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Effects of soil compaction caused by tillage and seed covering techniques on soil physical properties and performance of wheat crop

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Abstract

To link the damage caused to the soil structure by the movements of machinery and other crop production operations and their effects on plant fate, a 24-plots experiment was established. The impact of two secondary tillage implements (Disc harrow and cultivator) and four seed covering techniques ranging from zero planking to double planking with 152 kg weight were studied on plant vigor, rate of germination and ultimately yield of wheat. The objective of the study was to investigate the suitable soil compacting operations that should not harm the plant growth due to soil compaction but also give proper seed-soil contact. Regarding tillage implements, the results revealed that cultivator performed better than disc harrow. Among the four seed covering techniques, planking once with 30 kg weight showed the best performance. It was followed by planking once with 152 kg weight, which was better than zero planking and planking twice with 152 kg weight. Hence it can be concluded from the study that seed covering technique of planking with 30 kg weight and tillage with cultivator as secondary tillage equipment can boost the yield of wheat crop.

Introduction

Tillage is performed to reduce soil compaction, and facilitate air and water movement in order to promote plant growth. However, use of heavy equipment causes soil compaction (Larsen *et al*., 1994). Hence, the movement of water and gasses is restricted through soil due to increase in soil bulk density. The increase in soil bulk density also restricts root penetration. Unfortunately, this phenomenon is unavoidable and is perhaps inseparably associated with soil moisture and soil aeration characteristics. The net effect of these interactions is a general reduction in plant vigor (Tebruge, 1993).

In an attempt to study yield and physiological responses of selected grains and vegetable crops and to find out a mechanistic explanation of these responses, numerous studies have been conducted (Raghavan *et al.,* 1976; Cox *et al*., 1990; Lawrence *et al*., 1994; Dwyer *et al*., 1996; Rhoton, 2000; Lampurlanes and Centero-Martinez, 2003). Only few experiments are reported to integrate the knowledge of soil mechanics and agronomy to describe the exact crop yield to be expected as a function of particular machinery (Raghavan *et al.*, 1978).

There are contrasting results regarding the effects of tillage on wheat grains yield. Fuentes *et al*. (2003) did not find consistent grain yield difference while comparing winter wheat grown under conventional tillage and no-tillage systems. Almost similar results were found by Merril *et al.* (1996) for spring wheat grown under conventional tillage, minimum tillage and no-tillage during three seasons in a Pachic Haploboroll soil, and by Acharya and Sharma (1994) in a Typic Hapludalf soil of India. Hubbel and Staten (1951) considered that the compaction is beneficial to potato crop. Sheikh *et al*. (1978) also noted the compaction operations to be necessary for seed germination. Perhaps the later two authors tried to show the impact of seed-soil contact, which is important for seed germination (Khan, 1986).

In contrast, studies conducted by Amezketa (1999) revealed adverse effects of soil compaction on root penetration, air and water availability to plants. Phillips and Kirkham (1962) reported a reduction of 10% and Raghavan *et al.* (1978) found reduction of 45 to 50 tons of corn yields due to soil compaction. Khan *et al*. (1992) observed significant reduction in fate of wheat with increase of soil bulk density from 1.25 g cm^{-3} and 1.35 g cm^{-3} to 1.45 g cm^{-3}.

The intent of this study was to evaluate the effect of two commonly used secondary tillage implements (disc harrow and cultivator) with varying levels of pressures with planking (commonly used in Pakistan, to cover the seed and increase seed-soil contact) on soil physical properties, seed fate and yield of wheat, so as to assess the effects of soil compaction on crop production.

Materials and Methods

The study was performed at "farmer's field at Mochi Wala" village of Daraban Zam areas of Dera Ismail Khan, NWFP, Pakistan in 2005-06. The research area is a sandy clay loam soil with pH value of 7.65. Selected soil

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properties are shown in Table 1. Minimum and maximum temperatures during the growing period were 4.1°C in January and 33°C in April. The total rainfall during the crop period was 8.48 cm.

The field was tilled 15 days before sowing of crop with chisel plow to remove stubbles of previous (oilseed) crop and breakup the hard pan. Plowing was done to a depth of 25 cm. Afterward a land planner was used for leveling the small humps and breaking the clods which were formed due to chisel plow in the field. The field was irrigated using perennial water by flood irrigation method after two days of leveling. After irrigation, 24 plots each of 10 × 20 m^2 were prepared at the available moisture content. Nitrogen and phosphate fertilizer were applied at the rate of 100 kg Nha^{-1} and 75 kg P_2O_5 ha^{-1} in the form of urea and DAP, respectively. All the phosphate fertilizer was applied at the time of sowing, while nitrogen was applied in two doses i.e. first at the time of sowing and the remaining at the time of irrigation by broadcast method. Manual weeding operation controlled the weeds in the plots.

