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Phenological and yield components response of major exotic maize varieties to different levels of soil bulk densities

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ABSTRACT

Maize is the second staple food and a major cereal crop in Pakistan, but its actual yield is 25-30% less than the potential because of high soil bulk densities. Three exotic maize varieties (Baber, Pioneer-30P45, and Syngenta-6621) were evaluated under the three different soil bulk densities of 1.00 - 1.30, 1.30 - 1.60, and 1.60- 1.90 g cm^{-3}. Nine treatments were replicated three times, making 27 pots experiments under complete randomized design were tested. Results showed that bulk density significantly ($\alpha < 0.05$) affected all the parameters of the crops except the number of days to emergence. The fewest number of days to emergence (8.4), tasseling (60.9), silking (66.9), maturity (91.9), leaves per plant (6.3), as well as the lowest shoot thickness (0.49 cm) were obtained under the 1.00 - 1.30 g cm^{-3} density. This density also produced the tallest plants (174.7 cm), highest stover (5938.7 kg ha^{-1}), grain yields (1551 kg ha^{-1}), and harvest index (21.9 %). Conversely, most days to emergence, tasseling, silking, and maturity occurred at the bulk density of 1.60 - 1.90 g cm^{-3}, which also produced the shortest plants and the lowest grain stover and grain yields as well as the harvest index. It was concluded that increasing bulk density levels increase the number of days to tasseling, silking, maturity, and leaves per plant and shoot thickness. Syngenta-6621 was found late in maturity among the hybrids but produced superior stover and grain yields.

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1. INTRODUCTION

Maize is the second most highly produced and consumed cereal crop around the world. Different parameters such as soil bulk density, population density, solar flux, temperature, nutrients, water availability, and optimum tillage method can significantly impact increasing maize yield (Orfanou et al., 2019). Maize is sown from mid-April, ends in mid-June, and is harvested from early October to mid-November. Maize seed germinates in 10 to 14 days at 24°C, and it can take from 60 to 100 days to mature and reach harvest, depending upon variety and the amount of heat during the growing season(Yan et al., 2019). For obtaining optimum yields in maize, it is necessary that the pH of the soil does not deviate from 7.5 to 8.5. Maize is also sensitive to water logging (Alemu et al., 2013). In addition, soil bulk density or soil compaction is another reason for a lower yield in maize. According to Ramazan et al. (2012), the compacted layers in the soil are due to trafficking, which causes higher bulk densities and results in 35% less corn yield. Ding et al. (2021) reported the effects of different tillage techniques and straw mulching on the yield and phenology of the wheat-summer maize rotation system. They reported that straw mulch and deep tillage practices decrease soil bulk density from 2.1 to 1.78 g cm^{-3}, thus causing an increase of 15.2% in wheat and 6.97 % in maize crop yield in the wheat maize crop system.

Soil bulk densities play a vital role in improving maize yield. The nutrient uptake efficiency of maize plants is enhanced by decreasing soil bulk densities. Nitrogen recovery and Nitrogen absorption by root are also proportional to the soil bulk densities (Li et al., 2020). Soil compaction has long been known to cause most restrictions and yield reductions in many crops, especially in Maize (Ramazan et al., 2012). Wang et al. (2012) obtained successful results as tillage depth was increased from 0-40 cm. At this depth, bulk density was reduced to 9%, and the compactness of the soil was also reduced to 36.42%. In addition, the aggregate stability of the soil structure was improved; water holding capacity was also increased. Which ultimately resulted in an enhanced yield of maize. Sabir et al. (2021) reported that crop yield in different cereals could be reduced from 30% to 50% if the soil bulk density increased from 1.32 to 1.70 g cm^{-3}. Yan et al. (2019) applied farm yard manure along with biochar at different depths, i.e. 20 cm, 40 cm, and 60 cm, in maize crops to promote nutrient efficiency. The optimum results were achieved at a depth of 40 cm. However, bulk density was decreased by 5.9 % at 0-20 cm depth. As biochar was applied, it increased the soil temperature, grain yield, and the number of spikes. T. Zhang et al. (2021) reported that irrigation schedule and soil bulk density can significantly affect the yield and photosynthetic content of different maize hybrids.

