Research Article

Soil Physical Environment and Performance of Maize as Influenced by Subsoil Compaction and N Fertilization in a Sandy Loam Soils

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Abstract

Continuous use of heavy machines and puddling of rice fields results in the formation of sub-surface hard pan which affects the soil properties, soil-water-plant relations and plant growth. In an experiment three levels of subsurface compaction (C_0- Deep tilled /Control, C_1- Moderate subsoil compaction and C_2- High subsoil compaction) and three levels of nitrogen fertilization (N_1-155 kg N ha^{-1}, N_2-195 kg N ha^{-1} and N_3-235 kg N ha^{-1}) were compared to assess their effect on the soil physical properties, plant growth, root mass density and yields. The bulk density and penetration resistance was higher, while total porosity, cumulative infiltration and infiltration rate were lower under higher degree of subsoil compaction plots than that in deep till plots. The plant height, grain yield and biomass yield were less under higher degree of subsoil compaction over the normal. The higher dose of N fertilizer significantly improved the plant height, grain and biomass yield of maize. The root mass density was higher in 0-15 cm layer under C_2 treatment at knee high stage and pre-tasseling stage than that in C_0 treatment. The present study revealed that improved soil-plant-water relations along with higher maize yields can be achieved by breaking the hard pan restricting root growth formed due to use of heavy machines and puddling of rice fields.

Keywords: Bulk density, Penetration resistance, Root mass density, Yield, Subsoil compaction

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Introduction

In south Asia, maize is one of the most important cereal crop cultivated after rice and wheat in term of area, and produces food and forage for human and animal consumption. In Indian Punjab maize is cultivated over an area of 129’000 hectares, with a production of 475’000 tones and average yield of 3.68 t ha^{-1} [1]. A subsurface compacted layer formed as a result of use of heavy farm machinery for the cultivation of land under intensive cropping system [2]. This compacted layer is also formed below the plough layer due to puddling in rice-wheat cropping sequence practiced over a vast area in the Indo-Gangetic plains of the Indian sub-continent [3]. The subsoil compacted layer lead to degradation of soil health and decline in crop yield [4]. Soil compaction affects soil-water-plant relations, chemical and microbiological environment in subsoil that may hampers plant growth and crop yield [5-7]. The subsoil compaction affects saturated hydraulic conductivity, infiltration, bulk density [8] and penetration resistance [9]. Mamman and Ohu [10] also reported that soil bulk density and penetration resistance increased, while air permeability decreased with increase in the number of traffic passes. High soil strength layer developed as a result of heavy machinery may limit root growth and crop yield [7, 11] due to mechanical resistance offered to root growth and thus restrict the rate of oxygen supply to roots. Singh and Hadda [7] and Siemens and Peterson [12] reported maize yield reduction due to subsoil compaction. Such situations encourage farmers to apply more fertilizer to cover the risk of crop yield losses. It not only leads to soil and environment degradation but also increases the cost of production. Maize yield responds positively to an increase in the amount of N applied until the crop achieves optimum level [13]. An application of higher dose of N fertilizers by the farmers in the Indian Punjab for maize cultivation results in high production cost. However, the high fertilizer N level interact with the changes in soil physical environment resulted from use of heavy machinery and puddling need to be studied. Keeping these points in view, present investigation was carried out with an objective to assess the effect of subsoil compaction and N fertilization on soil physical properties, crop yield and root mass density.

Material and Methods

Location and experimental design

The field experiment was carried out for two years at the Research Farm of the Department of Soil Science, Punjab

Agricultural University, Ludhiana, in the central plain region of Indian Punjab located at an altitude of 247 m (asl), 30º54′ N latitude and 75º48′ E longitude. The experimental area is characterized with semi-arid climate by a very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. The July to September months receives about 80 per cent of the average annual rainfall. The mean monthly temperatures during the crop season vary from 29.3 to 33.8 ºC and annual average rainfall received is 733 mm.

The soil is alluvial, sandy loam in texture (64.8 % Sand, 18.9 % Silt and 16.3 % Clay), pH 7.63, EC 0.51 dS m^{-1} and soil organic carbon was 0.37%. The plant available water in soil profile (180 cm depth) was 21.8 cm with bulk density (Mg m^{-3}) of 1.49 at 0-15 cm depth and 1.63 at 15-30 cm depth. The Saturated Hydraulic conductivity (cm hr^{-1}) at 0-15 cm depth was 5.87 and at 15-30 cm depth was 1.95.

