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SUBSOIL COMPACTION EFFECTS ON SOIL PROPERTIES, NUTRIENT UPTAKE AND YIELD OF MAIZE FODDER (*Zea mays* L.)

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Abstract

Field experiments were conducted during the years 2003-2004 at Soil Chemistry Section, Ayub Agricultural Research Institute, Faisalabad, to evaluate the effect of hardpan and NPK fertilizers on soil properties, nutrient uptake and yield of maize fodder. Three hardpan levels, natural hardpan broken by chiseling (HP_0); natural hardpan (HP_1) and artificial hardpan (HP_2) by compacting soil with 10 ton-loaded trolley, were developed with three levels of NPK fertilizers (half recommended; recommended and double recommended dose). The results revealed that hardpan significantly reduced the nutrients uptake and yield of maize fodder in both the years. Chisel broken hardpan (HP_0) increased the yield of maize fodder 10 and 11% over natural hardpan (HP_1) and 14 and 20% over artificial hardpan (HP_2) during the years 2003 and 2004, respectively. Application of highest fertilizer nutrients dose significantly increased the fresh fodder yield of maize crop in both years. Lowest fodder yield was 35.6 and 29.7 ton^{-1} while highest yield was 40.9 and 35.6 ton^{-1}, obtained during 2003 and 2004, respectively. Maximum nutrient use efficiency (NUE) was obtained from the field where recommended dose of NPK fertilizer (90-60-40 kg ha^{-1}) was added, that was 77 and 65 kg maize fodder/kg nutrient in the years 2003 and 2004, respectively. The effect of hardpan and fertilizers on nitrogen, phosphorous and potassium concentration was significant during the year 2003 while during the year 2004 this effect on nitrogen concentration in maize plants was non-significant while on phosphorus and potassium concentration was significant. Chisel broken hardpan (HP_0) increased nitrogen uptake 1.2 and 6% over natural hardpan (HP_1) and 22 and 24% over artificial hardpan (HP_2) during the years 2003 and 2004, respectively.

Introduction

Pakistan is an agricultural country producing a variety of crops but their average yield is very low at farmer's level in comparison with research farms and other competing countries. Although improved crop genotypes and fertilizer use have increased the crop yield but the full potential of crop production has not been achieved. Different factors are responsible for low yield when hardpan below the surface soil is one of those factors. Traffic on agricultural land, inappropriate conventional tillage and poor timing of field operations decreases aggregate stability (Hakansson & Reeder, 1994) and creates sub-soil hardpan (Oussible *et al*., 1992).

This hardpan influences bulk density, porosity and penetration resistance of soil which directly or indirectly effects the growth and yield of crops by decreasing root penetration, aeration, water and nutrient movement (Alakukku & Elonen, 1994; Ishaq *et al*., 2003; Maurya, 1988; Gill & Aulakh, 1990). Use of chisel plow once in three years is recommended for normal cultivated soils in Pakistan but ignorance in this respect produces hardpan. In large-scale irrigation projects, especially in the subtropical regions, intensive mechanized cultivation of soil for wheat production leads to the development of a dense tillage hard pan at about 15 - 20 cm depth. Loosening of these compacted pans by deep tillage may result in 3-8 folds increase in infiltration rate, reduced bulk density and improved grain yield (Bennie & Botha, 1986; Maurya, 1988). Limited water and nutrient availability due to hardpan are major constrains to plant growth and yield in many soils. Lowery & Schuler (1991) studied the effects of subsoil compaction on nutrient uptake by maize (*Zee mays* L.) and reported that uptake of N and K were decreased, while of Fe and Mn increased with increasing compaction.

Sustainable agriculture in Pakistan implies not only the management and conservation of natural resources base (water, soil) but also a steady and substantial increase in crop yield (Ahmed *et al*., 1996). In Pakistan, the tillage operations by farmers are generally performed with bullock and tractor to the 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 specially in cotton and maize (Rafiq, 1990; Hussan & Gregory, 1999). Little information is available about the soil and crop response to subsoil compaction under local conditions. Thus, it is imperative to quantify the effects of tillage-induced hardpan on soil properties in relation to crop growth. A field experiment was therefore conducted to evaluate and quantify the effect of hardpan on soil properties, nutrient uptake and yield of maize fodder.