As the maize yield is lower in Khyber Pakhtunkhwa in particular and Pakistan in general, this research was carried out to find the effect of different levels of soil bulk densities on the yield of different maize varieties. The research is novel in the sense that it will provide baseline information to maize growers of the area on how much yield and phenology of maize are affected if we increase the soil bulk density.

2. MATERIALS AND METHODS

2.1 Research site

Three levels of bulk density combination and three different maize varieties under sandy loam soil conditions were studied for maize plant phenological and yield components at the University of Agriculture Peshawar, Pakistan, during the maize growing season. The study was conducted for 96 days, from June 2nd to September 5th, 2018.

2.2 Experimental design

A complete randomized design (CRD) was used in the experiment having two factors, i.e.: maize hybrids and bulk densities.

2.3 Treatments description

Factor A was maize varieties, namely V1 **(**Baber, Local), V2 (Pioneer-30P45), and V3 Syngenta-6621 (both V2 & V3 are hybrids), and factor B was soil bulk density range B1 (1.00 – 1.30), B2 (1.30 – 1.60), and B3 (1.60 – 1.90) g cm^{-3}. The factors were replicated thrice, totaling 27 different combinations of treatments.

2.4 Pots used in the experiment

The experiment was conducted in PVC (polyvinyl chloride) pots having 50 cm lengths and 20.35 cm internal diameter, making an area of 324 cm^2 and a volume of 4040 cm^3. For irrigation purposes, the drips were installed in the pots. The drips were divided into three subsections and installed on the top section at 20.32 cm, middle at 10.24 cm, and bottom at 20.32 cm sections at 5.24 cm each internally.

2.5 Experimental procedure

Before filling the pots, the soil was mixed with water. A rotary mixing machine driven by an electric motor having a roller drum of 100 kg capacity was used to mix the soil and water. The electromechanical test system was used to determine soil strength and compression in the pots. In each pot, 50 kg of this mixed dried soil was used. By varying the bulk density level combination, three different bulk density levels were created and tested by the Electromechanical Test System. To get different levels of bulk densities, the soil was weighed by electronic balance, and then the soil was poured into each pot to obtain the required level of bulk density. Before sowing of seed in the pot, 5% water by weight was added to all pots. The moisture content level was kept at 10 – 15% in the whole experiment in all the treatments throughout the growing season. In each pot, three seeds were planted at 2 cm depth, and then the pots were placed in the greenhouse. Cultural practices of pruning the weeds were undertaken as needed. The pruning process was done manually to avoid re-arranging the soil particle on the top layer. The seed emergence was recorded after three days and continued up to9 days in all the pots. After nine days, the plants were thinned to one per pot to prevent competition. Plant height was recorded after three days and was continuously taken at three-day intervals up to the harvesting of the crop. Plant leaves data were recorded over three days and were continuously taken at three-day intervals up to the harvesting of the crop. Plant shoot thickness data were recorded during the harvesting stage. Plant shoot thickness data were taken at the bottom and top of the first inter-nodes of the plant by vernier caliper. The stover weight was recorded during the harvesting stage. The dry weight of plant was recorded after oven dried at a temperature of 55°C. The data were recorded on parameters including days to emergence, days to tasseling, days to silking and days to maturity, plant height, shoot thickness, stover yield (kg ha^{-1}), leaves ($plant^{-1}$), grain yield (kg ha^{-1}), and harvest index (%).

2.6 Statistical analysis

The statistical software SAS (SAS Institute Inc) was used to analyze data. This analysis of variance provided the standard error difference and the application of Fisher's tests for comparing treatments (Sabir et al., 2021).

3.RESULT

The statistical analysis of the data in Table 1 shows that most of the study parameters are significantly ($P < 0.05$) affected by the increase in soil bulk density and the change in the crop variety. The interaction results are also significant for most of the parameters. The results that are not significant are days to emergence with bulk density and its interaction with the variety and the interaction effects of days to tasseling, plant height, shoot thickness, and harvest index (%).