The experiment was laid out in a split-plot design with three subsoil compaction levels as main plot treatments and three levels of fertilizer nitrogen as subplot treatments with three replications in the year 2012 and 2013. The surface 15-cm soil was removed and then the sub-surface layer was compacted with the passes of tractor mounted roller to achieve the desired bulk density of subsurface layer during both the years of study. The surface soil was put back on the place once the desired bulk density of the subsurface layer was achieved 7 days before the sowing of the crop. The subsoil compaction treatments employed were C_0- Deep tilled plots/Control (bulk density, Db= <1.6 g/cm^3), C_1- moderate subsoil compaction, (Db= 1.70-1.75 g/cm^3) and C_2- high subsoil compaction (Db>1.80 g/cm^3) at 15-30 cm depth. The maximum soil bulk density of 1.86 Mg m^{-3} at optimal water content (i.e., water content at which maximum compaction occurs) of 0.12 cm^3 cm^{-3} was observed using standard Proctor test. The nitrogen fertilizer amounts applied to maize were N_1-155 kg N ha^{-1}, N_2-195 kg N ha^{-1} and N_3-235 kg N ha^{-1}.

Cultural practices

After employing subsoil treatments, maize (*Zea mays* L.) (cultivar PMH-1) was sown on 27th June and 22th June during the years 2012 and 2013, respectively at a spacing of 60 cm × 20 cm (row to row and plant to plant spacing). The recommended amount of P, K and Zinc Sulphate (at the rate of 60, 30 and 25 kg ha^{-1}, respectively) along with one third of N (as urea) as per treatment was applied at the time of sowing and the remaining N was applied in two equal splits i.e. at knee high and at pre-tasselling stages. The recommended cultural practices (i.e fertilizers, herbicide, insecticides and other management practices) were followed as per package of practices given by Punjab Agricultural University [1] to ensure proper weed, insect and pest control.

Plant observations

Plant height was recorded at the time of harvesting as the mean height of five randomly selected plants from the base of plant to the base of first appeared leaf using measuring scale of 2.5 m. The crop was harvested at ground level by hands from an area of 15 m^2 located at the center of each plot of 4m x 6m. All the ears from each net harvested plot were sun dried and shelled with thresher. The grains were weighed immediately after threshing and moisture content of grains from each plot was determined. The grain yield (t ha^{-1}) was adjusted to 15 per cent moisture level, while straw yield was expressed on oven dry basis.

Root observations

Root sampling core with internal diameter of 7 cm was used to collect soil core samples from 0-15, 15-30, 30-60, 60-90 and 90-120 cm depth at knee high stage and pre-tasselling stage. The plant base was kept in the centre of the core in each experimental plot while taking the samples for root extraction. The roots were extracted from the core samples by washing under running water over 1 mm sieve. The washed roots were oven dried at 60^{0}C till constant weight was achieved. The root density (g m^{-3} of soil) was calculated as the ratio of weight of roots in a particular soil layer to the volume of the soil from which roots were extracted.

Soil measurement

Bulk density was determined from replicated undisturbed soil samples collected from the field at the depth of 0-15, 15-30, 30-45, 45-60, 60-90 cm. Bulk density (D_b ; measured as ratio of mass of soil in the core to the volume of core) and particle density (D_p) was used to calculate total porosity (TP) using the equation, TP= $(1-D_b/D_p)$. The constant head water permeameter method [14] was employed to measure hydraulic conductivity from 5-10 cm and 17-22 cm soil layer, while double metallic ring infiltrometer method [15] was used for *In-situ* infiltration rate measurement. The fall of water level in the inner ring of the double ring infiltrometer was recorded at different time intervals up to a cumulative time of 360 minutes from the start and cumulative infiltration (cm) and infiltration rate (cm min^{-1}) was worked out for each treatment. The soil moisture content was determined gravimetrically. Penetration resistance of the soil was measured using cone peneterometer and expressed in KPa.

Statistical analysis

The data from the experiment was analyzed employing procedure for split plot design [16] for analysis of variance (ANOVA) using PROC GLM (SAS software 9.1, SAS institute Ltd., USA). Duncan's multiple range test (DMRT) was used for mean comparisons when F-tests were found significant.

Results and Discussion

Effect of subsoil compaction and N fertilization on soil physical properties

The bulk density (D_b) of surface 0-15 cm surface soil layer did not differ significantly among various subsoil compaction treatments during the year the 2012 and 2013. However, the D_b for 15-30 cm subsoil layer was significantly higher under C_2 (high subsoil compaction (Db>1.80 g/cm^3)) treatment than that in C_0 (deep tilled) and C_1 (moderate subsoil compaction) treatments during the year 2012 and 2013 (**Table 1**). The higher D_b under C_2 treatment was resulted from subsoil compaction treatment. The D_b of 30-45 cm subsoil layer followed almost similar trend as that of 15-30 cm subsoil layer, except the D_b of 30-45 cm subsoil layer was less than that in layer above. Our results corroborate the findings of Mamman and Ohu [10] who reported that dry soil bulk density and penetration resistance increased with increase in the number of traffic passes.

