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Compaction and Subsoiling Effects on Soil Properties, Plant Nutrient Concentration and Yield of Cotton (*Gossipium hirsutum* L.)

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Abstract: Three hardpan levels; chisel broken hardpan, natural hardpan and artificial hardpan by compacting soil with 10 tone-loaded trolley, were developed to evaluate their effect on soil properties, nutrient uptake and yield of cotton, along with three levels of NPK fertilizers (half recommended, recommended and double recommended dose). The results revealed that natural hardpan and artificial hardpan caused yield reduction by 10 and 15% during the year 2004 and 9 and 14% during 2005, respectively. The maximum cotton yield during 2004 was obtained with two fold of recommended dose of NPK fertilizers that was not significant over yield with recommended dose of fertilizers. While during 2005, maximum cotton yield was obtained with recommended dose of fertilizers. Nutrient use efficiency, in case of recommended dose of NPK fertilizers was increased by 12 and 90% in the year 2004 and 23 and 94% in the year 2005 over half dose of recommended fertilizers and two fold of recommended dose of fertilizers, respectively. During 2004, hardpan broken with chiseling with double recommended dose of fertilizers gave maximum yield (3.28 t ha^{-1}) which was non-significant with hardpan broken with chiseling with recommended dose of fertilizers and natural hardpan with recommended dose of fertilizers. During 2005, maximum yield of 2.9 t ha^{-1} was recorded with hardpan broken with chiseling with recommended dose of NPK fertilizers. The effect of hardpan and fertilizers was significant on plant leaf NPK concentration during both years except phosphorus concentration during 2005. Chisel broken hardpan with two fold of recommended fertilizers gave utmost plant leaf NPK concentration but it was non-significant with chisel broken hardpan with recommended dose of fertilizers.

Key words: Cotton · NPK Concentration · penetration resistance · subsoil compaction · yield

INTRODUCTION

Tillage refers to the different mechanical manipulations of the soil that are used to provide the necessary soil conditions favorable to the crop growth. A proper tillage can alleviate soil related constrains while improper tillage may lead to a range of degradative processes, e.g., deterioration in soil structure, accelerated erosion, depletion of soil organic matter and soil fertility and disruption in water cycles, organic carbon and plant nutrients [1]. Repeated use of tillage implements over the years created hardpan at about 15 cm depth. This hardpan influences bulk density, porosity and penetration resistance of soil which directly or indirectly affects the growth and yield of crops. Hardpan due to subsoil compaction of agricultural soils is a global concern due to adverse effects on crop yield and environment [2].

A number of studies have investigated the effects of root-restricting compacted soil layers on crop yield and the effects of subsoiling to shatter the compacted zones. Results are contradictory. The soils subsoiling resulted in an increase of cotton yields at two locations, did not affect yields at four locations and decreased yields at the remaining two locations [3]. The paraplowing effects soil physical properties for more than 2 yr but crop yield was not improved [4]. Fall chiseling with a paratill needed to be conducted annually to ensure minimizing the effects of soil compaction on crop growth [5]. In an experiment on barley (*Hardeum vulgare* L.), root length density in the upper 30 cm of soil and rooting depth decreased as the number of tractors passes increased from zero to six [6]. Bulk density and soil strength on traffic sides of a plant row can be much greater than those in the non-traffic side of the same row [7, 8]. Compaction can also result in low

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water use efficiency [9] and less use of fertilizers [10]. In developing countries, tillage operations by farmers are generally performed with bullock and tractor to depth of 10-15 cm. Repeated use of tractor-driven cultivators creates a hardpan at about 15 cm depth which hinders the movement of water and air and inhibits growth of plant roots [11, 12]. So an experiment was planned to quantify the effects of tillage-induced hardpan on soil properties and crop growth.

MATERIALS AND METHODS

A two year study (2004-2005) was planned on research farms of Soil Chemistry Section, Ayub Agricultural Research Institute (AARI), Faisalabad, Pakistan (31°26' North and 73°06' East'). The soil at the experimental site is fine-loamy, mixed, *hyperthermic Typic haplargids*, covering 21% of canal irrigated area of the Punjab, Pakistan [13].

