practices. Moreover, herbicide application at the pre-emergence stage significantly increased the biological and grain yield of maize crop but exerted no significant effect on the physical properties of soil measured at any stage. In light of these results, deep tillage practices (such as mould board plough and rotavator) could be recommended for improving the physical properties of soil and yield of maize crop.

Keywords: Bulk density, biological yield, grain yield, herbicides, moisture, penetration, tillage

Introduction

After wheat and rice, maize is the third important cereal crop in Pakistan. It is an important cereal crop as it serves as food for human, feed for poultry and fodder for livestock, and also provides raw materials for various industries. It contributes 2.9 percent to value agriculture and 0.6 percent to GDP of the country. In 2019-20, maize was cultivated on an area of 1413 thousand hectares of land producing 7236 thousand tonnes of grain with an average grain yield of 5121 kg ha^{-1} (Pakistan Bureau of Statistics, 2019-20). Although maize crop has shown an increasing trend in production due to introduction of hybrid seed and improved varieties, the total production is far less than the demand in the country. The demand of poultry only is more than maize grain production in Pakistan. Out of current production, about 60% is being utilized in poultry feed, 28% in wet milling like Rafhan and 6% in food indicating increasing demand of maize grain particularly for poultry feed and silage in the country. There is therefore a need to further increase the production of maize by addressing the factors hindering the yield of maize. Besides other factors weed infestation is one of the major problems which not only cause reduction in yield but also deteriorates the quality of grains of maize. As reported weeds can reduce the grain yield of maize by 25-80%, and in some cases causes complete failure of crop in case of severe infestation (Chikoye and Ekeleme, 2003).

Soil tillage is among the important factors that affect soil properties and subsequently exert remarkable

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influence on crop yields. Among the crop production factors, tillage practices affect the sustainable use of soil resources through its influence on soil properties (Lal and Stewart, 2013) and subsequently contributes up to 20% increase in crop production (Khurshid *et al.*, 2006) and tillage practices have been found to improve the physical properties of soil by providng suitable condition for plants to grow and produce (Khattak *et al.*, 2006). Tillage practices not only control weeds and reduce its biomass but also help to break down the crop residues making it easier to decomposition. Moreover, soil tillage practices are used to provide better seedbed for root development and growth, weeds control, crop residue management, minimize soil erosion, level surface of the soil for proper planting, irrigation, drainage, and mixing organic matter in the soil (Temesgen *et al.*, 2001). Among tillage tools, mouldboard plough is used for soil inversion, mixing up the crop residues and eradicates the weeds. Similarly chisel and disk ploughs are also used and recommended in hard and wet soils to cut the root stubbles. Deep tillage practices such as mould board plough followed by rotavator, disc plough and chisel reduce the penetration resistance and bulk density of the soil (Khattak *et al.*, 2004). Usman *et al.* (2010) reported significant effect of deep tillage on crop production. However, tillage changes the characteristics of the pores network in soil including the number, size and distribution of pores which in turn control the ability of soil to store and diffuse air, water, and agricultural chemicals and, hence regulate erosion, runoff, and crop performance (Khan *et al.*, 2001). Therefore, only the judicious use of tillage practices can be employed, whereas improper tillage may cause a variety of problems, for example, destruction of soil structure, accelerated erosion, loss of organic matter, soil fertility and others (Lal, 1993; Khattak *et al.*, 2006). The excessive and unnecessary tillage operations give rise to phenomena that are harmful to soil. Yalcin *et al.* (2005) suggested that appropriate combination of tillage and herbicide application with recommended doses should be adopted to increase the crop production.

Various weed management techniques such as chemical, mechanical, cultural and biological control measures have been used to minimize yield losses of crops due to weeds infestation. The cultural methods of weed control is still effective and popular among farmers, but it is relatively costly, time consuming and laborious. Therefore, the judicious use of chemicals (herbicides) has been recommended to control weeds and reduce its biomass in crops effectively with minimum cost (Chikoye *et al.*, 2004). The application of herbicides at pre-emergence stage showed best and promising results in terms of weed control, crop nourishment as well as in water and nutrient uptake (Sunitha *et al.*, 2010). Various herbicides are used for effective control of weeds in maize crop (Uddin and Amin, 2019). There is however limited information on the effect of herbicide application on soil properties. This experiment was therefore undertaken to assess the influence of different tillage practices and herbicide application on the physical properties of soil and yield of maize crop in a heavy textured soil in Peshawar valley.