Table 1 Effect of subsoil compaction and N fertilization on Bulk density (Mg m^{-3}) and Penetration resistance (KPa)

	2012			**2013**			**2012**			**2013**		
	0-15	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**
C_0	1.53a	1.60c	1.52c	1.49a	1.60c	1.54b	1026.5ab	1889.8c	1588.6b	1044.4ab	1981.1c	1605.3b
C_1	1.52a	1.73b	1.64b	1.55a	1.73b	1.62a	992.6b	2098.1b	1640.7b	1011.8b	2201.1b	1657.0b
C_2	1.53a	1.82a	1.72a	1.52a	1.81a	1.69a	1048.8a	2562.2a	1852.8a	1060.3a	2650.3a	1888.9a
p-value C	0.76	<0.001	<0.001	0.29	0.001	0.004	0.037	<0.001	0.005	0.072	<0.001	0.002
N_1	1.53a	1.70a	1.59b	1.50a	1.69a	1.59a	1020.6a	2165.0a	1683.1a	1030.8a	2229.5a	1715.0a
N_2	1.52a	1.72a	1.63ab	1.52a	1.71a	1.62a	1025.81a	2146.9a	1678.3a	1036.0a	2251.8a	1690.5a
N_3	1.54a	1.73a	1.64a	1.53a	1.72a	1.63a	1021.6a	2238.2a	1720.7a	1049.6a	2351.2a	1744.9a
p-value N	0.66	0.14	0.068	0.60	0.61	0.44	0.95	0.21	0.66	0.61	0.42	0.70
p-value C x N	0.18	0.43	0.53	0.48	0.40	0.64	0.45	0.23	0.30	0.81	0.59	0.44

Different letters in each column of experimental factors show significant differences at < 0.05 probability level.

The penetration resistance (PR) of soil increased with depth (Table 1). The PR of C_2 treatment at 15-30 cm subsoil layer was significantly higher than that in C_0 and C_1 treatment that reached a critical limit that negatively affected the root growth. The PR values at 30-45 cm soil depth were statistically higher under C_2 treatment than that in C_0 and C_1 treatment. The PR values were higher at 15-30 cm soil depth than that in 0-15 cm surface layer. Kozicz [17] found that the PR in subsoil layer was two times higher than that in plough layer. Becher [18], Munkholm and Kay [19] and Singh *et al.* [3] also reported higher soil strength under compacted zones due to cultivation.

The total porosity was higher under lower D_b than that in higher D_b soil. Total porosity was higher under C_0 treatment in comparison to C_1 and C_2 treatment at all depths during the year 2012 and 2013 (**Table 2**). The total porosity was significantly higher under C_0 treatment as compared to C_1 and C_2 treatment at 15-30 cm and 30-45 cm soil depth. Bulinski and Niemczyk [20] reported 8% reduction in macro-porosity of the compacted soil while the micro-porosity decreased by 5.8%. The bulk density, penetration resistance and total porosity were not significantly affected by the interactive effect of subsoil compaction and N fertilization.

The subsoil compaction and N fertilization had no significant effect on saturated hydraulic conductivity at 5-10 cm depth after the harvesting of maize in the year 2013 (**Table 3**). However, saturated hydraulic conductivity of the 17-22 cm soil depth reduced significantly in response to subsoil compaction treatments. The saturated hydraulic conductivity of C_2 and C_1 treatments were respectively 2.8 and 1.6 times less as compared to C_0 treatment. The primary reason for the reduction of saturated hydraulic conductivity was found to be the reduction in macropores under higher level of subsoil compaction.

Table 2 Effect of subsoil compaction and N fertilization on total porosity (v/v). Different letters in each column of experimental factors show significant differences at < 0.05 probability level

Treatments/	2012			2013		
Soil depth	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
C_0	0.416a	0.379a	0.398a	0.428a	0.396a	0.419a
C_1	0.423a	0.341b	0.367b	0.406a	0.347b	0.391b
C_2	0.417a	0.308c	0.337c	0.417a	0.317c	0.365b
p-value C	0.76	<0.001	<0.001	0.19	<0.001	0.004
N_1	0.419a	0.355a	0.371a	0.425a	0.360a	0.402a
N_2	0.423a	0.333b	0.367a	0.416a	0.352a	0.388a
N_3	0.414a	0.341ab	0.365a	0.411a	0.348a	0.386a
p-value N	0.66	0.07	0.69	0.50	0.65	0.44
p-value C x N	0.18	0.20	0.76	0.32	0.47	0.64

Table 3 Effect of subsoil compaction and N fertilization on saturated hydraulic conductivity of soil after the harvesting of maize during the year 2013. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