The soil had a natural hardpan (Bulk Density = 1.65 g cm^{-3}) at 15 cm depth was considered as control. To compare the effects of this hardpan with a soil having no hardpan, the natural hardpan was broken by chiseling (Bulk Density =1.40 g cm^{-3}). An artificial hardpan of high bulk density (1.80 g cm^{-3}) was also created by removing the upper 15 cm soil and exposed soil surface was compacted with 10 tones load in a tractor driven trolley. The experiment was laid out in permanent plots following split plot design having three hardpan treatments in main plots with three replications and four fertilizer rates i.e. control (F0), half recommended doses (F1), recommended doses (F2) and two fold of recommended doses (F3) in the sub plots with three replications. Recommended fertilizer for cotton was 90-60-40 kg ha^{-1}, nitrogen (N), phosphorous (P) and potassium (K), respectively. Full dose of P, K and 1/2 N was applied at sowing time and remaining half N, 30 days after sowing. Area for main plot was 106m×105m and for sub plot was 26m×35m. Before sowing, seeds were acid delinted by Sulfuric acid @ 1L $10kg^{-1}$ of seed. Sowing was done on 25th May with drill and flat sowing was converted into furrows before 1st irrigation. Thinning was completed before 1st irrigation within 20-25 days of planting and plant to plant distant, 6-9 inches and row-to-row distance, 30 inches was maintained. 1st irrigation was given after 30-40 days of planting. Subsequent irrigations were given 15-21 days intervals.

Before sowing composite soil samples were collected from 0-15 and 15-30 cm depth, air-dried, grounded and passed through 2 mm sieve. Soil samples were analyzed for pH_s [14], electrical conductivity (EC_s) [15], organic matter [16], Olsen P [17], CH_3COONH_4 extractable K [18] and total N contents [19].

Table 1: Physical and chemical characteristics of soil

Characteristics	Units	Depths 0-15 cm	15-30 cm
Physical			
Sand	g Kg^{-1}	405	406
Clay	g Kg^{-1}	282	285
Silt	g Kg^{-1}	312	304
Textural class	-	Sandy clay loam	Sandy clay loam
Bulk density	g cm^{-3}	1.41	1.68
Penetration resistance	Mpa	0.72	1.25
Chemical			
EC_e	dSm^{-1}	0.82	0.72
pH_s	-	7.7	7.8
Organic matter	g Kg^{-1}	9.9	7.2
Kjeldhal-N	g Kg^{-1}	0.50	0.45
Olsen-P	mg Kg^{-1}	7.84	4.35
NH_4-OAc Ext. K	mg Kg^{-1}	176	128

Physical properties of soil like textural class, bulk density (BD) and penetration resistance (PR) were also determined at the start of the study and after the harvest of each crop to see the changes brought about by different treatments. Soil bulk density and soil penetration resistance was measured by using the core method and cone penetrometer (30° cone tip angle, 9.2×10^{-3} m diameter), respectively [20].

At maturity, plant leaf samples were collected randomly from whole plant, oven dried at 70°C for 48 hours, grounded and digested in acid mixture (HNO_3 and $HClO_4$) and NPK concentrations were determined [19,21].

Cotton yield (seed + lint) was recorded and nutrient use efficiency (NUE) was calculated as below.

$$NUE = \frac{\text{yield with fertilizer (kg)} - \text{yield with out fertilizer (kg)}}{\text{Fertilizer nutrients applied (kg)}}$$

All the data were analyzed statistically for the analysis of variance technique [22]. The comparisons among the treatment means were made by Duncan's multiple range test [23].

RESULTS

Soil analysis: The results regarding physical properties of soil (Table 2) revealed that hardpan significantly affected the bulk density and penetration resistance. In

Table 2: Effect of hardpan on physical properties of soil

	Bulk density (mg/m^3)				Penetration Resistance (Mpa)			
	2004		2005		2004		2005	
Treatments	*at sowing*	*at harvesting*	*at sowing*	*at harvesting*	*at sowing*	*at harvesting*	*at sowing*	*at harvesting*
HP0	1.42 c	1.61 b	1.63 b	1.66 b	0.67 c	0.73 b	0.75 c	0.78 b
HP1	1.65 b	1.63 b	1.64 b	1.65 b	1.11 b	1.09 a	1.06 b	1.09 a
HP2	1.84 a	1.79 a	1.78 a	1.76 a	1.28 a	1.25 a	1.26 a	1.19 a
LSD		0.0717				0.2028		

Means sharing same letter don't differ significantly (P=0.05)

HP0= Natural hardpan broken with chiseling, HP1= Natural hardpan, HP2 = Artificial hardpan

Table 3: Hardpan effects on Cotton yield

		Cotton yield (t ha^{-1}) (seed + lint)	
Tr. no.	Treatments	2004	2005
1	Natural hardpan broken by chiseling (HP0)	2.83 a	2.55 a
2	Natural hardpan (HP1)	2.56 b	2.33 b
3	Artificial hardpan (HP2)	2.40 c	2.21 c
LSD	0.09	0.07	