Materials and Methods

Field experiment

A field experiment was conducted to assess the influence of different tillage practices & herbicide application on the physical properties of soil and yield of maize crop at the research farm of Agriculture University, Peshawar during 2018 and 2019.

Experimental design

The experiment was set up in a randomized complete block (RCB) design with split plot arrangements. Tillage practices were kept in main plots while herbicide application in sub plots. The detail of tillage and herbicide treatments were as follows:

Factor 01: Tillage practices

T_1 = Mould Board (MB) plough followed by rotavator
T_2 = Disc Harrow 2 times
T_3 = Rotavator 2 times
T_4 = Cultivator twice followed by planking (as control)

Factor 02: Herbicide application

H_1 = Pre-emergence
H_2 = Post-emergence
H_o = Control plot

Experimental procedure

Seedbed was prepared prior to sowing, where mould board plough was applied one month before sowing, while the remaining tillage practices such as disc harrow, rotavator and cultivator were applied just before sowing. Herbicides were applied after sowing the crop. The field was irrigated prior to sowing the maize crop. After achieving the field capacity, maize variety Azam was planted in rows 75 cm apart with plant to plant distance of 20 cm using maize planter.

The data on bulk density, moisture content and penetration resistance of soil at 0-20 cm depth were recorded at three stages i.e., before tillage application, after tillage application and after crop harvest. Moreover, the data on grain and biological yield of maize crop was recorded at harvest stage.

Measurement of bulk density (g cm^{-3})

The soil bulk density was determined in each treatment plot (3 samples per plot) at 0-20 cm soil depth with the help of core sampler using digger and auger. The core sampler of 5 cm was driven at the depth of 0-20 cm in the soil. Proper care was taken to avoid any hardness or break the core during the whole process. After sampling, the core samples were carefully removed and weighed with the help of digital balance before keeping in the oven for drying. The core soil samples were kept in oven at 105 ºC for about 24 hours. The samples were taken out of the over and re-weighed for determination of moisture content. The expression, $\rho b = Ms / Vt$ was used to calculate the bulk density of soil (Ramazan *et al.*, 2012).

Measurement of soil moisture content (%)

For moisture determination, soil samples were weighed before and after drying in oven at 105ºC for 24 hours. The loss in weight was considered moisture content in soil and was calculated using the following expression (Khattak *et al.*,2006):

$$\text{Moisture content \%} = \frac{[\text{(Wet soil weight)} - \text{(Oven dry soil weight)}] \times 100}{\text{Oven dry soil weight}}$$

Measurements of penetration resistance (N cm^{-2})

Penetration resistance of the soil was determined at 0-20 cm soil depth using penetrometer in each plot before tillage, after tillage and after crop harvest. Two cm^2 cone base area in penetrometer was used to calculate the soil penetration resistance using the following equation (Khattak *et al.*, 2006):

Core Index (Ci) = Force(F)/Area (A) (Where Ci = Core Index (N cm^{-2}), F is the Force applied in (N) and A is the area in per Cm^2)

Biological yield (kg ha^{-1})

Biological yield of maize crop was determined in each treatment plot after crop harvest using the following formula (Amin *et al.*, 2014):

$$\text{Biological yield (kg ha}^{-1}) = \frac{\text{Biological yield in harvested area (kg)}}{\text{Harvested area (m}^2)} \times 10{,}000$$

Grain yield (kg ha^{-1})

Cobs from the harvested plants were removed, dried and then threshed using maize sheller. The grains were weighed on digital balance and then converted to kg ha^{-1}