3.1 Days to emergence

The effect of bulk density on the phenological parameters of hybrid maize varieties is given in Table 2. The hybrids are significantly different from each other on days to emergence, while the bulk density showed a non-significant result on days to emergence and the interaction was also non-significant in days to emergence. The mean values showed that among varieties, Pioneer-30P45 took more days (10.5) to emerge followed by Baber and Syngenta-6621 with 7.7 and 7.5 days, respectively. Similarly, fewer days of 8.4 were recorded for low bulk density B1, while more days of 8.6 were recorded for B2 and B3.

Table 1. Summary of ANOVA of the effect of soil bulk density on phenological and yield attributes of three hybrid maize varieties

Parameter	Significance		
	Variety (V)	Bulk Density (BD)	Interaction (V x BD)
Days to Emergence	*	ns	ns
Days to Tasseling	*	*	ns
Days to Silking	**	**	*
Days to Maturity	**	**	*
Plant Height	*	*	ns
Shoot Thickness	**	*	ns
Stover Yield (kg ha^{-1})	**	**	**
Leaves ($Plant^{-1}$)	**	**	*
Grain Yield (kg ha^{-1})	**	*	*
Harvest Index (%)	**	*	ns

Table 2. Effect of bulk density on phenological parameters of hybrid maize varieties

	Baber	Pioneer-30P45	Syngenta-662	Mean
Bulk density levels days to emergence				
B1	7.4	10.3	7.4	8.4a
B2	7.8	10.5	7.5	8.6a
B3	7.8	10.6	7.5	8.6a
Mean	7.7b	10.5a	7.5c	
Days to tasseling				
B1	53.3	63.2	66.2	60.9b
B2	54.2	63.7	67	61.6a
B3	54.1	63.9	67.8	61.9a
Mean	53.9c	63.6b	67.0a	
Days to silking				
B1	63.3	67.8	69.5	66.9b
B2	63.3	68.2	69.5	67.0a
B3	64.2	68.3	69.9	67.5a
Mean	63.6b	68.1a	69.6a	
Days to maturity				
B1	90.8	91.7	93.2	91.9b
B2	90.9	92.3	94.1	92.4a
B3	91	92.8	94.8	92.9a
Mean	90.9c	92.3b	94.0a	
Shoot thickness				
B1	0.49	0.51	0.54	0.51a
B2	0.48	0.51	0.53	0.51a
B3	0.46	0.50	0.52	0.49b
Mean	0.48c	0.51b	0.53a	

3.2 Days to tasseling

The data of days to tasseling are given in Table 2. Days to tasseling were significantly ($P \leq 0.05$) affected in hybrids as well as bulk density, but the interaction effect was not significant. Fewer days to tasseling (53.9) were recorded for Baber, followed by Pioneer-30P45 with 63.6 days. However, more days to tasseling (67.0) were recorded for Syngenta-662. In bulk density levels, few days to tasseling (60.9) were recorded for B1 followed by 61.6 for B2 and 61.9 for B3 in reaching corn to tasseling.

3.3 Days to silking

The data of days to silking are given in Table 2. Days to silking were significantly ($P \leq 0.05$) affected in hybrids and by bulk density, and the interaction effect was significant. Fewer days to silking (63.6) were recorded for Baber, followed by Pioneer-30P45 with 68.1 and Syngenta-662 with 69.6 days. Similarly, under bulk density levels, the lowest days to silking (66.9) were recorded for B1, followed by 67.0 for B2, and the most days of 67.5 were recorded for B3 in reaching the crop to silking stage.

3.4 Days to maturity

The data of days to maturity are given in Table 2. Days to maturity were significantly ($P < 0.05$) affected in hybrids and by bulk density, and the interaction effect was significant. Fewer days to maturity of 90.9 in the crop were Baber, followed by 92.3 for Pioneer-30P45, and the most days of 94.0 Syngenta-662. In bulk density levels, minimum days of 91.9 were B1, followed by 92.4 for B2, while maximum days of 92.9 were recorded for B3 in reaching the crop to maturity stage.

3.5 Shoot thickness (cm)

The data of shoot thickness are given in Table 2. Plant shoot thickness was significantly ($P \leq 0.05$) affected in hybrids and by bulk density, and the interaction effect was significant. Thicker plant shoots of 0.53 cm in the crop were Pioneer-30P45, followed by 0.51 cm for Syngenta-662, while thin shoots of 0.48 cm were found in Baber. In bulk density levels, thick shots of thickness 0.51 cm were recorded for B1 and B2, while maximum shoots of 0.49 cm were recorded for B3.