Table 4: Fertilizer effects on Cotton yield and nutrient use efficiency

		Cotton yield (t ha^{-1}) (seed + lint)		Nutrient use (kg Cotton yield efficiency /kg nutrient)	
Tr. no.	Treatments	2004	2005	2004	2005
1	Control (F0)	2.04 c	1.93 d	-	-
2	½ recommended dose of NPK (F1)	2.44 b	2.52 b	2.42	1.58
3	Recommended dose of NPK (F2)	2.93 a	2.64 a	2.70	1.94
4	2 × recommended dose of NPK (F3)	2.98 a	2.33 c	1.41	1.00
LSD	0.15	0.08			

Table 5: Hardpan and Fertilizer effect on yield of Cotton (t ha^{-1})

	2004				2005			
Treatments	F0	F1	F2	F3	F0	F1	F2	F3
HP0	2.22 f	2.62 de	3.21 a	3.28 a	2.00 f	2.67 b	2.90 a	2.53 cd
HP1	1.88 I	2.38 efg	3.04 ab	2.92 bc	1.98 f	2.45 d	2.61 bc	2.31 e
HP2	2.03 hi	2.31 fg	2.52 def	2.71 cd	1.80 g	2.53 cd	2.43 d	2.22 e
LSD	0.26				0.10			

Means sharing same letter don't differ significantly (P=0.05)

comparison with natural hardpan, breaking hardpan with chisel plough reduced the bulk density and penetration resistance by 11 and 42% while artificial hardpan increased these by 10 and 10.4%, respectively. During two years of study (2004-2005) bulk density and penetration resistance of same treatment remained the same.

Yield and nutrient use efficiency: The data (Table 3, 4 and 5) indicated that natural hardpan and artificial hardpan caused yield (seed + lint) reduction by 10 and 15% during the year 2004 and by 9 and 14% during 2005, respectively. All the fertilizer rates produced statistically higher yield than that of control treatment. The maximum cotton yield of 2.98 t ha^{-1} during 2004 was obtained with two fold of recommended dose of NPK fertilizers (F3) that was not significant over yield with recommended dose of fertilizers (F2). While during the year 2005, maximum cotton yield of 2.64 t ha^{-1} was obtained with

Table 6: Effect of hardpan on nutrient concentration in Cotton leaf

Treatments		2004				2005			
		F0	F1	F2	F3	F0	F1	F2	F3
N g/kg	HP0	40.2 ef	43.7 ab	43.3 b	44.0 ab	40.5 e	45.6 bc	46.2 ab	46.8 a
	HP1	40.1 ef	41.9 cd	43.9 ab	44.4 a	41.0 e	45.0 c	45.1 c	45.8 abc
	HP2	39.6 f	40.3 ef	41.0 de	42.1 c	38.7 f	43.9 d	44.9 c	45.4 bc
LSD	0.10					0.098			
Pg/kg	HP0	4.1 cde	4.9 ab	5.1 a	4.9 ab	3.9	4.1	4.5	4.6
	HP1	4.0 de	4.8 abc	4.9 ab	4.6 abc	3.8	3.9	4.2	4.5
	HP2	3.8 e	4.5 bcd	4.7 bcd	4.8 abc	4.0	3.9	4.1	4.3
LSD	0.07					NS			
K g/kg	HP0	30.2 e	30.4 de	31.0 cd	33.1 a	24.7 ab	28.5 ab	29.6 a	29.9 a
	HP1	28.9 f	30.1 e	30.2 e	32.5 a	24.9 ab	29.6 a	27.6 ab	28.4 ab
	HP2	26.5 g	31.8 b	31.5 bc	31.6 bc	23.4 b	25.2 ab	26.1 ab	26.4 ab
LSD	0.07					0.06			

Means sharing same letter don't differ significantly (P=0.05)

recommended dose of fertilizers (F3). Nutrient use efficiency (NUE), at the recommended dose of NPK fertilizers (F2) was increased by 12 and 90% in the year 2004 and 23 and 94% in the year 2005 over half dose of recommended fertilizers (F1) and two fold of recommended dose of fertilizers (F3), respectively. After control treatment, minimum cotton yield (2.44 t ha^{-1}) during 2004 was recorded with half recommended dose of NPK fertilizers (F1) and during the year 2005, minimum cotton yield (2.33 t ha^{-1}) was recorded with two fold of recommended dose NPK fertilizers (F3). Minimum nutrient use efficiency of 1.41 kg cotton yield per kg nutrient during 2004 and 1 kg cotton yield per kg nutrient during 2005 was obtained with two fold of recommended dose of NPK fertilizers. Hardpan and fertilizer interaction was found significant in both years. During the year 2004, hardpan broken with chiseling with double recommended dose of fertilizers (F3) gave maximum yield (3.28 t ha^{-1}) which was non-significant with chisel broken hardpan with recommended dose of fertilizers and natural hardpan with recommended dose of fertilizers. During 2005, maximum yield of 2.9 t $ha^{-1}$was recorded with chisel broken hardpan with recommended dose of NPK fertilizers. The lowest yield of 1.9 t ha^{-1} during 2004 and 1.8 t ha^{-1} during 2005 was produced under natural and artificial hardpan where no fertilizer was applied, respectively.