Disc harrow and cultivator were used as a secondary tillage implements for comparison. The seeds were sown with the help of manually driven hand drill to a depth of 5 cm. The seed was sown at the rate of 100 kg ha^{-1}. After sowing seeds, four seed covering techniques were applied (as per farmers' practice in the area) in this experiment to cover seeds and increase seed/ soil contact. The techniques were:

$T_{1:}$ Zero planking,
$T_{2:}$ Planking once with 30 kg weight
$T_{3:}$ Planking once with 152 kg weight (two persons were on the plank)
$T_{4:}$ Planking twice with 152 kg weight (two persons were on the plank)

A total of five irrigations were applied at an interval of approximately one month interval. The irrigation schedule (frequency and amount) was determined according to the average soil water content of the soil.

Soil sampling and measurement of soil physical properties

The soil samples for the measurement of soil bulk density and soil moisture content of the groove made by each implement were taken with the help of tube soil sampler (diameter 1.90 cm) from three randomly selected rows. Soil samples were weighed in wet form and then were placed in an oven at 105° C for about 24 hours. After 24 hours, soil samples were weighed again and soil moisture content was calculated. The data for penetration resistance were taken on the same day with the help of cone penetrometer (diameter 2.78 cm) from the same selected rows. For the rate of emergence, emerged seedlings were counted daily from the three randomly selected rows of each plot. After 30 days of sowing, the following growth measurements of the ten randomly taken plants were recoded from randomly selected rows of each plot:

a) Fresh weight of the plant
b) Dry weight of the plant
c) Root length of the plant
d) Shoot length of the plant

Number of tillers per square meter was counted after 60 days of sowing. To record biological and grain yield, harvesting of three randomly selected rows of each plot was done by hand at the time of maturity of the crop. The data were analyzed statistically by using split plot design (Steel *et al*., 1997).

Results and Discussion

Soil physical properties

Bulk density

The effect of tillage implement and seed covering techniques on soil bulk density around the groove showed that the results for tillage implements and its interaction with soil covering techniques were non-significant (Table 1). However, the effects of seed covering techniques on soil bulk density were significant. Comparing the seed covering techniques with one another, it was observed that the bulk density was increased in T_3 and T_4, while the bulk density was low in T_1 and T_2. There was an overlapping of treatments with one another.

The interaction between tillage implements and seed covering techniques clearly explained the effects of main and sub treatments on soil bulk density. However, the values (1.33 – 1.42 g cm^{-3}), in all the plots except some of the values in zero planking (T_1) were reasonably high in relation to favorable root growth condition (1.32 g cm^{-3}) as reported by Mai (1978).

Table 1. Effect of tillage implements with seed covering techniques on different soil parameters

Treatment	Soil Bulk density (g cm^{-3})			Moisture Content (%)			Penetration Resistance (kg cm^{-3})		
	Implement			Implement			Implement		
	Disc*	Culti**	Mean	Disc	Culti	Mean	Disc	Culti	Mean
T_1	1.3	1.3	1.3a	16.9	16.3	16.60	2.7	2.7	2.70
T_2	1.3	1.3	1.3ab	15.8	16.3	16.05	2.7	2.9	2.80
T_3	1.4	1.4	1.4bc	16.8	17.4	17.10	2.9	2.8	2.85
T_4	1.4	1.4	1.4c	15.2	17.2	16.2	2.8	3.0	2.90
Mean	1.35	1.35		16.18	16.80		2.78	2.85	

* Disc harrow
** Cultivator

Other studies on tillage implement have also found increase in soil compaction (Martinez *et al.*, 2008; Dao, 1996; Shiekh *et al.*, 1980; Raghavan *et al*., 1976) as well as opposite results i.e. decrease in soil compaction (Ball-Coelho *et al*. 1998; Schonning and Rasmussen, 2000). Martinez *et al*. (2008) understands that the contrasting effects of soil management experiments in soil bulk density are common. They are mostly related to management factors such as planting machinery (machine weight, tire width, inflation pressure) number of machine passes, as well as the soil moisture content at which the soil is tilled (Czyz, 2004; Botta *et al.*, 2005). Sheikh *et al*. (1980) found that soil bulk density with three passes of cultivator was higher than the soil bulk density with two passes of disc harrow. Similarly Raghavan *et al*. (1976) found increase in soil bulk density with every pass of tractor on same point. Similar results had also been shown by Chaudhry (1985) who observed a significant effect of direct drilling seed sowing techniques on soil bulk densities when he compared the effects of different seed sowing techniques.