Table 1: Bulk density (g cm^{-3}) of soil before tillage at 0-20 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two Years**
MB Plough (T1)	1.48	1.48	1.48c
Disc Harrow (T2)	1.59	1.55	1.57b
Rotavator (T3)	1.54	1.53	1.53b
Cultivator (T4)	1.69	1.63	1.66a
LSD for Tillage	0.06	0.03	0.03
Herbicide			
Pre-Emergence (H1)	1.57	1.55	1.56a
Post-Emergence (H2)	1.57	1.55	1.56a
Control (H_o)	1.57	1.55	1.56a
LSD for Herbicide	NS	NS	NS
Year			
2018			1.57
2019			1.55
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

using the following formula (Din *et al.*, 2013 a, b):

$$\text{Grain yield (kg ha}^{-1}) = \frac{\text{Grain yield in harvested area (kg)}}{\text{Harvested area (m}^2)} \times 10{,}000$$

Statistical analysis

The data were statistically analysed using statistical package appropriate to RCB design with split plot arrangements. The means of the treatments were compared using LSD test at 5% level of probability (Steel *et al.*, 1997). The individual effects of tillage, herbicide application and their interactions were expressed in tables for each parameter.

Results and Discussion

Bulk density of soil before tillage operation

Statistical analysis of the data obtained during 2018 and 2019 revealed that the application of tillage practices had significant effect but that of herbicide application had a non-significant effect on the bulk density of soil at 0-20 cm depth (Table 1). The interactive effect of tillage (T) and herbicide (H) treatment on bulk density of soil was also non-significant ($p<0.05$). The same trend with respect to influence of tillage and herbicide treatments was maintained during both the years. On average, the highest bulk density of soil (1.66 g cm^{-3}) was obtained in treatment which was prepared twice with cultivator followed by planking, while the lowest bulk density (1.48 g cm^{-3}) was obtained in treatment receiving mould board plough followed by rotavator. Similar results were reported by Khattak *et al.* (2006) who also found that mould board plough significantly lowered the bulk density of soil and improved the physical conditions of soil.

For herbicide treatments, no significant differences in soil bulk density of soil were recorded as all the values were identical (1.56 g cm^{-3}) for all treatment plots. The interactive effect of tillage (T) x herbicide (H), year (Y) x H, Y x T and Y x T x H was non-significant on the bulk density of soil. Amin *et al*. (2014) also found that the application of deep tillage such mould board plough decreased the bulk density of soil and enhanced the crop yield. Similar results were also reported by Ramazan *et al*. (2012) where mould board plough reduced the hardness and compaction of the soil.

Bulk density of soil after tillage operation

The data obtained on bulk density of soil after tillage operation during 2018 and 2019 are reflected in Table 2. Statistical analysis of the data showed that the effect of tillage practices was significant but that of herbicide application on bulk density of soil was non-significant ($p<0.05$). The interactive effect of tillage x herbicide (TxH) on bulk density of soil was also non-significant. The highest

Table 2: Bulk density (g cm^{-3}) of soil after tillage at 0-20 cm soil depth as affected by different tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two Year**
MB Plough (T1)	1.39	1.39	1.39c
Disc Harrow (T2)	1.51	1.48	1.49a
Rotavator (T3)	1.43	1.43	1.43b
Cultivator (T4)	1.49	1.47	1.48a
LSD for Tillage	0.06	0.03	0.03
Herbicide			
Pre-Emergence (H1)	1.46	1.44	1.45a
Post-Emergence (H2)	1.46	1.44	1.45a
Control (H_o)	1.46	1.44	1.45a
LSD for Herbicide	NS	NS	NS
Year			
2018			1.46
2019			1.44
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

Table 3: Bulk density (g cm^{-3}) of soil after crop harvest at 0-20 cm soil depth as affected by different tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two Year**
MB Plough (T1)	1.535	1.54	1.54c
Disc Harrow (T2)	1.563	1.56	1.56ab
Rotavator (T3)	1.555	1.56	1.56b
Cultivator (T4)	1.575	1.58	1.58a
LSD for Tillage	0.02	0.02	0.01
Herbicide			
Pre-Emergence (H1)	1.558	1.56	1.56a
Post-Emergence (H2)	1.557	1.56	1.56a
Control (H_o)	1.556	1.56	1.56a
LSD for Herbicide	NS	NS	NS
Year			
2018			1.56
2019			1.56
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

