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Effect of soil compaction and fertilizer placement depth on growth, yield, nutrient uptake of maize (*Zea mays* L.) and soil properties in *tarai* soils of Uttarakhand

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Abstract

Soil compaction and placing of fertilizer in undesirable depth in soil are the most serious threat under intensive cultivation system in poorly drained heavy textured soil. In view of this, a field experiment was conducted during *kharif* season of 2014-15 to understand the effect of soil compaction and fertilizer placement depth on performance of maize crop, nutrient uptake and soil properties. The soil was heavy textured i.e. silty clay loam with poor drainage and receiving about >1400 mm rainfall annually. Root length and root length density of plants in compacted plots (1.54 and 1.63 Mg/m^3) decreased remarkably from 1.50-4.60 cm and 0.06-0.11 cm/cm^3, respectively, compared with non-compacted soil (1.34 Mg/m^3) however root dry weight did not exhibit response against soil compaction. Maximum grain yield of 5613.4 and 5593.0 kg/ha was recorded with non-compacted soil (1.34 Mg/m^3) and 0-10 cm fertilizer placement depth, respectively, however at par yields were obtained between 1.54 and 1.63 Mg/m^3 compaction levels. Compaction and fertilizer placement depth showed highest adverse effect on Zn uptake (14.70-20.42%) whereas least on P uptake (6.23-11.0%). Non compacted soil (1.34 Mg/m^3) and placing fertilizer at 0-10 cm depth maintained favourable oxidizable organic carbon and hydraulic conductivity but reduced with increase in compaction and placement depth. In general, strong negative and non-significant relationships of the compaction and fertilizer placement depth with growth and yield parameters, yields, nutrient uptake and soil properties were estimated.

Highlights

- Soil compaction at 1.54 Mg/m^3 and fertilizer placement at 0-20cm depth reduced the maize grain yields by 10.6 and 8.8% over 1.34 Mg/m^3 and 0-10 cm depth respectively, and further increase in compaction and depth had less effect.
- Uptake of nutrients was affected more between compaction levels of 1.34 and 1.54 Mg/m^3 but for fertilizer placement depths between 0-20 and 0-30 cm.
- Organic carbon reduced significantly by 9.8% at 1.54 Mg/m^3 over non-compacted soil but was at par with 1.63 Mg/m^3 however hydraulic conductivity reduced significantly at all compaction levels. Fertilizer placement depth had significant effect on organic carbon, pH and electrical conductivity.

Keywords: Maize, soil compaction, fertilizer placement depth, growth and yield, nutrient uptake, soil properties

Maize (*Zea mays* L.) is the third most important staple food crop in the world after wheat and rice but in term of productivity, it ranks first followed by rice and wheat. This is not only an important food and fodder crop for human being and animals but also is being used for manufacturing of many industrial products. Therefore, owing to its various uses, maize is known as 'Queen of cereals'. Therefore, the need for increasing its production has become a global priority in context of its multidimensional uses. This crop has tremendous genetic variability, which enables it to thrive in all kinds of climates but thrives best in a warm climate (rainy season) therefore, grown throughout the year in India. Maize can be grown in all types of soils ranging from sandy to heavy clay, however, is best adopted to well drained sandy loam and silty loam soils. The climate of *tarai* region of Uttarakhand is humid sub tropical with annual rainfall of more than 1400 mm and about 85% rain received during rainy season therefore, soil remains above the field capacity most of the time of the crop season. Rice-wheat crop rotation is dominant for the past more than three decades but maize is also grown in many part of the *tarai* region particularly in *kharif* season. For the preparation of seed bed, broadcasting of fertilizers over the soil surface in blanket manner and moreover use of repeated heavy machinery at the same depth over the years are the common practice adopted by the farmers of this region under intensive cropping system hence the soil of this region facing many physical disturbances to obtain optimum output. The problem of soil compaction is one of the major agricultural and environmental concerns in modern day intensive agriculture and land use in general and has been recognized as a major physical threat to soil fertility throughout the world (Soane and Van, 1994).