Materials and Methods

Site: A two year study (2003-2004) was conducted on research farms of Soil Chemistry Section, Ayub Agricultural Research Institute (AARI), Faisalabad ($31^o26'$ North and $73^o06'$ East). The soil at the experimental site is fine-loamy, mixed, *hyperthermic Typic haplargids*, covering 21% of canal irrigated area of the Punjab, Pakistan.

The soil had a natural hardpan (Bulk Density = 1.65 Mg m^{-3}) at 15 cm depth. To compare the effects of this hardpan with a soil having no hardpan, the natural hardpan was broken by chiseling (Bulk Density =1.40 Mg m^{-3}). An artificial hardpan of high bulk density (1.80 Mg m^{-3}) was also created by removing the upper 15 cm soil and exposed soil surface was compacted with 10 ton load in a tractor driven trolley. The experiment was laid out in permanent plots following split plot design with three hardpan treatments in main plots and four fertilizer (NPK) rates i.e., control (F0), half recommended dose (F1) (45-30-20), recommended dose (F2) (90-60-40) and 2 × recommended dose (F3) (180-120-80) in the sub plot with three replications. Full dose of PK and half N was applied at sowing and remaining half N 30 days after sowing.

Soil and plant analysis: Before sowing the crop, composite soil samples were collected from 0-15 and 15-30 cm depths, air-dried, ground and passed through a 2 mm sieve. Soil samples were analyzed for pH_s (McLean, 1982b), electrical conductivity (EC_e) (Rhoades, 1982a), organic matter (Nelson & Sommers, 1982), Olsen P (Olsen & Sommers, 1982), NH_4oAc extractable K (Knudsen *et al*., 1982) and total N contents (Rhoades, 1982b).

Physical properties of soil like 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 (Blake & Harthe, 1986) and cone penetrometer (30^o cone tip angle, 9.2×10^{-3} m diameter), respectively.

Table1. Physical and chemical characteristics of 20 cm layer of the experimental site at AARI, Faisalabad, Pakistan.

Characteristic	Unit	Means	
		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	Mg m^{-3}	1.35	1.65
Penetration resistance	MPa	0.70	1.20
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 K^{-1}	166	118

Plant samples were collected at maturity and oven dried at 70^{o}C for 48 hrs, ground and digested in acid mixture (HNO_3 and $HClO_4$) prior to chemical analysis. Total P was determined using vanadomolybdophosphoric acid yellow color method; K flame photo metrically (Yoshida *et al*., 1976) and N concentration by the method described by Tector (1991).

Yield data were recorded and nutrient use efficiency (NUE) was calculated as below:

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

Crop yield and nutrient uptake: Fodder yield and nutrient uptake by maize fodder were measured. All the data were analyzed statistically by variance analysis technique (Gomez & Gomez, 1984). The comparison among the treatments means were made by Duncan's multiple range test (Duncan, 1955).

Results and Discussion

Soil characteristics: The results regarding the physical properties of soil revealed that hardpan significantly increased the bulk density and penetration resistance (Table 2). In comparison with natural hardpan, breaking hardpan with chisel plough reduced the bulk density and penetration resistance by 11 and 42% while artificial hardpan increased by 10 and 10.4%, respectively. During two years of study (2003-2004) bulk density and penetration resistance of each treatment remained the same.

Table2. Effect of hardpan on physical properties of soil before and after harvest.

Treatments	Bulk density (Mg/m^3)				Penetration Resistance (Mpa)			
	2003		2004		2003		2004	
	At sowing	At harvesting	At sowing	At harvesting	At sowing	At harvesting	At sowing	At harvesting
HP0	1.40 c	1.60 b	1.61 b	1.63 b	0.66 c	0.73 b	0.74 c	0.76 b
HP1	1.65 b	1.63 b	1.64 b	1.65 b	1.08 b	1.04 a	1.06 b	1.06 a
HP2	1.80 a	1.74 a	1.75 a	1.77 a	1.23 a	1.15 a	1.16 a	1.17 a
LSD		0.0717				0.2028		