Penetration resistance

The effect of tillage implement (disc harrow cultivator) and the four different seed covering techniques and interaction of these parameters on penetration resistance around the groove (Table 1) showed non-significant ($p \leq 0.05$) difference in penetration resistance in the plots tilled with the two implements as well as in the four seed covering techniques. The interaction between the implement and seed covering techniques did not show any consistent trend. All the values (2.68 – 2.96 kg cm^{-2}), however, were fairly below what Sheikh *et al*. (1980) found during his study (3.57 – 5.70 kg cm^{-2}). This may be due to less number of passing of implements in the study. In the study of Sheikh *et al*. (1980), cultivator was used two times while disc harrow was used three times. The other reason of different results may be chisel plowing before sowing in this study. The third possible reason could be difference in soil texture.

Soil moisture content

The effect on soil moisture content around groove profile by both the implements was non-significant ($p \leq 0.05$) (Table 1). Although the grooves made by cultivator were slightly wetter than the grooves made by disc harrow yet the difference was non-significant. Same non-significant trend was also observed in all four seed covering techniques.

Rate of seedling emergence at day 7

Seedling emergence count (5.59%) on the plots plowed with cultivator recorded significantly ($p \leq 0.05$) higher than disc harrow (2.49%) at 7th day after sowing (Table 2). However, seed covering techniques did not have significant effects on seedling emergence (percentage) on this day.

The best performance appeared in the field tilled with cultivator and planked with 30 kg weight (T_2), followed by the fields with single planking of 152 kg weight (T_3). The possible reason of higher rate of emergence in the fields tilled with cultivator was groove formation. Cultivator made U shaped groove and threw the soil to either sides. While disc harrow made V shaped groove and threw the soil back to its original place. Therefore, the weight of soil above the seed hindered the germination of seed and seedlings to emerge. This weight was more detrimental, when the plank moved over it causing more compaction on the seed. On the other hand reduced emergence rate with zero planking (T_1) may be due to low seed-soil contact and high rate of evaporation due to open grooves in plots plowed with disc harrow. With disc harrow, planking once with 30 kg weight (T_2) gave the worst results. The reason might be clod formation in T_2. Clods above the seed in the grooves were not pulverized properly with small weight. These were pulverized as the weight of planking increased. However, due to creation of high soil compaction, the proper benefit of pulverization could not be achieved. In the plots of cultivator, clods formation occurred, but, not in the groove or above the seeds. Consequently, the seeds were

Table 2. Effect of tillage implements with seed covering techniques on rate of emergence (%)

Treatment	Emergence on day 7			Emergence on day 14			Emergence on day 21			Emergence on day 28		
	Implement			Implement			Implement			Implement		
	Disc*	Culti**	Mean	Disc	Culti	Mean	Disc	Culti	Mean	Disc	Culti	Mean
T_1	2.39	5.64	4.015	32.11	26.11	29.11ab	38.12	39.97	39.05	54.83	43.11	48.97ab
T_2	1.61	6.28	3.945	31.37	32.44	31.91a	35.77	39.25	37.51	51.56	50.11	50.84ab
T_3	3.94	5.83	4.885	34.00	29.33	31.67ab	40.03	36.05	38.04	60.98	50.91	55.95a
T_4	2.00	4.61	3.305	27.81	27.05	27.43b	32.86	36.55	34.71	41.44	46.38	43.91b
Mean	2.49a	5.59b		31.32	28.73		36.70	37.96		52.20	47.63	

* Disc harrow
** Cultivator

covered with thin layer of soil resulting in good germination and emergence. With the increase in compaction, the emergence decreased. This showed that the compaction was harmful for seed germination due mainly to low rate of diffusion of gasses.