Treatment	5-10 cm	17-22 cm
C_0	6.750a	2.876a
C_1	6.627a	1.562b
C_2	6.526a	0.992c
p-value C	0.65	<0.001
N_1	6.761a	1.749a
N_2	6.643a	1.804a
N_3	6.500a	1.878a
p-value N	0.56	0.71
p-value C x N	0.07	0.56

Table 4 Effect of subsoil compaction on soil moisture retention (cm) of soil after the harvesting of maize during the year 2013

Soil depth	Soil moisture retention at 0.3 bar			Moisture content at 15 bar		
	C_0	C_1	C_2	C_0	C_1	C_2
0-15	13.30	13.40	13.45	5.60	5.60	5.70
15-30	13.80	14.10	15.20	5.80	6.10	6.63
30-60	14.70	14.84	15.30	5.90	6.30	6.54
60-90	14.90	14.70	15.20	6.30	6.30	6.40
90-120	15.40	15.30	15.30	6.60	6.70	6.65
120-150	15.50	15.60	15.60	6.70	6.70	6.60
150-180	15.50	15.62	15.60	6.70	6.60	6.70

The increase in the soil moisture retention was observed at 0.3 bar at 15-30 and 30- 60 cm soil layer under C_2 and C_1 treatment compared to C_0 treatment after the harvesting of maize during the year 2013 (**Table 4**). At 15 bar suction pressure soil moisture retention was also higher at 15-30 and 30-60 cm layer under C_2 treatment followed by C_1 treatment than that in C_0 treatment. The increase in soil moisture retention at 0.3 and 15 bar pressure might be attributed to reduced macroporosity and increase in microporosity of soil as a result of soil compaction.

The cumulative infiltration was 25.1, 17.6 and 12.5 cm in C_0, C_1 and C_2 treatment, respectively during the year 2012, while it was 27.5, 19.9 and 14.9 cm in C_0, C_1 and C_2 treatment respectively during the year 2013 (**Figure 1 a, b**) after six hours of initiation of infiltration. The reduction in infiltration rate was observed under higher subsoil compaction levels. After 360 minutes, infiltration rate was 4.18, 2.93 and 2.08 cm hr^{-1} in C_0, C_1 and C_2 treatment respectively during the year 2012 and 4.58, 3.31 and 2.48 cm hr^{-1} under C_0, C_1 and C_2 treatment respectively during the year 2013. The reduction in cumulative infiltration and infiltration rate under C_2 treatment as compared to C_0 treatment might be attributed to decreased total porosity due to higher bulk density of subsoil layer under C_2 treatment. Dikinya [21] also observed lower infiltration rate in compacted sandy loam soil. Reicosky *et al.* [22] attributed the decrease in infiltration due to compaction that increased number of contacts between individual soil particles which lead to increase in tortuosity of water flow, and thereby reduce infiltration.