soil bulk density of 1.49 g cm^{-3} was recorded in plots treated with disc harrow while the lowest soil bulk density of 1.39g cm^{-3} was obtained for treatment treated with mould board plough. The next lowest bulk density of soil was obtained for treatment treated with rotavator. Khattak *et al*. (2006) reported that the application of mould board plough followed by rotavator significantly reduced hardness of the soil and improved the soil structure compared to the application of secondary tillage implements. The effect of herbicide application was also non- significant on bulk density of the soil measured after tillage operation. Moreover, the interactive effects of TxH, YxH, YxT and YxTxH were also non-significant on the bulk density of soil measured after tillage operation. Amin *et al*. (2014) also reported that the application of mould board plough lowered the bulk density of soil and reduced hardness of the soil. Wiyo *et al*. (1987) reported that the bulk density of the surface soil was significantly reduced with the application of deep tillage practices. In another experiment, Khattak *et al*. (2006) found that mould board plough was more effective in decreasing the bulk density of soil and in increasing the crop yield .

Bulk density of soil after crop harvest

Mean data on bulk density of soil measured after crop harvest during 2018 and 2019 revealed that tillage practices significantly affected the bulk density of soil, but the effect of herbicide application was non-significant (Table 3). The highest bulk density of 1.58g cm^{-3} was recorded for treatment treated with cultivator twice followed by planking and the lowest bulk density of 1.54 g cm^{-3} was found in soil receiving mould board plough. Khattak *et al*. (2006) reported that ploughing with mould board plough and chisel plough significantly lowered the bulk density of soil.

Moreover, the effect of herbicide application was non-significant on lowering the bulk density of soil measured after crop harvest. Similarly, the interactive effects of T×H, YxH, YxT and YxTxH were also non-significant on bulk density of the soil. Amin *et al*. (2014) and Ramzan *et al*. (2012) found that mould board plough was more effective in reducing the bulk density of soil. Ahmad and Maurya (1988) also found that bulk density of soil was significantly reduced with the application of deep tillage practices. Mould board plough followed by rotavator significantly reduced the bulk density of soil as reported by Kar *et al*. (1986). Deep tillage practices such as chisel plough, mould board plough and disc plough significantly lowered the bulk density mostly in compact and hard soil (Ghuman and Sur, 2001). Similar findings were also repeated by Amin *et al*.(2014) where application of deep tillage implements such as mould board plough significantly reduced the bulk density of soil.

Table 4: Moisture contents (%) of soil before tillage at 0-20 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two years**
MB Plough (T1)	15.9	15.6	15.7a
Disc Harrow (T2)	12.5	13.7	13.1b
Rotavator (T3)	14.1	16.3	15.2a
Cultivator (T4)	11.7	13.9	12.8b
LSD for Tillage	0.88	NS	1.68
Herbicide			
Pre-Emergence (H1)	13.5	14.9	14.2a
Post-Emergence (H2)	13.5	14.9	14.2a
Control (H_o)	13.5	14.9	14.2a
LSD for Herbicide	NS	NS	NS
Year			
2018			13.5
2019			14.9
Significance			*
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

Table 5: Moisture contents (%) of soil after tillage at 0-20 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two years**
MB Plough (T1)	13.1	15.0	14.1a
Disc Harrow (T2)	10.2	12.1	11.2b
Rotavator (T3)	10.4	12.3	11.3b
Cultivator (T4)	9.8	11.7	10.8b
LSD for Tillage	1.24	1.26	0.82
Herbicide			
Pre-Emergence (H1)	10.9	12.8	11.8a
Post-Emergence (H2)	10.9	12.8	11.8a
Control (H_o)	10.9	12.8	11.8a
LSD for Herbicide	NS	NS	NS
Year			
2018			10.9
2019			12.8
Significance			**
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

Moisture content of soil before tillage operation

The differences in moisture content of soil among tillage treatments were significant during 2018 but non-significant during 2019 (Table 4). The average data revealed that the effect of tillage practices on moisture content of soil was significant but that of herbicide application was non-significant effect. On average, the maximum moisture content of 15.7% was recorded for treatment receiving