Rate of seedlings emergence on day 14

Number of seedlings emerged on 14th day were counted from the same lines which were understudy on day 7. It was observed that the effect of tillage implements on the rate of emergence at 14th day from sowing was non-significant ($p \leq 0.05$) (Table 2). In the seed covering techniques, planking with 30 kg (T_2) showed the highest emergence rate followed by planking once with 152 kg planking (T_3). In the study of interaction between the two implements and four seed covering techniques, the best performance appeared in the plots of disc harrow with planking once with 152 kg weight (T_3) followed by the plots of cultivator having planking with 30 kg (T_2). This shows that live seedlings emerged till this day which could not emerge due to soil compaction at early stage.

In the plots of zero planking (T_1) and planking twice with 152 kg (T_4) showed poor emergence, the major reason could be early emergence of seedlings in the plots of zero planking whereas, in other plots lived but un-emerged seedlings emerged at later stage also. On the other hand, the lowest emergence from the plots plowed with disc harrow and planked twice with 152 kg weight showed the detrimental effect of soil compaction.

Rate of seedlings emergence on day 21

The effect of tillage implements on the rate of emergence at the end of 3rd week after sowing i.e. on 21st day from sowing was non-significant ($p \leq 0.05$) (Table 2). Same was the case in seed covering techniques. The results of interaction between and main and sub treatments confirm the effects. All the techniques with both the implements showed almost the same rate of emergence. The number of plants increased in the field with single planking (T_3) and double planking with 152 kg weight (T_4), which was low in previous days. Germinated seed emerged with slow rate in compacted soil. The reason for slow rate of emergence in compacted soil could be low oxygen diffusion rate especially when soil was wet (Chaudhry, 1985).

Rate of seedlings emergence on day 28

Like the rate of emergence in 3rd week i.e. on day 21, the effect of tillage implements on the rate of emergence at the end of 4th week i.e. on 28th day from sowing was also non-significant ($p \leq 0.05$) (Table 2). However, regarding seed covering techniques, maximum plants emerged in plots planked once with 152 kg (T_3). The results of interaction between and main and sub treatments showed that maximum plants emerged in plots plowed with disc harrow and planked once with 152 kg (T_3). The number of plants increased in the field with single (T_3) and double planking with 152 kg weight (T_4). Germinated seed emerged with slow rate in compacted soil. The reason for slow rate of emergence in compacted soil, as stated earlier, could be low oxygen diffusion rate especially when soil was wet (Chaudhry, 1985). Detrimental effects of high soil compaction was also observed by Flocker and Menary (1960), who found one day delay in emergence of tomato seedlings in the soil bulk density of 1.70 g/cm^3 than 1.10 g/cm^3. Chaudhry (1985) also found higher seedling emergence with opener causing less soil compaction (wing opener) compared to opener which caused high soil compaction around seed/soil environment (triple disc harrow opener).

Fresh weight of plant

The effect of tillage implement on fresh weight of randomly taken 30 days old plants together with the effects of different techniques of seed covering and interaction

between these two parameters is shown in Table 3. Effects of the two tillage implements (Disc harrow and Cultivator) on fresh weight of the plants were non-significant.

The fresh weight of plants from the plots of single planking with 30 kg (T_2) was significantly ($p \leq 0.05$) higher from the plot with double planking (152 kg weight) (T_4). In the study of interaction between tillage implements and seed covering techniques, it is clear that the fresh weight of the plants with cultivator with one planking of 30 kg was the highest among all the plots. In case of disc harrow fresh weight of the plants was higher in the plots with single planking of 152 kg. While in the plots with double planking with 152 kg weight, both the implements showed the minimum fresh weight of the plant. The data showed a negative effect of soil compaction with double planking of 152 kg weight on the fresh weight of the 30 days old plants.

Flocker and Menary (1960) also showed the decrease in fresh weight of 30 days old tomato plants with increase in soil compaction. This phenomenon is attributed to delay in germination or in the in-time germination but non-emergence of seedlings. The other reason is due to lack of oxygen availability. According to Chaudhry (1985) a significant decrease of oxygen was observed in compact soil.

Dry weight plant^{-1}

Effect of tillage implements on dry weight per plant was not significant (Table 3). The seed covering techniques with planking once of 30 kg weight (T_2) recorded significantly heavier dry weight per plant than the seed covering techniques of double planking with 152 kg weight (T_4). The highest dry weight per plants was recorded in the seed covering techniques with single planking of 30 kg weight (T_2). However, the dry weight per plant decreased with the increase in soil compaction. The minimum weight was recorded in the techniques of double planking of weight 152 kg weight (T_4). Increased compaction hindered the proper growth of plants.