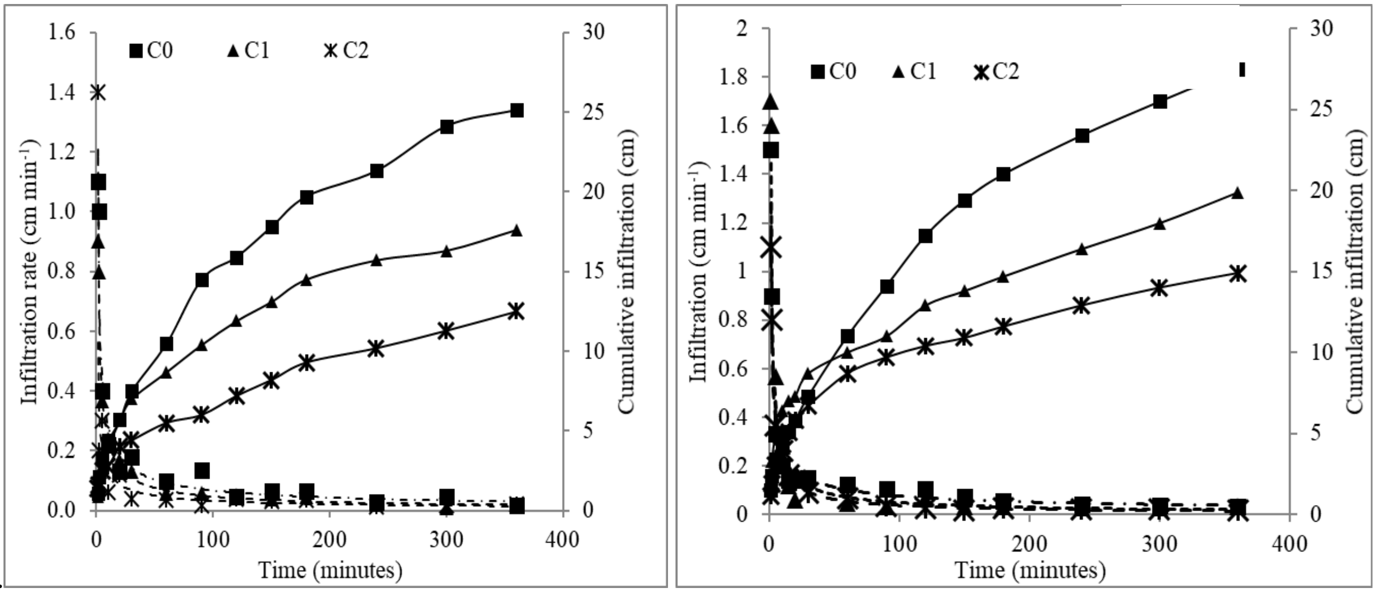

Figure 1 Cumulative infiltration (solid line) and infiltration rate (dotted line) as affected by subsoil compaction treatments during the year of 2012 (a) and 2013 (b)

Effect of subsoil compaction and N fertilization on plant growth, grain and biomass yield

The increase in the soil strength of subsoil layer significantly affected the plant height (**Table 5**). Maximum plant height (267.4 and 258.75 cm) was recorded under the C_0 treatment against minimum (248.3 and 223.5 cm) under C_2 during the year 2012 and 2013 respectively. The C_2 treatment resulted in reduction in plant height by 7.1 % and 13.6 % as compared to C_0 treatment at the time of harvesting during the year 2012 and 2013, respectively. The reduced plant height in C_2 treatment might be due to restricted root growth under higher subsoil strength. Nitrogen fertilization significantly increased the plant height. The maximum plant height (265.3 and 252.8 cm) was recorded at harvesting stage in N_3 plots compared with minimum plant height (251.6 and 234.2 cm) under N_1 treatments during the year 2012 and 2013 respectively. The results obtained corroborates the findings of Akbar *et al.* [23] and Rasheed *et al.* [24] that plant height was higher under higher N application rate. The application of higher doses of nitrogen increased the stem elongation that increased plant height [25]. Hussaini *et al.* [26] also reported that plant height, leaf area index and growth rate were significantly higher with application of higher N fertilizer.

Table 5 Effect of subsoil compaction and N fertilization on plant height, grain and biomass yield of maize. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

Treatments	**Plant height (cm)**		**Grain yield (t ha^{-1})**		**Biomass yield (t ha^{-1})**	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**
C_0	267.3a	258.7a	6.307a	5.494a	16.99a	15.00a
C_1	256.3b	244.8b	5.738b	4.391b	15.96ab	13.83b
C_2	248.3b	223.5c	5.326b	4.158b	14.69b	13.13b
p-value C	0.003	<0.001	0.0026	<0.001	0.016	<0.001
N_1	251.5b	234.2b	5.400a	4.346b	14.53b	13.28b
N_2	255.1b	240.0b	5.763ab	4.646ab	16.12a	13.98b
N_3	265.3a	252.8a	6.208a	5.049a	17.00a	14.72a
p-value N	0.023	0.002	0.01	0.038	0.009	0.0034
p-value C x N	0.053	0.40	0.65	0.99	0.96	0.44

Maximum grain yield was recorded under C_0 treatment than C_1 and C_2 treatments during the years 2012 and 2013 (Table 5). The reduction in maize yield was 15.5 and 24.3 per cent under higher subsoil compaction (C_2 treatment) as compared to C_0 treatment during the years 2012 and 2013, respectively. Singh and Hadda [7] also reported 10-17 per cent yield reduction in maize due to subsoil compaction. The vehicular traffic induced compaction reduced the average maize yield by about 13 %, was reported by Siemens and Peterson [12]. The reduced maize yield under higher degree of subsoil compaction may also be attributed to the restricted root growth. Allmaras *et al.* [27] also observed that high root growth restrictions under higher degree of subsoil compaction may lower the crop yield.

Maize grain yield improved significantly in response to N application. The N_3 treatment resulted in 14.8 and 16.1 per cent increase in grain yield than that in N_1 during the year 2012 and 2013, respectively. An increase in grain yield may be attributed to higher plant growth in response to higher level of N fertilization as compared to the recommended dose of N fertilizer. The results also corroborate the findings of Inamullah *et al.* [28] who found an increase in grain yield with higher dose of N fertilizer application.