Table 6: Moisture contents (%) of soil after crop harvest at 0-2 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two years**
MB Plough (T1)	13.3	13.4	13.3a
Disc Harrow (T2)	10.4	11.5	10.9b
Rotavator (T3)	11.0	12.3	11.6b
Cultivator (T4)	9.3	9.0	9.2c
LSD for Tillage	0.56	1.73	0.84
Herbicide			
Pre-Emergence (H1)	11.0	11.5	11.2a
Post-Emergence (H2)	11.0	11.5	11.2a
Control (H_o)	11.0	11.5	11.3a
LSD for Herbicide	NS	NS	NS
Year			
2018			11.0
2019			11.5
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

mould board plough followed by rotavator while the lowest moisture content of 12.8% was recorded for treatment receiving cultivator twice followed by planking. Herbicide application however didn't exert any significant effect on moisture content of soil before tillage application. The interactive effects of T×H, YxT, YxH and YxTxH were also non-significant for moisture content of soil measured before tillage application. Similar results were achieved by Amin *et al*. (2014), Din *et al*. (2013a and 2013b), Ramazan *et al*. (2012) and Khattak *et al*. (2006) who also found that primary tillage implements such as mould board plough followed by rotavator conserved more moisture in the soil as compared with shallow tillage.

Moisture content of soil after tillage operation

The average data obtained on moisture content of soil after application of tillage practices during 2018 and 2019 revealed that the application of different tillage practices significantly affected the moisture content of soil but herbicide application did not exert any significant effect on soil moisture content of soil (Table 5). On an average, the maximum soil moisture content of 14.1% was recorded in soil which were prepared by mould board plough while the minimum moisture content of 10.8% was found in soil receiving cultivator twice followed by planking. However, differences in moisture content of soil between herbicide treatments were statistically non-significant. The interactions between different factors (TxH),(YxH), (YxT) and (YxTxH) for moisture contents measured after tillage application were statistically non-significant.

Moisture content of soil after crop harvest

The results obtained on moisture content of soil after crop harvest during 2018 and 2019 revealed that differences between tillage treatments were significant but non-significant among herbicide treatments (Table 6). The mean data revealed that maximum moisture content of 13.3% was obtained in soil prepared by mould board plough while the minimum moisture content of 9.2% was obtained in soil which was prepared by cultivator twice followed by proper planking. However, herbicide application revealed a non-significant effect on moisture content of soil after harvest of maize crop. Moreover, the interactions between different factors (T×H), (YxH), (YxT) and (YxTxH) for moisture contents of soil measured after crop harvest were statistically non-significant. These results are in agreement with the findings of Khattak *et al* (2006), Amin *et al*. (2014) and Din *et al*. (2013a and 2013b) who also found that the application of mould board plough conserved and stored more moisture in soil compared with the application of shallow tillage such as cultivator, rotavator and disc harrow. Al-Tahan *et al*. (1992) also reported that the as application of mould board plough exerted significant effect on soil moisture content of soil compared with other tillage practices. Moreover, Hobbs (1986) also reported that the application of mould board plough to the required depth had significant effect on soil moisture conservation and crop productivity.

Penetration resistance (N cm^{-2}) of soil before tillage operation

The data obtained on penetration resistance of soil before application of tillage practices during 2018 and 2019 are presented in Table 7. The mean data showed

Table 7: Penetration resistance (N cm^{-2}) of soil before tillage at 0-20 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two years**
MB Plough (T1)	507.5	460.0	483.8d
Disc Harrow (T2)	568.8	510.0	539.4b
Rotavator (T3)	543.8	496.3	520.0c
Cultivator (T4)	590.4	575.4	582.9a
LSD for Tillage	43.34	32.83	25.25
Herbicide			
Pre-Emergence (H1)	552.5	510.3	531.4a
Post-Emergence (H2)	552.5	510.3	531.4a
Control (H_o)	552.8	510.6	531.7a
LSD for Herbicide	NS	NS	NS
Year			
2018			552.6
2019			510.4
Significance			***
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