Root length plant^{-1}

Non-significant difference was found on root length per plant by the two implements (Table 3). Maximum length of root per plant was recorded in the plots with zero planking (T_1). Length of root with zero planking and planking once with 30 kg weight was significantly ($p \leq 0.05$) higher than the length of roots with planking once and twice with 152kg weight. However, non-significant ($p \leq 0.05$) difference was observed in the root length with zero planking and planking once with 30 kg. Non-significant difference in root length was also observed when the seed were covered with planking once and twice with 152 kg weight.

As regards the interaction between tillage implements and seed covering techniques, the best performance was observed in the plots with zero planking in the plots plowed with disc harrow, however, the root length decreased with increase in soil compaction. In the plots plowed with cultivator, the root length also decreased with the increase of soil compaction. Minimum root length was recorded in the plots plowed with cultivator and planking twice with 152 kg weight each. Decrease of root length with the increase in soil compaction was also observed by many scientists. Baker and Mai (1982) observed the cross section of a soil profile, in which the lupin root was diverted from hard soil to soft soil.

Shoot length plant^{-1}

The effect of implements on the shoot length per plant was statistically non-significant ($p \leq 0.05$) (Table 3). In seed covering techniques length of shoot with zero planking, planking once with 30 kg and planking once with 152 kg were significantly higher from the shoot length of plants from the plots of double planking with 152 kg each. However, their effect among themselves remained non-significant. This shows that only significant increase in soil compaction above the seed would affect the length of shoot. The result of interaction between tillage implements and

Table 3. Effect of tillage implements with seed covering techniques on plant fate

Treatment	Fresh weight per plant (g)			Dry weight per plant (g)			Root length per plant (mm)			Shoot length per plant (mm)			Number of tillers meter^{-2}		
	Implement			Implement			Implement			Implement			Implement		
	Disc*	Culti**	Mean	Disc	Culti	Mean	Disc	Culti	Mean	Disc	Culti	Mean	Disc	Culti	Mean
T_1	1.94	2.21	2.08 ab	0.43	0.33	0.38 ab	78	70	74 a	299	288	294 a	119	136	128 a
T_2	2.03	2.50	2.27 a	0.45	0.42	0.44 a	71	61	66 a	272	288	280 a	212	181	197 b
T_3	2.23	1.97	2.10 ab	0.35	0.25	0.30 ab	51	51	51 b	285	281	283 a	154	170	162 c
T_4	1.56	1.70	1.63 b	0.25	0.20	0.23 b	44	39	42 b	241	246	244 b	83	148	116 a
Mean	1.94	2.10		0.37	0.30		61	55		274	276		142	159	

* Disc harrow
** Cultivator

seed covering techniques proved the effect of tillage implements and seed covering techniques. The highest soil compaction decreased the shoot length in both the implements; this was because of slower growth rate of late emerged seedlings in the compacted zone.

Number of tillers m^{-2}

Although the number of tillers in the plots plowed with cultivator was more than the number of tillers in the plots plowed with disc harrow but statistically the effect of both the implements on the number of tillers m^{-2} was not significant (Table 3). In the seed covering techniques planking with 30 kg weight showed the best performance over all the techniques, followed by the techniques of planking once with 152 kg weight. Higher number of tillers appeared in the lots of zero planking than the plots of two planking with 152 kg each. However, the difference was non-significant. The interaction between tillage implements and seed covering techniques proves results of the effects of main and sub treatments. Number of tillers decreased with increase in load and number of planking due mainly to increase in soil compaction. The data of root/shoot length of the plants also indicated that soil compaction caused detrimental effects on plants growth resulting in the formation of number of tillers. However, less number of tillers with zero planking was due to low seed/soil contact.

Biological yield

The effect of disc harrow and cultivator on biological yield with the effect of different seed covering techniques and interaction between these two parameters is shown in Table 4.

It is clear from the Table that the effect of tillage implements was non-significant on biological yield of the crop. In seed covering techniques, the best yield appeared in the plots of zero planking followed by planking once with 30 kg weight and then by planking once with 152 kg weight. The yield of the plots with zero planking and planking once with 30 kg weight were significantly higher from the yield of the plots planked twice with 152 kg weight each. However, their effect was not significant when compared with planking once with 152 kg weight.