3.6 Leaves (plant $^{-1}$)

The data of Leaves $Plant^{-1}$ are given in Table 3. Leaves plant $^{-1}$ were significantly ($P \leq 0.05$) affected in hybrids and by bulk density, and the interaction effect was significant. More leaves of 8.1 were Syngenta-662, followed by Pioneer-30P45 of 6.4 leaves, while fewer leaves of 5.1 were found in Baber. In bulk density levels, the most leaves was B1 (6.7), followed by B2 with 6.6, and the fewer leaves was B3 (6.3).

3.7 Plant height

The data of plant heights are given in Table 3. Plant heights were significantly ($P \leq 0.05$) affected in hybrids and by bulk density, and the interaction effect was significant. Higher plants of height 189.1 cm were Syngenta-662, followed by Pioneer-30P45 of 171 cm, while a minimum height of 161.2 was recorded for Baber. In bulk density levels, higher plants of 174.7 cm were B1 followed by 73.8 for B2, while a minimum height of 172.9 was B3.

3.8 Stover yield (kg ha^{-1})

The data of stover yield (kg ha^{-1}) is given in Table 3. Stover yield (kg ha^{-1}) was significantly ($P \leq 0.05$) affected in hybrids and by bulk density as well as the interaction effect was significant. The highest yield was Syngenta-662 (6709 kg ha^{-1}), followed by Pioneer-30P45 (5961.7 kg ha^{-1}), and the lowest was Baber (5048.0 kg ha^{-1}). In bulk density levels, the highest yield were B1 (5938.7 kg ha^{-1}), and then B2(5904.3kg ha^{-1}), and the lowest was B3 (5875.7 kg ha^{-1}).

Table 3. Effect of bulk density on yield parameters of hybrid maize varieties

	Baber	Pioneer-30P45	Syngenta-662	Mean
Bulk density levels leaves (Plant^{-1})				
B1	5.3	6.5	8.3	6.7a
B2	5.2	6.5	8.1	6.6a
B3	4.9	6.1	7.8	6.3b
Mean	5.1c	6.4b	8.1a	
Plant height (cm)				
B1	162.3	171.7	190	174.7a
B2	161.3	171	189.1	173.8a
B3	160.1	170.3	188.2	172.9b
Mean	161.2c	171.0b	189.1a	
Stover yield (kg ha^{-1})				
B1	5060	5966	6790	5938.7a
B2	5045	5965	6703	5904.3b
B3	5039	5954	6634	5875.7c
Mean	5048c	5961.7b	6709.0a	
Grain yield (kg ha^{-1})				
B1	1488	1542	1623	1551.0a
B2	1430	1540	1600	1523.3b
B3	1410	1523	1588	1507.0c
Mean	1442.7c	1535.0b	1603.7a	
Harvest index (%)				
B1	22.9	21.6	21.2	21.9a
B2	22.1	21.4	19.3	20.9b
B3	19.9	21.1	19.1	20.0b
Mean	21.6a	21.4b	19.9c	

3.9 Grain Yield (kg ha^{-1})

The data of grain yield (kg ha^{-1}) is given in Table 3. Grain yield (kg ha^{-1}) was significantly ($P \leq 0.05$) affected in hybrids varieties, and bulk density, as well as the interaction effect, was significant. The highest yield (1603 kg ha^{-1}) was Syngenta-662, followed by Pioneer-30P45, with a yield of 1535.0 kg ha$^{-1,}$ while the lowest 1442.7 kg ha^{-1} was recorded for Baber. In bulk density levels, higher yield of 1551.0 kg ha^{-1} was recorded in B1, followed by 1523.3 for B2, while minimum yield of 1507.0 kg ha^{-1} was B3.

3.10 Harvest index (%)

The data of harvest index (%) is given in Table 3. Harvest index (%) was significantly ($P \leq 0.05$) affected in hybrids and by bulk density, but the interaction effect was not significant. The highest harvest index was Baber (21.6%), followed by Pioneer-30P45 (21.4%), while the lowest was Syngenta-662 (19.9%). In bulk density levels, B1 is the highest harvest index (21.9%), followed by B2 (20.9%) and B3 (20.0%) for the lowest.