Biomass yield was significantly higher under C_0 than C_1 and C_2 during both years (Table 5). The higher biomass yield under C_0 treatment might be attributed to higher dry matter accumulation and plant height. Unger and Kaspar [29] also found reduction in plant growth, grain yield and biomass yield due to negative effect of compaction on water infiltration and aeration. The N_3 treatment resulted in 17.0 and 10.8 per cent higher biomass yield than N_1 treatment during the year 2012 and 2013, respectively. Application of higher dose of N fertilizer over recommended N fertilizer resulted in increased vegetative growth which had improved the biomass yield. Inamullah *et al.* [28] also found an improvement in biomass yield with application of higher dose of N fertilizer.

The interaction effect of subsoil compaction and N fertilization were non-significant for plant height, grain yield and biomass yield during the year 2012 and 2013 (Table 5).

Effect of subsoil compaction and N fertilization on root growth

At knee high stage

The root mass density at 0-15 cm was highest under C_2 treatment during the year 2012 and 2013 (**Table 6**). Root mass density at 0-15 cm depth was significantly higher under C_3 treatment followed by C_1 and C_2 treatments. The root mass density decreased with depth during both years.

Table 6 Effect of subsoil compaction and N fertilization on root mass density (g m^{-3}) at knee high stage of Maize. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

Soil depth	2012			2013		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
C_0	424.90b	98.13a	15.59a	374.17b	95.82a	13.98a
C_1	475.54a	83.36b	11.21b	430.20a	81.31b	9.68b
C_2	480.17a	75.90c	9.56b	441.97a	75.45b	8.47b
p-value C	0.028	<0.001	<0.001	<0.001	0.001	<0.001
N_1	427.48b	80.49b	11.02b	388.69b	78.67b	9.65a
N_2	468.56ab	84.24b	11.65b	410.66b	83.41ab	10.77a
N_3	484.57a	92.67a	13.69a	446.99a	90.49a	11.71a
p-value N	0.034	<0.001	0.019	<0.001	0.045	0.16
p-value C x N	0.76	0.078	0.41	0.90	0.96	0.15

There was reverse trend at 15-30 and 30-45 cm depth where root mass density was higher under C_0 treatment as compared to C_1 and C_2 treatments. The bulk density and penetration resistance of 15-30 cm soil layer was higher under C_2 treatment, might be the reason of higher root mass density in 0-15 cm layer under C_2 treatment, as the lower layer might be restricting root growth. The bulk density and penetration resistance of 15-30 cm soil layer was lower under C_0 treatment that resulted in higher root mass density in 15-30 and 30-45 cm soil layer in this treatment. Laboski *et al.* [30] in a field experiment found confined roots almost entirely to the top 60 cm of soil because it had high soil strength and bulk density due to compacted soil layer. The application of higher dose of N had significantly improved the root mass density in all treatments under at all depths than that in lower N dose. The higher penetration resistance might had restricted root penetration to deeper soil layer while N fertilization had improved the root mass density in the all layers due to adequate supply of N for plant growth. The interaction effect of subsoil compaction and N fertilization were non-significant for root mass density at knee high stage of maize.

At pre-tasseling stage

The information on root mass density as affected by various subsoil compaction and N fertilization treatments recorded at tasselling stage of crop are presented in Table 7. Most of the root mass was confined to 0-15 cm of soil profile (65-75 per cent of total) followed by 15-30 cm (16-24 per cent of total) and very low root mass was in 30-60 cm soil depth (4-6 per cent of total), insignificant amount (2.0-3.5 per cent of total) in 60-90 cm soil depth and insignificant amount (0.9-1.8 percent of total) was recorded in 90-120 cm soil profile. The highest root mass density of 1603.3 and 1568.6 g m^{-3} was observed at 0-15 cm layer under C_2 treatment during the year 2012 and 2013 (**Table 7**). In 0-15 cm soil layer root density was significantly higher under C_2 treatment than that in C_0 and C_1

treatment during the year 2012 and 2013. Rosolem and Takahashi [31] found that root growth decreased quadratically in the compacted layer and an increase in root growth in the superficial soil layer due to subsurface compaction. However, a reverse trend in root mass density was observed for deeper layers, where a significantly higher root mass density under C_0 treatment was observed than that in C_1 and C_2 treatment. Higher root growth restriction under C_2 treatment due to its higher bulk density and penetration resistance had confined higher root mass in 0-15 cm soil layer, while in deeper soil depths C_0 treatment had higher root mass density due to lower penetration resistance of subsoil layer. The results are in conformity with Grzesiak [32] who reported that maize root growth was limited by the soil compaction due to higher penetration resistance and bulk density. Several studies [33-35] also reported that subsoil compacted layer affect the root amount, growth and its distribution pattern in the soils.

The N application significantly affected the root mass density. The root mass density was higher under N_3 treatment than that in N_1 and N_2 treatment due to higher plant growth as a result of proper nutrition of maize crop. The interaction effect of subsoil compaction and N fertilization were non-significant for root mass density at pre-tasseling stage of maize.