Table 8: Penetration resistance (N cm^{-2}) of soil after tillage at 0-20 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two Year**
MB Plough (T1)	262.5	242.5	252.5d
Disc Harrow (T2)	342.5	322.5	332.5b
Rotavator (T3)	302.5	282.5	292.5c
Cultivator (T4)	402.4	382.4	392.4a
LSD for Tillage	0.13	0.13	0.09
Herbicide			
Pre-Emergence (H1)	327.5	307.5	317.5a
Post-Emergence (H2)	327.5	307.5	317.5a
Control (H_o)	327.4	307.4	317.4a
LSD for Herbicide	NS	NS	NS
Year			
2018			327.5
2019			307.5
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

that the application of tillage practices significantly affected the penetration resistance of soil. The data revealed that penetration resistance was lowest in soil following mould board plough and highest when ploughed with cultivator. On an average, the maximum penetration resistance of 582.9 N cm^{-2} was recorded in soil receiving cultivator twice followed by planking while the minimum penetration resistance of 483.8 N cm^{-2} was recorded in soil treated with mould board plough. These findings are in line with the results obtained by Khattak *et al*. (2006) who also found that the application of mould board plough significantly lowered the penetration resistance of soil. The data further showed that the maximum penetration resistance of 531.7 N cm^{-2} was recorded in soil receiving no-herbicides compared with the herbicide treated soils (Table 7). The interactions between different parameters such as TxH, YxH, YxT, and YxTxH revealed non-significant effect on penetration resistance of soil. Ram**a**zan *et al*. (2012) and Amin *et al*. (2014) also reported that the application of deep tillage implements such as mould board plough and chisel plough lowered the hardness and compaction of soil. However, Idowu *et al*. (2019) reported that soil physical parameters including mean weight diameter of dry aggregates, wet aggregate stability, and penetrometer resistance were mostly not significant with tillage, while three out of the six biological parameters (diversity index, total soil fungi, and AM fungi) were significant with tillage ($p\leq 0.05$).

Penetration resistance of soil after tillage operation

The data obtained on penetration resistance of soil after application of tillage practices during 2018 and 2019 are presented in Table 8. The average data revealed that penetration resistance of soil was significantly affected by different tillage practices while non-significantly by herbicide application. On average, the maximum penetration resistance of 392.4 N cm^{-2} was obtained in soil which was ploughed by cultivator twice followed by planking while the lowest penetration resistance of 252.5 N cm^{-2} was recorded in soil treated with mould board plough suggesting that the application of mould board plough reduced the penetration resistance of soil. These results are in line with those of Khattak *et al*. (2006) who also found that primary tillage such as mould board plough significantly lowered the hardness and compaction of soil. The data further showed that the interactive effects of TxH, YxH, YxT, and YxTxH were non-significant on penetration resistance of soil. The findings of Amin *et al*. (2014) and Ramazan *et al*. (2012) are in line with our results, who also found that the application of tillage tools such as mould board ploughsignificantly reduced the penetration resistance of soil.

Table 9: Penetration resistance (N cm^{-2}) of soil after crop harvest at 0-20 cm soil depth as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two years**
MB Plough (T1)	225.0	255.0	240.0c
Disc Harrow (T2)	333.8	363.8	348.8b
Rotavator (T3)	317.4	347.4	332.4b
Cultivator (T4)	390.0	420.0	405.0a
LSD for Tillage	22.97	22.97	15.08
Herbicide			
Pre-Emergence (H1)	316.5	346.5	331.5a
Post-Emergence (H2)	316.6	346.6	331.6a
Control (H_o)	316.6	346.6	331.6a
LSD for Herbicide	NS	NS	NS
Year			
2018			316.5
2019			346.5
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	NS	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

Penetration resistance of soil after crop harvest

The data obtained on penetration resistance of soil obtained after maize harvest during 2018 and 2019 are presented in Table 9. The average data revealed that penetration resistance of soil was significantly affected by tillage practices. On an average, the maximum penetration resistance of 405.0 N cm^{-2} was obtained for soil receiving cultivator twice followed by planking while the lowest penetration resistance of 240.0 N cm^{-2} was recoded for soil receiving mould board plough suggesting that the application of mould board plough reduced the penetration resistance of

Table 10: Biological yield (kg ha^{-1}) of maize as affected by tillage practices and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two Year**
MB Plough (T1)	10565	10685	10625a
Disc Harrow (T2)	9742	9862	9802c
Rotavator (T3)	10189	10309	10249b
Cultivator (T4)	9075	9195	9135d
LSD for Tillage	199	204	131
Herbicide			
Pre-Emergence (H1)	10483	10603	10543a
Post-Emergence (H2)	10113	10233	10173b
Control (H_o)	9083	9203	9143c
LSD for Herbicide	147	150	101
Year			
2018			9893
2019			10013
Significance			NS
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	***	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicide, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