The over use of machinery especially passing of heavy tractors has been recognized as the major anthropogenic cause of soil compaction (Saffih-Hdadi *et al.,* 2009) especially in poorly drained soil hence soil compaction is one of the major abiotic problems in heavy texture soil for maize crop during *kharif* season in this region. Many studies have shown that plant growth and productivity decrease with soil compaction by reducing the root enlargement, restricting oxygen, water and nutrient supply. Low hydraulic conductivity caused by compaction may induce water shortage to plant growth especially for high transpiring plants. The restrictions to plant growth in compacted soil are also caused by oxygen deficit. Most of the farmers are aware of compaction problems, but the significance is often underestimated. Furthermore, recovery and amelioration of compacted soil could be slow, if it occurs. The depth of fertilizer placement is an integral part of effective nutrient management (Xuejun *et al.,* 2006) and crop growth because placement depth strongly influences the subsequent mobility and availability of nutrients hence reduces yield remarkably. Moreover degree of compaction also strongly influences the mobility and availability of nutrients. Most research over the year have placed emphasis on just distance of the band to the neglect of depth of placement and therefore, varying the depth of fertilizer placement together with distance of placement from the plant will provide an in depth knowledge with regard to the appropriate depth of fertilizer placement for optimum plant usage. Correct fertilizer placement ensures minimal losses due to leaching, vaporization and complex formation which may render the nutrient unavailable to the intended crop (Tisdale *et al*., 2003) and consequently improves the nutrient use efficiency and encourages higher yield.

The aim of present study was to understand the growth, yield and nutrient uptake behaviour of maize as well as soil properties as influenced by different degree of soil compaction and fertilizer placement depth in heavy textured soil of *tarai* region.

Materials and Methods

The field experiment was conducted during *kharif* season of 2014-15 with maize variety 'Suwarna' at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand situated at 29^o N latitude, 79.3^o E longitude and at an altitude of 243.2 m at foothills of *Shivalik* range of Himalaya. The soil of Pantnagar is classified as silty clay loam hyperthermic *Aquic Hapludoll* developed on calcareous alluvial sediments, medium textured with a high micaceous component, poor in drainage, firm silty clay loam up to 0.76 m depth with mollic epipedon followed by silt loam up to 1.50 m depth and relatively high in fertility. The experimental soil was neutral in reaction (pH 6.9), low in salt content 0.25 dS/m and available N 138.0 kg/ha, medium in organic carbon 0.70%, available P 34.5 kg/ha and available K 162.6 kg/ha. The plot size was 10m × 20m. The treatments were arranged factorially in a randomized block design with three replications.

Prior to establishment of compaction recommended one third dose of N and full dose of P and K was broadcasted over the field uniformly in each plot followed by two cross passing of cultivator adjusted to depths of 10, 20 and 30 cm for proper placement/ mixing of fertilizers. The crop was fertilized with recommended dose of fertilizer (RDF) @ N–120, P_2O_5

– 60, K_2O – 40 kg ha^{-1} supplied through urea, NPK and muriate of potash. Compaction was performed just before the sowing of seed. Compaction was created by compacting plots using 25 kg wooden block falling from a height of 50 cm. The two levels of compaction were obtained in such a way that treated plots were completely covered by compacting one time and two times for achieving two levels of compaction. However, conventional tillage (normal) treatment received no compaction. Therefore, the experiment consisted the three levels of compaction viz., normal (1.34 Mg/m^3), soil compacted one time (1.54 Mg/m^3) and soil compacted two times (1.63 Mg/m^3) and three levels of fertilizer placement depth viz., 0-10 cm, 0-20 cm and 0-30 cm.

Immediately after compaction, undisturbed soil samples at 15 cm depth were collected from three randomly selected points in each plot in the cores of known volume and bulk densities were determined (Blake and Hartge, 1986) and mean values were taken for treatments comparison. For the determination of saturated hydraulic conductivity additional three random soil samples from each plot were collected in cores and hydraulic conductivity were measured with a permeameter under stationary condition and mean was calculated. After the crop harvest, soil samples collected from three different locations at 15 cm depth in each plot, soil pH, electrical conductivity (EC) and organic carbon were estimated following standard methodology. Growth and yield attributes were measured with using five randomly selected plants at harvest time. The method as described by Tannant (1975) was used to record root length from which root length density was subsequently calculated. Grain yield of each plot was recorded at 15 per cent moisture content on a dry weight basis and then yield on hectare basis was calculated. After the crop harvest, N, P, K and Zn uptake was analyzed with plant and grain samples and final uptake was calculated and converted on hectare basis.

Results and Discussion

Effect on growth and yield parameters

Growth and yield parameters were in general decreased with increase in soil compaction and fertilizer placement depth (Table 1). Emergence of seeds was found to be non- significantly affected by compaction and fertilizer placement depth. Germinated seeds emerged with slow rate with increase in soil compaction and fertilizer placement depth. Germination of seeds per day was found to be decreased by 10.4 per cent when density increased from 1.34 to 1.63 Mg/m^3. The reason for slow rate of emergence in compacted soil could be low oxygen diffusion rate (Latif *et al*, 2008). The maximum growth attributes were recorded with non-compacted soil (1.34 Mg/m^3) however brace roots on nodes per plant were higher with medium level of compaction. At harvest, root length and root length density of plants grown on compacted plots (1.54 and 1.63 Mg/m^3) decreased remarkably from 1.50-4.60 cm and 0.06-0.11 cm/cm^3, respectively, compared with non-compacted soil (1.34 Mg/m^3) however root dry weight did not exhibit response against soil compaction.