Chemical composition of cotton leaf: Results presented in Table 6 regarding NPK concentration in cotton leaf at flowering stage revealed that during the year 2004, maximum nitrogen concentration (4.4%) was recorded from natural hardpan where double recommended dose of fertilizer was applied which was non-significant with natural hardpan where recommended dose of fertilizers was applied and with hardpan broken by chiseling where two fold of recommended and half of recommended dose of fertilizer was used, respectively. Maximum phosphorus concentration (0.51%) was recorded from hardpan broken by chiseling with recommended dose of fertilizer while it was non-significant with all other treatments except treatments where no fertilizer was used. Hardpan broken by chiseling with two fold of recommended fertilizer gave utmost potassium concentration (3.25%) that was non-significant with natural hardpan where two fold of recommended dose of fertilizer was applied. During the year 2005, maximum nitrogen concentration (4.68%) was obtained from hardpan broken by chiseling with two fold of recommended dose of fertilizer which was non-significant with hardpan broken by chiseling where recommended dose of fertilizer was practiced and natural hardpan where two fold of recommended dose of fertilizer was used. There was non-significant effect of hardpan and fertilizer levels on phosphorous concentration in cotton leaf during 2005. Maximum potassium concentration was obtained from hardpan broken by chiseling where two fold of recommended dose of fertilizer was used but it was non-significant with all treatments except, artificial hardpan where no fertilizer was practiced.

DISCUSSION

Conventional cotton production practices in developing countries involve several shallow tillage operations that lead to hardpan formation in subsoil region. Site used for this experiment also has hardpan at 15 cm depth. We created an artificial hardpan and broke natural hardpan by chiseling to compare its effect on cotton.

Data in Tables 3, 4 and 5 indicated that natural hardpan and artificial hardpan caused the yield reduction by 10 and 15% during the year 2004 and 9 and 14% during 2005, respectively and higher rates of fertilizer were not able to overcome hardpan constrains. This decrease in crop yield due to subsoil compaction may be partially a result of low nutrient and water uptake and availability under compacted soil conditions [9]. Physical conditions detrimental to root proliferation in subsoil are frequently related to hardpans that develop below plough layer and higher levels of fertilizers cannot overcome hardpan constrains [24, 25]. This hardpan has high bulk density, high penetration resistance, reduced soil aeration, few macropores for roots to grow through and mechanical impedance great enough to markedly reduce root growth rates [11, 12]. Our results are also supported by previous studies [26, 27].

Data regarding the effect of hardpan and fertilizers on NPK concentration in cotton leaf (Table 6) indicated that double recommended dose of fertilizer increased uptake but it was nonsignificant with recommended dose of fertilizer while half dose of fertilizers decreased cotton leaf NPK contents. Similar results are reported by some scientists [9, 28]. Reduction in soil water availability due to decrease water infiltration, less volume of soil explored by the roots and anatomical and morphological changes in the root system and a small portion of macro pores in compacted soil may account for lower NPK concentration in plant leaf. Several studies have documented increased rates of denitrification or N_2O production in compacted soils but other losses may also occur through increased surface runoff in compacted soils due to lower water infiltration [29, 30]. According to literature, deep tillage (subsoiling) of certain clayey soils in the fall when the soil profile is dry significantly increases yields and net returns from this production system [31]. For optimum yields, many soils require deep tillage as a method of alleviating soil compaction after every three years. However, this tillage event can be costly. An experiment can be conducted to determine if mapping the layer of soil compaction and then delivering tillage to the exact depth of soil compaction may reduce tillage power requirements while maintaining cotton yields. Average cotton yields over this three-year period showed that site-specific tillage produced yields equivalent to those produced by the uniform deep tillage treatment while requiring 27% less tillage power [32]. Continued development of technology and equipment necessary for site-specific tillage could contribute to a more energy efficient food production system.

CONCLUSIONS

Subsoil compaction, whether natural or induced by vehicle traffic, reduces crop yield and quality because of several factors. The severity of subsoil compaction artificially created in this experiment may not occur in traditional small-scale farming practices, the potential of severe subsoil compaction in alluvial soils exists with progressive increase in mechanization of farm operations in Punjab and elsewhere in world. Therefore, appropriate measures such as periodic chiselling; controlled traffic, conservation and site specific tillage and incorporation of crops with deep tap root systemic rotation cycle are necessary to minimize the risks of subsoil compaction.

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