In the data of interaction between tillage implements and seed covering techniques, both the implements showed minimum yield with the technique of planking twice with 152 kg weight. This proves that the methods of planking twice with 152 kg weight caused highest compaction and therefore is harmful for biological yield. The biological yield in the plots tilled with disc harrow and zero planking was higher than all the seed covering techniques performed with disc harrow. However, it was never as good as the yield obtained with technique of planking once with 30 kg weight in the plots tilled with cultivator. The reason for lower yield in the plots tilled with cultivator with zero planking was due to low seed-soil contact and higher moisture loss through evaporation due to open grooves. However, it showed the best results when it was covered with plank of 30 kg weight. The decrease yield with planking of 152 kg weight (once or twice) was due to higher soil compaction.

Grain yield

The effect of tillage implement on yield of wheat crop with four different seed covering techniques of planking and the interaction between these two parameters is also shown in Table 4. There appeared to be significantly ($p \leq 0.05$) higher grain yield in the plots tilled with cultivator (44.57 qu ha^{-1}) than those tilled with disc harrow (37.67 qu ha^{-1}). In the different seed covering techniques, planking once with 30 kg weight gave the maximum yield and was significantly higher than the yield obtained with zero planking and planking twice with 152 kg weight. The techniques of planking once with 152 kg also gave significantly ($p \leq 0.05$) higher yield than the techniques of planking twice with 152 kg. However, its difference with zero planking and planking with 30 kg weight remained no-significant. The difference in yield from the plots of zero planking and planking twice with 152 kg was also non-

Table 4. Effect of tillage implements with seed covering techniques on plant fate

Treatment	Biological yield (q ha^{-1})			Grain yield (q ha^{-1})		
	Implement			Implement		
	Disc harrow	Cultivator	Mean	Disc harrow	Cultivator	Mean
T_1	154.44	150.00	152.22 a	41.94	37.82	39.88 ac
T_2	141.11	162.13	151.62 a	38.03	54.50	46.27 b
T_3	143.33	146.39	144.86 ab	35.67	47.51	41.59 ab
T_4	130.83	135.39	133.11 b	34.96	38.85	36.91 c
Mean	142.43	148.48		37.65 a	44.67 b	

significant. In the study of interaction between tillage implement and seed covering techniques the best results were observed in the plots of cultivator with one planking of 30 kg weight. Disc harrow showed the best performance in the plots of zero planking. In the plots of zero planking plowed with disc harrow performed better than cultivator due to difference in groove formation. The groove formed with cultivator with zero planking remained open while in disc harrow, the soil turned over and covered the seed. Therefore, the seed in these plots got proper seed-soil contact and produced better yield. Sheikh *et al*. (1978) also found decrease in yield with increasing number of passing of the implements. However, the results of present study negate the general opinion that disc harrow is better than cultivator.

Conclusion

The results of the experiment show that plants responded negative to soil compaction. Compaction affects soil moisture, aeration, temperature nutrition and soil strength. All these factors affect other relations and combinations of relations that affect the growth of plant. Two tillage implements (disc harrow and cultivator) and four seed covering techniques compacted the soil to different level. This procedures resulted in relatively, high soil bulk densities, at least in the upper layer of the soil (150 mm). A high degree of clods were also observed in the case of zero planking which created least compaction among all seed covering techniques. High compaction delayed the emergence and growth process. In the plots tilled with disc harrow having two planking with 152 kg weight showed almost negligible emergence on 14th day after sowing. However, such detrimental effect did not occur in the plots plowed with cultivator given same set of treatment for seed covering techniques.

The reduction of fresh and dry weights of the plants occurred due to delay in growth processes caused by compaction. The length of root and shoot also reduced due to high compaction. The effect of soil compaction was also observed on the formation of less number of tillers and ultimately causing a decrease in the yield of the wheat crop.

In this regard two possible explanations can be inferred:

(a) Rate of seedling emergence was reduced with increase in soil compaction. However, the reduction in yield can not be attributed only to increased soil bulk density. It can be partly attributed to formation of more clods. The clods allowed the seed to germinate but hindered the emergence of seedling. On later stage, irrigation softened the soil of high compaction and helped germinated but un-emerged seedlings to germinate. The rate of emergence increased in such compacted soils after first irrigation. However, the rate of emergence could not increase in the plots with low compaction but having clods. The clods did not allow proper seed-soil contact.

(b) Secondly, the wheat being a shallow rooted plant can not obtain the proper moisture content in compacted soil.

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