Table 7 Effect of subsoil compaction and N fertilization on root mass density (g m^{-3}) at pre-tasseling stage of maize at different soil depth during the year 2012 and 2013. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

Soil depth	2012					2013				
	0-15	15-30	30-60	60-90	90-120	0-15	15-30	30-60	60-90	90-120
Subsoil compaction levels										
C_0	1350.9c	476.2a	112.9a	61.8a	38.2a	1267.0c	444.8a	97.7a	47.0a	29.4a
C_1	1482.0b	429.8b	96.9b	54.7b	32.9b	1450.8b	397.7b	81.7b	43.0b	24.7b
C_2	1603.3a	379.5c	88.3c	48.5c	20.3c	1519.6a	370.1b	72.0c	38.7c	16.9c
p-value C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001
Nitrogen fertilization levels										
N_1	1394.1c	400.3b	90.2c	49.3b	26.9b	1331.5c	376.1b	74.6c	39.4c	20.3b
N_2	1473.5b	434.8ab	98.0b	53.1b	31.0a	1410.6b	413.0ab	83.8b	41.7b	24.4a
N_3	1568.6a	450.4a	110.0a	62.7a	33.6a	1495.3a	423.5a	93.1a	47.7a	26.3a
p-value N	<0.001	0.27	<0.001	<0.001	0.01	<0.001	0.049	<0.001	<0.001	0.018
p-value C x N	0.98	0.93	0.80	0.28	0.69	0.97	0.95	0.87	0.088	0.76

Conclusion

The present investigation was carried out to access the effect of subsoil compaction and nitrogen fertilization on the soil physical properties, plant growth, yields and root mass density under sandy loam soil in the central alluvial plain of Indian Punjab. The results show that bulk density and penetration resistance were significantly high under higher degree of subsoil compaction. However, there was decrease in total porosity, cumulative infiltration and infiltration rate due to compacted subsoil layer. The N fertilization showed non-significant effect on the soil physical properties. The plant height, grain yield and biomass yield were less under C_2 treatment than that in C_0 treatment. The higher dose of N fertilizer significantly improved the plant height, grain and biomass yield of maize. The root mass density was higher in 0-15 cm layer under C_2 treatment at knee high stage and pre-tasseling stage than that in C_0 treatment. However, a reverse trend was observed at 15-30, 30-60, 60-90 and 90-120 cm soil depth, where root mass density was higher in C_0 treatment than that in C_1 and C_2. Deep tillage be encouraged before the sowing of maize crop grown after harvesting of puddled rice to improve the infiltration, ground water recharge, rooting depth of plants and to achieve higher yields.

References

[1] Anonymous (2016) Package of practices for crops of Punjab: Kharif 2016. Punjab Agricultural University, Ludhiana, 33:25-39.

[2] Flowers M, Lal R. (1998) Axle load and tillage effect on soil physical properties and soybean grain yield on a mollic ochraqualf in Northwest Ohio. Soil Till Res 48: 21-35.

[3] Singh J, Salaria A, Kaul A. (2015) Impact of soil compaction on soil physical properties and root growth: A review. Inter J Food Agric Vet Sci 5:23-32

[4] Hamza MA, Al-Adawi SS, Al-Hinai KA. (2011) Effect of combined soil water and external load on soil compaction. Soil Res 49: 135–142.