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

Table 3. Hardpan and fertilizer effects on maize fodder yield and nutrient use efficiency.

a. Hardpan effects

Tr. no.	Treatments	Maize fodder yield ($t\ ha^{-1}$)	
		2003	2004
1.	Natural hardpan broken by chiseling	40.9 a	35.6 a
2.	Natural hardpan	37.1 b	32.2 b
3.	Artificial hardpan	35.6 b	29.7 c
	LSD	1.40	4.86

b. Fertilizer effects

Tr. no.	Treatments	Maize fodder yield ($t\ ha^{-1}$)		Nutrient use efficiency (Kg maize fodder /Kg nutrient)	
		2003	2004	2003	2004
1.	Control (F0)	30.9 d	25.2 c	-	
2.	½ recommended dose of NPK (F1)	34.5 c	28.4 bc	47	42
3.	Recommended dose of NPK (F2)	42.4 b	35.0 ab	77	65
4.	2 × recommended dose of NPK (F3)	49.1 a	38.6 a	60	45
	LSD	1.62	6.19	-	-

Yield and nutrient use efficiency: The data regarding yield of maize fodder and nutrient use efficiency (Table 3a,b and Table 4) indicated that natural hardpan and artificial hardpan caused the yield reduction by 11 and 15% during the year 2003 and 11 and 20% during 2004, respectively. All the fertilizer rates produced statistically higher yield than that of control treatment. The maximum fresh fodder yield of 49.1 t ha^{-1} during 2003 and 38.6 t ha^{-1} during 2004 were obtained with two fold of recommended dose of NPK fertilizers. However, at this rate nutrient use efficiency was reduced by 22% in 2003 and 30% in 2004 which was maximum (77 kg fodder kg^{-1} nutrient during 2003 and 65 kg fodder kg^{-1} nutrient during 2004) at the recommended dose of NPK fertilizers. After control treatment minimum fresh maize fodder yield of 34.5 t ha^{-1} during 2003 and 28.4 t ha^{-1} during 2004 while nutrient use efficiency of 47 kg fodder kg^{-1} nutrient during 2003 and 42 kg fodder kg^{-1} nutrient during 2004 were obtained with the half recommended dose of fertilizers. Hardpan and fertilizer interaction in both years was found significant. Hardpan broken with chiseling and double recommended dose of fertilizers gave maximum fresh fodder yield of 51.1 and 41.9 t ha^{-1} in 2003 and 2004, respectively. The lowest yield of 29.3 t ha^{-1} during the year 2003 and 24.4 t ha^{-1} during 2004 were produced under artificial hardpan where no fertilizer was applied.

Chemical composition of maize plant: The results regarding NPK concentration in maize plants at tesselling stage revealed that during the year 2003 maximum nitrogen and phosphorous concentration of 1.8 & 0.24% were recorded respectively, from zero hardpan (HP0) where double recommended dose of fertilizers was applied (Table 5), while recommended and double recommended dose of fertilizers at all hardpan levels showed statistically similar potassium concentration. During the year 2004, the maximum phosphorous concentration was obtained from zero hardpan (HP0) where double recommended doze of fertilizer was used (0.21%) and potassium from zero hardpan where recommended doze of fertilizer was applied (2.81%), while nitrogen concentration was not affected by hardpan and fertilizers levels.

Nutrient uptake by maize plant: The data regarding uptake of nitrogen, phosphorous and potassium revealed that during the year 2003, maximum nitrogen (166.5 kg ha^{-1}), phosphorous (21.8 kg ha^{-1}) and potassium (268.3 kg ha^{-1}) uptake were obtained from zero hardpan (HP0) with double recommended dose of fertilizers (Table 6). While during the year 2004 maximum nitrogen uptake (82.9 kg ha^{-1}) was recorded from natural hardpan (HP1) where double recommended dose of fertilizers was applied. Maximum phosphorous uptake (15.9 kg ha^{-1}) was obtained from zero hardpan (HP0) with double recommended dose of fertilizers and potassium uptake (205.9 kg ha^{-1}) from zero hardpan (HP0) where recommended dose of fertilizers was applied. This study clearly indicated that nutrients uptake especially N, P and K by maize (*Zea mays L.*) crop were decreased with increasing compaction (Lowery & Schuler, 1991). The results obtained from the present study were also supported by the findings of Bennie & Botha (1986). Many researchers recommended the chisel plow once in three years for normal cultivated soils in Pakistan (Ishaq *et al*., 2003; Hassan & Gregory, 1999; Ahmed *et al*., 1996).