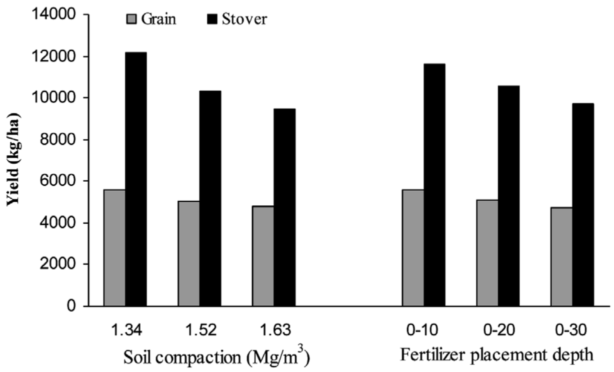

Fig. 1: Effect of compaction and fertilizer placement depth on grain and stover yields

The two compacted soils reduced the growth parameters from 0.4-22.7% over non-compacted soil where the magnitude of reduction was noticed higher with 1.63 Mg/m^3 compaction level than the 1.52 Mg/cm^3 over non-compacted soil. Fertilizer placement depth showed significant effect on plant height, brace roots on nodes per plant and root length density however placement of fertilizer at 0-10 cm depth resulted higher growth parameters compared with other placement depths. Significant differences in plant height and root length density were recorded between placement depths however number of brace nodes was at par between 0-10 and 0-20 cm depth. Among the yield attributes, grain and stover yields and anthesis silking

Table 1: Effect of soil compaction and fertilizer mixing depth on growth and yield attributes of maize

Treatment	Speed of emergence (seeds/day)	Plant height (cm)	No. of brace roots on nodes/ plant	Root dry weight (g/plant)	Root length (cm)	Root length density (cm/cm^3)	ASI (days)	Cob length (cm)	100 grain weight (g)
				Compaction					
1.34 Mg/m^3	24.0	138.0	10.0	2.46	20.3	0.53	3.00	14.6	31.00
1.52 Mg/m^3	23.9	136.7	13.0	2.21	18.8	0.47	4.56	14.2	30.18
1.63 Mg/m^3	21.5	127.2	12.8	2.10	15.7	0.42	4.11	14.1	29.40
CD (p=0.05)	NS	1.7	1.3	NS	1.3	0.04	1.22	NS	1.18
				Fertilizer placement depth					
0-10 cm	23.0	140.6	12.9	2.28	18.9	0.51	4.33	14.8	29.47
0-20 cm	23.7	133.0	12.2	2.26	18.3	0.47	3.33	14.2	31.30
0-30 cm	22.8	128.3	10.7	2.23	17.7	0.43	4.00	13.9	29.83
CD (p=0.05)	NS	4.0	1.1	NS	NS	0.03	0.66	NS	NS
Interaction	NS	NS	S	S	S	NS	NS	NS	NS

interval were found significantly affected with soil compaction and fertilizer placement depth however non significant effect was obtained for cob length and 100 grain weight owing to fertilizer placement depth. Least anthesis silking interval which is considered favourable for more grain formation in cob was found under non-compacted soil (1.34 Mg/m^3) and placing of fertilizer up to 20 cm depth. Non-compacted soil (1.34 Mg/m^3) and fertilizer placement at 0-10 cm depth produced highest grain and stover yield but decreased with increase in level of these factors (Fig.1).

The percentage decrease in grain yield was 10.6 and 8.8 when compaction was increased from 1.34 to 1.52 Mg/m^3 and fertilizer placement depth increased from 0-10 to 0-20 cm, respectively, but the decrease in yield was more with further increase in compaction to 1.63 (14.4%) and fertilizer placement depth to 0-30 cm (15.2%). However, compaction had more adverse effect on yield than fertilizer placement depth. Gysi *et al*. (2000) also reported decrease in yield with increase in soil compaction while Larson *et al. (*1960) found significant reduction in maize and oat yields with placing the fertilizer at 16 inches deep as compared to placing at surface. Results also indicated that either increasing compaction to 1.52 Mg/m^3 over normal ploughed condition or shifting of fertilizer placement from 0-10 to 0-20 cm leads more reduction in grain and stover yields than subsequent increased in levels of these factors which suggested that increase in compaction or fertilizer placement depth beyond the established level has less effect on yields. Interaction effect of compaction and fertilizer placement depth was observed only for root parameters.