4. DISCUSSION

The results showed a significant impact of varieties and soil bulk density on both yield and phonological parameters of maize crops. Days to emergence differed significantly among varieties which could be due to the fact that different varieties have different emergence times. Bulk density showed a non-significant effect because seeds were sown at a depth of 3 to 4 cm, where the bulk density of soil is very good for germination due to no compaction. In addition, high porosity and moisture content facilitate the seeds to germinate properly. Orfanou et al. (2019) also reported that the second phenophase parameter, days to emergence, is significantly different in terms of varieties, while compaction has no effect on days to emergence. Similarly, Z. Zhang et al. (2021) reported that soil compactness causes the high bulk density of soil, which can reduce yield upto 25% for different maize hybrids. The findings of Ramazan et al. (2012)are also in line with the findings of this research. Days to tasselling were significantly affected by varieties and soil bulk densities. As the crop roots penetrate upto 12 cm deep in search of nutrients and water at the tasseling stage, increasing bulk density will affect this intake by roots, thereby causing a delay in days to taselling. Anjum et al. (2018)and Li et al. (2020) also reported a change in days to tasseling of maize with different bulk densities of soil. Wang et al. (2022) also reported a negative correlation between hybrid maize yield with the increase in soil compactness. This could be because roots need to take up more nutrients for the plant, which were restricted by soil with high compaction due to higher bulk densities. Moreover, the significant effect of hybrid varieties could be the result of the different genetic backgrounds of each hybrid. Ramazan et al. (2012) also found that various hybrids responded differently for days to maturity.

Tillage in subsoil caused a reduction in bulk density up to 9% and compactness of soil upto 36.42%. S. Wang et al. (2019) reported that reducing bulk density by deep tillage like subsoil enhances soil condition as stability of the structure is improved; soil water storage is increased, which in turn enhances the yield of maize. Shoot thickness was adversely affected by bulk densities, although a significant change in varieties is due to their genetic characteristics. These results are in accordance with Anjum et al. (2018), who reported that various hybrids responded differently for shoot thickness. In contrast, Sabir et al. (2021) reported that various hybrids responded differently in shoot thickness, but no effect was due to soil compaction. However, Yan et al. (2019) also recorded a significant change in shoot thickness in maize by different bulk densities in soil. In support to present research findings, X. Wang et al. (2019) also reported that phenology and yield decrease with an increase in soil bulk density. Moreover, plant height was significantly affected by both factors. In addition to differences among maize hybrids for plant height, soil compaction also restricted the plants from gaining height. These results are in accordance with the earlier findings of Li et al. (2020), who reported that various hybrids responded differently in plant height.

Grain and stover yield were significantly affected by both factors, which could be due to the fact that different varieties show different phonological responses, affecting the yield parameters. Imran et al. (2015) reported that various hybrids responded differently in biological and specially stover and grain yield. The results are also in line with Ramazan et al. (2012), who concluded that higher bulk densities significantly impact the maize wheat cropping system yield. Similarly, the harvest index was affected significantly, which could be due to the fact that different hybrids exhibit different phonologies due to soil bulk densities and their genetic response. Ding et al. (2021) studied the effects of varying tillage techniques and straw mulching on the yield and phenology of the wheat-summer maize rotation system. They reported that straw mulch and deep tillage practices decrease soil bulk density from 2.1 to 1.78 g cm^{-3}, thus causing an increase of 15.2% in wheat and 6.97 % in maize crop yield in the wheat maize crop system. Afzalinia and Zabihi (2014) and Ding et al. (2021)also reported differential responses of various maize hybrids for harvest index.

5. CONCLUSION

Based on current research findings, it is concluded that increasing bulk density levels increases days to tasseling, silking, maturity, leaves per plant, and shoot thickness. Maximum values of desirable plant parameters of maize crops could be achieved if the soil bulk density ranges from 1.0 to 2.0 g cm^{-3}. Syngenta-6621 was found late in maturity among the tested hybrids while it surpasses in stover as well as grain yields. Based on the significance of the data, the bulk density of soil may be determined before sowing maize in sandy loam soil to get a higher yield and better crop physiology.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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