Table 4. Hardpan and fertilizer effect on yield of maize fodder (t ha^{-1}).

Treatments	2003				2004			
	F0	F1	F2	F3	F0	F1	F2	F3
HP0	32.5 g	35.4 f	44.9 cd	51.1 a	26.9 def	31.9 cde	39.6 abc	41.9 a
HP1	29.3 h	32.3 g	39.1 e	47.4 bc	24.6 f	28.8 ef	34.1 bcde	38.8 ab
HP2	31.0 gh	35.7 f	43.2 d	48.7 ab	24.4 f	28.1 ef	31.3 de	35 bcd
LSD	2.81				4.86			

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

Table 5. Effect of hardpan on nutrient concentration in maize fodder.

	Treatments	2003				2004			
		F0	F1	F2	F3	F0	F1	F2	F3
N %	HP0	1.2 ab	1.4 ab	1.6 ab	1.8 a	0.9	1.2	1.2	1.1
	HP1	1.2 ab	1.5 ab	1.5 ab	1.7 ab	1.0	1.0	1.3	1.3
	HP2	1.1 b	1.1 b	1.3 ab	1.6 ab	1.1	1.1	0.9	1.2
	LSD	0.5899				NS			
P %	HP0	0.14 bc	0.19 ab	0.19 ab	0.24 a	0.13 e	0.17 b	0.17 b	0.21 a
	HP1	0.13 c	0.18 ab	0.19 ab	0.21 ab	0.12 e	0.17 b	0.18 b	0.19 a
	HP2	0.12 c	0.15 bc	0.17 ab	0.17 ab	0.11 e	0.13 d	0.16 c	0.15 c
	LSD	0.0715				0.0023			
K %	HP0	1.9 b	2.5 a	2.8 a	2.9 a	1.80 ab	2.20 ab	2.81 a	2.05 ab
	HP1	1.7 b	1.8 b	2.6 a	2.8 a	1.75 b	2.35 ab	2.20 ab	2.05 ab
	HP2	1.6 b	1.7 b	2.5 a	2.7 a	1.60 b	1.75 b	2.51 ab	2.51 ab
	LSD	0.4321				0.9161			

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

Table 6. Effect of hardpan on nutrient uptake of maize plant.

Treatments		2003				2004			
		F1	F2	F3	F4	F1	F2	F3	F4
N uptake (kg/ha)	HP0	70.2 h	89.2 g	102.3 e	166.5 a	48.0 f	68.9 d	85.5 ab	82.9 b
	HP1	66.9 h	96.4 ef	106.7 d	147.2 b	45.7 f	54.9 e	81.0 bc	89.4 a
	HP2	58 I	63.9 hi	91.5 fg	135.7 c	46.1 f	55.6 e	53.5 e	75.6 c
LSD		6.499				5.421			
P uptake (kg/ha)	HP0	8.19 fg	12.1 de	15.8 bc	21.8 a	6.4 ef	10.0 d	12.2 c	15.9 a
	HP1	6.9 g	10.5 ef	13.4 cd	17.5 b	5.6 fg	9.4 d	11.5 c	13.8 b
	HP2	6.8 g	9.5 f	13.2 d	14.7 cd	5.1 g	7.1 e	9.4 d	9.9 d
LSD		2.479				1.149			
K uptake (kg/ha)	HP0	11.2 gh	159.3 f	226.3 c	268.3 a	89.6 i	129.8 g	205.9 a	193.8 b
	HP1	94.9 I	116.7 g	198.3 d	232.3 bc	78.9 j	125.2 h	170.5 c	147.1 e
	HP2	89.6 i	104.7 h	182.9 e	238.9 b	72.2 k	91.9 i	143.4 f	162.5 d
LSD		7.847				2.587			

Means sharing same letter don't differ significantly ($P \leq 0.05$)

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