Effect on nutrient uptake

Both compaction and fertilizer placement depth significantly influenced the nutrient uptake and increasing levels of these decreased the nutrient uptake (Table 2). The negative relationship between soil compaction and fertilizer placement depth has been reported by many workers (Sur *et al.*, 1980; Punyawardena and Yapa, 1990, and Singh *et al.*, 2015).

Table 2: Effect of soil compaction and fertilizer placement depth on nutrients uptake by maize

Treatment	N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)	Zn uptake (g/ha)
		Compaction level		
1.34 Mg/m^3	189.25	61.18	62.80	551.44
1.52 Mg/m^3	160.91	54.75	52.39	455.08
1.63 Mg/m^3	145.22	48.73	47.49	388.19
CD (p=0.05)	19.71	6.58	7.57	99.97
		Fertilizer placement depth		
0-10 cm	180.33	58.93	61.70	573.66
0-20 cm	170.34	54.56	52.81	457.21
0-30 cm	144.71	51.16	48.17	363.84
CD (p=0.05)	10.09	2.88	3.97	31.31
Interaction	NS	NS	NS	S

They concluded that decreased nutrient uptake with increasing soil compaction and fertilizer placing depth was due to decreased root growth, lower root surface for absorption of water and nutrients, increase in the length of mass flow and diffusion for nutrient movement.

The reduction in nutrient uptake was more prominent between 1.34 and 1.52 Mg/m^3 (10.51-17.47%) than between 1.52 and 1.63 Mg/m^3 (9.75-14.70%) however for the fertilizer placement depth, higher reduction of P and K uptake was recorded between 0-10 cm and -20 cm whereas N and Zn uptake showed more reduction between 0-20 and 0-30 cm. The uptake of P between subsequent increase in compaction and fertilizer placement depth and uptake of Zn between subsequent increase in placement depth were observed at par. Among the uptake of different nutrients, maize plants showed highest reduction in Zn uptake ranging from 17.5-29.0 % and 20.3-36.6% for compaction and fertilizer placement depth, respectively, compared with non-compacted soil and 0-10 cm depth. The data also indicated that compaction had pronounced effect on nutrients uptake compared to that of fertilizer placement depth. The uptake of the nutrients was observed in the order of Zn>K>N>P and Zn>K>P>N for compaction and fertilizer placement depth, respectively. There was no interaction effect of soil compaction levels and fertilizer placement depths on nutrient uptake except zinc uptake.

Table 3: Effect of soil compaction and fertilizer placement depth on soil properties

Treatment	Organic C (%)	pH	EC (dS/m)	Hydraulic conductivity (cm/hr)
Compaction level				
1.34 Mg/m^3	0.61	7.00	0.22	2.46
1.52 Mg/m^3	0.55	6.97	0.23	1.32
1.63 Mg/m^3	0.58	6.99	0.23	0.84
CD (p=0.05)	0.03	NS	NS	0.29
Fertilizer placement depth				
0-10 cm	0.77	7.06	0.21	1.64
0-20 cm	0.48	6.98	0.22	1.58
0-30 cm	0.49	6.91	0.24	1.40
CD (p=0.05)	0.02	0.05	0.01	NS
Interaction	S	NS	NS	S

Effect on soil properties

Soil properties measured after crop harvest indicated that increasing compaction or fertilizer placement depth deteriorated the soil properties. A significant influence on organic carbon and saturated hydraulic conductivity by compaction and on organic carbon, soil reaction (pH) and EC by fertilizer placement depth was observed however pH and EC and saturated hydraulic conductivity did not show any significantly change with the processes of compaction and for fertilizer placement depth, respectively (Table 3). Non compacted soil (1.34 Mg/m^3) maintained higher oxidizable organic carbon over compacted soils. Increasing compactive force to 1.52 Mg/m^3 over non-compacted soil (1.34 Mg/m^3) slightly decreases the organic carbon content by 9.84% however further increase in compactive force tends to build up organic carbon by 5.45% over 1.52 Mg/m^3 bulk density. The higher organic carbon in non-compacted soil is indicative of more conversion of organic residue of previously grown crop into oxidizable form. Similar results were also obtained by Phukan and Baruah (2015) in soils of tea growing areas. A decrease in pH value was noted in soil subjected to compaction while compaction leads to increased soil electrical conductivity.