[5] Hamza MA, Anderson WK. (2005) Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil Till Res 82: 121–145.
[6] Mosaddeghi MR, Mahboubi AA, Safadoust A. (2009) Short-term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in western Iran. Soil Till Res 104: 173–179.
[7] Singh J, Hadda MS. (2015) Maize (Zea mays L.) response to subsoil compaction and nitrogen fertilization under semi-arid irrigated conditions. J Appl Nat Sci 7: 493–500.
[8] Li C, Zhou S. (1994) Effects of soil bulk density on the growth of maize seeding stage. Acta Agric Boreali-Sinica 9: 49–54.
[9] Singh J, Hadda MS. (2014) Soil and plant response to subsoil compaction and slope steepness under semi-arid irrigated condition. Inter J Food Agric Vet Sci 4 (3): 95-104.
[10] Mamman E, Ohu JO. (1998) The effect of tractor traffic on air permeability and millet production in a sandy loam soil in Nigeria. Ife J Tech 8:1–7.
[11] Jamieson JE, Morrisr J, Mullinsc E. (1988) Effect of subsoiling on physical properties and crop growth on a sandy soil with a naturally compact subsoil. Proceedings of the 11th Conference of the International Soil Tillage Research Organisation 2, 499-503.
[12] Siemens J, Peterson D. (1997) Compaction: causes and effects. Cooperative Extension Service. The Department of Agricultural Engineering. University of Illinois at Urbana-Champaign, IL, USA.
[13] Zand-Parsa S, Sepaskhah AR. (2001) Optimal applied water and nitrogen for maize. Agric Water Manage 52: 73-85.
[14] Klute A, Dirksen C. (1986) Saturated hydraulic conductivity and diffusivity; laboratory methods. pp. 687-732. In 'Methods of Soil Analysis, Part 1 Physical and Mineralogical Methods'. (eds Klute A) American Society of Agronomy-Soil Science Society of America: Madison, WI.
[15] Bouwer H. (1986) Intake rate: Cylinder infiltrometer. Pp 825-843 In: Methods of Soil Analysis. Klute A. (ed.) ASA Monograph 9. ASA. Madison, WI.
[16] Gomez KA, Gomez AA. (1984) Statistical Procedures for Agricultural Research, John Wiley and Sons, Inc, U K.
[17] Kozicz J. (1996) Compacting soil with traction mechanisms of aggregates at cultivating cereals and root crops. Post Nauk Rol 4:51–64.
[18] Becher HH. (1998) Resistances to penetration of aggregates from loess-derived top-soils at different soil water tensions. Soil Till Res 47:73–81.
[19] Munkholm LJ, Kay BD. (2002) Effect of water regime on aggregate-tensile strength, rupture energy, and friability. Soil Sci Soc Am J 66: 702-709.
[20] Bulinski J, Niemczyk H. (2001) Effect of method of agricultural outfit running on the field on soil properties and sugar beet yielding. Annals Warsaw Agricu Univ Agric Engg 41:39–44.
[21] Dikinya O. (1994) Effect of Compaction on Management of Agricultural Soils. Proceeding 20th SARCCUS Standing Committee for Soil Science, Windhoek.
[22] Reicosky DC, Voorhees WB, Radke JK. (1981) Unsaturated flow through a simulated wheel track. Soil Sci Soc Am J 45: 3-8.
[23] Akbar H, Jan MT, Amanullah J. (2002) Yield potential of sweet corn as influenced by different level of nitrogen and plant population. Asian J Plant Sci 16:631-63324.
[24] Rasheed M, Mahmood T, Nazir MS, Bhutta WA, Ghaffar A. (2004) Nutrient efficiency and economics of hybrid maize under different planting methods and nutrient levels. Intern J Agric Biol 6:922-925.
[25] Thakur DR., Prakash O, Kharwara PC, Bhalla SK. (1997) Effect of nitrogen and plant spacing on yield, nitrogen uptake and economics in baby corn (Zea mays L.). Indian J Agron 43: 668-671.
[26] Hussaini MA, Ogunlela VB, Ramalan AA, Falaki AM. (2001) Growth and development of maize (Zea mays L.) in response to different levels of nitrogen, phosphorous and irrigation. Crop Res 22:141-49.
[27] Allmaras RR, Kraft JM, Miller DE. (1988) Effects of soil compaction and incorporated crop residue on root health. Annual Review Phytopathol 26: 219-43.
[28] Inamullah, Shah NH, Rehman N, Siddiq M, Khan Z. (2011) Phenology, yields and their correlations in popular local and exotic maize hybrids at various nitrogen levels. Sarhad J Agric 27: 363-69.
[29] Unger PW, Kaspar T C. (1994) Soil compaction and root growth: a review. Agron J 86: 759-766.
[30] Laboski CAM., Dowdy RH, Allmaras RR, Lamb JA. (1998) Soil strength and water content influences on corn root distribution in a sandy soil. Plant Soil 203:239–47.
[31] Rosolem CA, Takahashi M. (1998) Soil compaction and soybean root growth. In: Box, J.E. (Ed.), Root Demographics and their Efficiencies in Sustainable Agriculture, Grasslands and Forest Ecosystems.

Proceedings of the 5th Symposium of the International Society of Root Research, Clemson, South Carolina, USA, pp. 295–304.

[32] Grzesiak MT. (2009) Impact of soil compaction on root architecture, leaf water status, gas exchange and growth of maize and triticale seedlings. Plant Root 3:10-16.

[33] Sidhu SS. (1980) Water retention, transmission and other physical properties of soils under paddy in Punjab. M.Sc. Thesis, Punjab Agricultural University, Ludhiana.

[34] Sur HS, Prihar SS, Jalota SK. (1980) Effect of rice-wheat and maize-wheat rotation on water transmission and wheat root development in a sandy loam soil of Punjab, India. Soil Till Res 1: 361-71.

[35] Sur HS, Sidhu SS. (1982) Effect of rice-wheat and corn-wheat rotation on physical properties and root growth of wheat in a sandy loam soil. Paper presented at the 12th international congress of soil science held on 8-16 February, New Delhi.

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