Table 11: Grain yield (kg ha^{-1}) of maize as affected by tillage and herbicide application

	Year		
Tillage	**2018**	**2019**	**Average of two years**
MB Plough (T1)	3461	3408	3434a
Disc Harrow (T2)	3305	3225	3265c
Rotavator (T3)	3407	3327	3367b
Cultivator (T4)	3190	3174	3182d
LSD for Tillage	64	71	44
Herbicide			
Pre-Emergence (H1)	3471	3420	3446a
Post-Emergence (H2)	3377	3313	3345b
Control (H_o)	3175	3118	3146c
LSD for Herbicide	24	37	22
Year			
2018			3341
2019			3284
Significance			***
Interaction	Significance	Interaction	Significance
Y x T	NS	Y x H	NS
T x H	***	Y x T x H	NS

Means in last column followed by different letter(s) within each category (i.e., tillage, herbicides, year) are significantly different at 5% level of probability: * = Significant at 5% level of probability.

soil. The data obtained are in line with that of Khattak *et al.* (2006) who also found that the application of mould board plough and chisel plough significantly lowered the penetration resistance of soil. The data further revealed that herbicide application did not exert any significant effect on penetration resistance of soil. Moreover, the interactions between different factors such as TxH, YxH, YxT, and YxTxH reflected no-significant effect on penetration resistance of soil. Ramazan *et al.* (2012) and Amin *et al.* (2014) also reported that the application of mould board plough significantly reduced the penetration resistance of soil.

Biological yield of maize (kg ha^{-1})

The biological yield of maize crop obtained during 2018 and 2019 as affected by different tillage practices and herbicide application are shown in Table 10. The mean data revealed that the effects of tillage practices, herbicide application and their interaction were significant on biological yield. On average, the maximum biological yield of 10625 kg ha^{-1} was obtained for treatment receiving mould board plough while the lowest biological yield of 9135 kg ha^{-1} was recorded for treatment receiving cultivator twice followed by planking. Among herbicide treatments, the maximum biological yield of 10543 kg ha^{-1} was recorded for treatment receiving herbicides at pre-emergence stage while the minimum biological yield of 9143 kg ha^{-1} in the control treatment. Moreover, the interaction between TxH was significant, while that of YxT, YxH and YxTxH were non-significant for biological yield of maize. These results are in line with those reported by Imran *et al.* (2013), Din *et al.* (2013a and 2013b), Amin *et al.* (2013) who found that the application of tillage implements such as mould board plough significantly increased the biological yield of crops.

Grain yield of maize (kg ha^{-1})

The statistical analysis of the two year data revealed that the effects of tillage practices, herbicide application and interactions between TxH were significant on the grain yield of maize crop. On average, the maximum grain yield of 3434 kg ha^{-1} was obtained for treatment ploughed with mould board plough while the minimum grain yield of 3182 kg ha^{-1} was recorded for treatment ploughed with cultivator twice followed by planking. Among herbicide treatments, the maximum grain yield of 3446 kg ha^{-1} was recorded for treatments that received herbicide at pre-emergence stage compared with 3146 kg ha^{-1} in the control. The application of herbicides reduces the population of weeds and increases nutrient uptake in crop which results in maximum grain yield of maize crop (Khan *et al.*, 2002). Moreover, the interactions between TxH was significant, while that of YxT, YxH and YxTxH were non-significant for grain yield of maize. Similar findings were reported by Din *et al.* (2013a and 2013b) who found that tillage practices such as mould board plough significantly increased the yield of corn crop both under rainfed and irrigated conditions. Similar findings were also reported by Imran *et al.* (2013) and Amin *et al.* (2013) where the application of deep tillage implements significantly increased the grain yield of crops. However, Wasaya *et al.* (2017a) suggested that field should be prepared with chisel plough followed by cultivator to obtain higher grain yield of maize and net returns under semi-arid conditions of Pakistan. In another experiment, Wasaya *et al.* (2017b) recommended after two years of experimentation that farmers should cultivate the soil using chisel plough along with cultivator and apply nitrogen in three splits to obtain higher grain yield of maize hybrid.

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