Table 4: Growth and yield attributes, soil properties and nutrient uptake correlation with soil compaction and fertilizer placement depth

Parameters	Soil compaction	Fertilizer placement depth
Speed of emergence	-0.815	-0.279
Plant height	-0.852	-0.999
Brace roots on nodes/ plant	0.340	-0.466
Root length	-0.969	-0.100*
Root length density	-0.996*	-0.100*
Anthesis silking interval	0.784	-0.324
Grain yield	-0.991	-0.995
Organic carbon	-0.615	-0.881
pH	-0.451	-0.532
Electrical conductivity	0.927	0.982
Hydraulic conductivity	-0.996*	-0.967
N uptake	-0.100*	-0.969
P uptake	-0.993	-0.997*
K uptake	0.998*	-0.984
Zn uptake	-0.999*	-0.998*

But, a remarkable negative impact of increase in compaction was observed in the marked decline in the hydraulic conductivity of soil. Results are in conformity with the finding of Ocloo *et al.* (2014), Singh *et al.* (2015). Increase in compaction from 1.34 to 1.52 and 1.52 to 1.63 Mg/m^3) reduced the hydraulic conductivity of soil to 46.3 and 36.4%, respectively. The reduction in saturated hydraulic conductivity with intensification of compaction might be due to distortion of structural flow paths, connectivity and hydraulic effectiveness of many macro pores (Schwen *et al.,* 2011). The less reduction in hydraulic conductivity of soil with additional increase in compaction suggested that soil tends to be more responsive to initial heavy loads than subsequent loads even when the later may be much heavier. Increase in placement depth of fertilizer reduced the values of organic carbon, pH and hydraulic conductivity however EC found to be increased. Placement of fertilizer up to 20 cm depth reduced organic carbon level by 37.7% over 0-10 cm which was found at par with 0-30cm which indicated that fertilizer placement depth had more impact on changing in organic carbon between 0-10 and 0-20 cm than between 1.34 and 1.52 Mg/m^3. Similarly placing fertilizer at 0-10 cm depth arrested more organic carbon than non-compacted soil (1.34 Mg/m^3) which might be attributed to higher amounts of root residue/biomass production. Compared with initial levels, compaction and fertilizer placement depth levels reduced the soil properties at harvest time however organic carbon was found to increase only at 0-10 cm depth. Interaction effect of compaction and fertilizer placement depth was found significant only for organic carbon and saturated hydraulic conductivity.

Relationship of compaction and fertilizer placement depth levels with growth and yield attributes

The relationship computed among soil compaction, fertilizer placement depth and growth and yield attributes and grain yield implied that compaction and fertilizer placement depth did show in general a strong negative and non-significant relation (ranging from -0.279 to -0.999) with most of the growth and yields parameters however root parameters and nutrient uptake were found to be significantly correlated (Table 4). Root length and root length density had negative and significant correlations with compaction (-0.969 and -0.996*) and fertilizer placement depth (-1.00* and -1.00*), respectively, indicating greater dependency of root parameters on compaction and fertilizer placement depth. However, both factors had low level of influence on brace roots on nodes. Similar relationships of root parameters with compaction and fertilizer placement depth were also reported by Ramazan *et al*. (2012) and Ji *et al. (*2013). The negative relation of compaction and fertilizer placement depth with root length and its density were expected because of increased mechanical impedance provides less space available for proliferation and growth of roots as well as reduced infiltration and hydraulic conductivity which are most conducive to water and nutrient movement and uptake. Soil organic carbon and pH showed non-significant negative correlations with both factors while correlations between electrical conductivity and both factors were strongly positive (0.927, 0.982). However, saturated hydraulic conductivity was found to be strongly and negatively correlated with compaction (-0.966*). A strong negative and significant correlation of compaction with N (-1.00*) and Zn (-0.998*), strong negative and non-significant with P uptake (-0.993) and strong positive and significant with K uptake were recorded. Whereas N (-0.969) and K (-0.984) uptake was found to be correlated strongly negative and non-significant and P (-0.997*) and Zn (0.998*) uptake was noted strongly negative and significant with fertilizer placement depth. Chaudhari *et al.* (2014) also reported similar correlations between soil properties and soil compaction.

The present study revealed the adverse effect of soil compaction and fertilizer placement depth on soil properties and growth, yield and nutrient uptake by maize crop but further increase in compaction or fertilizer placement depth beyond the established level has less effect. Compaction and fertilizer placement depth showed in general negative relationship with growth, yield nutrient uptake and soil properties. The compaction effect may vary on soil type, moisture content, cultivation practices etc. Therefore, more research is needed to identify optimum levels of some common factors influencing compaction as well as depth of fertilizer placement.

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