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Research Article

Soil Chemical Environment of Alluvial Sandy Loam Soil Influenced By Subsoil Compaction and Nitrogen Fertilization under Maize Cultivation

Jagdish Singh*, M S Hadda and Dhanwinder-Singh

Department of Soil Science, Punjab Agricultural University, Ludhian, India

Abstract

The experiment was conducted to evaluate the effect of subsoil compaction and nitrogen fertilization on the soil chemical environment, yield and partial factor productivity of maize. Three level of subsoil compaction and three level of nitrogen application were evaluated employing split-plot design with three replications. The data was collected on the soil chemical properties (pH, EC, OC, Ammonical N, Nitrate N, Available P, Available K and Micronutrients), yield (grain yield and biomass yield), maize nutrient uptake (grain, straw and total). The data revealed significant effect of subsoil compaction and nitrogen fertilization on soil pH, EC, Soil organic carbon, Ammonical-N, however micronutrient was not found significantly affected in response to the subsoil compaction and nitrogen fertilization. The grain and biomass yield were significantly higher in the low subsoil compaction level (C_0) and higher rate of N application (N_2). The data also showed that the partial factor productivity (PFP_N) declined under higher degree of subsoil compaction. Thus, it became imperative to break the subsurface compact layer to achieve higher yield and factor productivity.

Keywords: Subsoil compaction**,** factor productivity, ammonical and nitrate nitrogen, micro-nutrients

***Correspondence**
Author: Jagdish Singh
Email: jagdishsingh@pau.edu

Introduction

The use of farm machinery for has been increased many folds for various field operations such as ploughing, planking, disc harrowing, weeding, etc. for saving time and labour. The increase in number of passes and load of machines had resulted in risk of compaction [1]. Flower and Lal, [2] reported the development of subsoil compacted layer as a result of vehicular traffic used for field operations, while Sur *et al* [3] attributed the development of subsoil compacted layer or plough pan due to puddling in rice-wheat cropping sequence resulted from degradation of soil structure. The passes of machines lead to unfavorable changes to soil physical properties, such as soil structure degradation that is closely associated with adverse changes in the soil porosity, bulk density, penetration resistance and infiltration [4]. The degradation soil physical environment also influences shoot and root growth and development and soil chemical environment. Nevens and Reheul [5] and Singh *et al* [1] also reported reduced root system and decreased nutrient availability in compacted soils resulted in decreased shoot growth and crop yield. The soil compaction increases mechanical impendence, creates unfavourable root growth conditions, and restricts oxygen, water, and nutrient supply [6, 7]. De Neve and Hofman [8] reported that the compaction of soil results in the depression of the carbon mineralization rate. The change in the aeration status, water transmission characteristics may lead to changes in the soil pH, EC, soil organic carbon content, nitrogen tranformations, and micronutrient availability, etc. Thus, the experiment was carried out to assess the impact of subsoil compaction and nitrogen fertilization on the changes in the soil chemical environment, maize yield, nitrogen uptake and partial factor productivity.

Material and Methods

Experimental Site

A field experiment was conducted under an irrigated cropping system at Punjab Agricultural University, Ludhiana, Punjab, India (30º54′ N, 75º48′ E) for 2 years (2012 and 2013). The site is located in semi-arid climate with hot and humid conditions from July to September (receiving 70-80 % of annual rainfall during this period), cold winters from November to January, mild climate during February and March and very hot and dry summer from April to June. The experimental site had a sandy loam soil texture with 7.63 soil pH, 0.51 dSm^{-1} soil electrical conductivity, 0.32 % soil organic carbon, 1.49 Mg m^{-3} bulk density and 5.87 cm hr^{-1} saturated hydraulic conductivity.

Experimental Design

The main plot treatments have three subsoil compaction levels and subplot have three doses of nitrogen, were applied according to split-plot design with three replications. The desired bulk density of the subsoil compact layer as per treatments were given by removing the surface 15-cm soil and then compacting the sub-surface layer with passes of tractor mounted roller to the desired bulk density. The soil compaction treatments were C_0- Control (no compaction), C_1- Moderate compaction, (bulk density= 1.70-1.75 Mg m^{-3}) and C_2- High compaction (bulk density>1.80 Mg m^{-3}) at 15-30 cm depth. The nitrogen treatments were N_0-125 Kg N ha^{-1}, N_1-157 Kg N ha^{-1} and N_2-188 Kg N ha^{-1}.

Crop management

The sowing of the maize crop was done in the 4^{th} week of June, on the same day for all plots with row to row spacing of 60 cm and plant to plant spacing of 20 cm during the year 2012 and 2013. The diammonium phosphate, murate of potash and zinc Sulphate with one third of recommended dose of nitrogen (as Urea 46 % N) was applied at the time of sowing and remaining nitrogen was applied in two equal splits i.e. at knee high and at pre-tasselling stages. The recommended cultural practices as per the *Package of Practices for Kharif Crops* of Punjab Agricultural University were followed to ensure proper weed, insect and pest control.

Sample collection

Soil samples were collected from 0-15, 15-30 and 30-45 cm depth after the harvesting of crop during the year 2012 and 2013. Soil samples were air dried, ground and passed through a sieve with 2 mm mesh and were analyzed for soil pH (by potentiometer in a soil and water suspension at soil water ratio of 1:2), soil electrolytic conductivity (EC) (by conductivity meter of supernatant solution of 1:2 soil water solution), organic carbon content (wet digestion, Walkly and black method), Nitrate and Ammonical nitrogen (Kjeldahl's method), Available Phosphorus (Olsen method), and Available Potassium (Ammonium Acetate extraction). The content of microelements Zn, Cu, Mn, and Fe after extraction with DTPA for 2 hours on a rotating mixer at the soil:extractant solution ratio 1:10, extracts so obtained were analyzed using the ICP-AES.

The cobs from each net harvested plot were sun dried for three days and shelled. Moisture content of grains from each plot was determined and adjusted to 15 per cent moisture level and expressed in t ha^{-1}. The grain yield and biomass yields were recorded after drying and threshing of produce. Plant and grain samples were ground and analyzed for N concentration with the Kjeldahl method. The N content of each fraction was calculated as the product of N concentration by its biomass. The partial factor productivity of nitrogen use was calculated as the ratio of grain yield to fertilizer applied.

Statistical Analysis

Statistical analysis was executed using the general linera model of SAS PROC GLM (SAS software 9.1, SAS Institute Ltd., USA) for the analysis of variance as per split plot design. Duncan's multiple range test (DMRT) was used to compare treatment means.

Results and discussion

Weather Conditions

The weather data (**Figures 1** and **2**) deviated from the 30 years normal data during the 2 year of the study had shown a wide variation for rainfall and pan evaporation in this region. There was sufficient sunshine and high temperature to acquire enough heat units to reach physiological maturity. There was shortage of rainfall during the second year (2013) of study period in comparison to normal rainfall data.

Soil pH, Electrical Conductivity and soil organic carbon

The perusal of data reveal that subsoil compaction and nitrogen fertilization had no significant effect on the pH of soil in 0-15 cm soil depth (**Table 1**), however subsoil compaction had significantly affected the pH of 15-30 cm layer. The subsoil compaction treatment C_2 had significantly reduced the pH of soil by 0.2 units than that in C_0 treatment, while C_1 treatment had pH at par with C_0 and C_2 treatments. Nitrogen fertilization had not significantly affected the pH of 15-30 cm soil. Glab and Gondek [10] (2012) also reported similar findings. Bhandral et al. [7] attributed the change in pH to a low level of nitrification in the compacted soil that may have resulted in the release of lesser protons to the soil system.

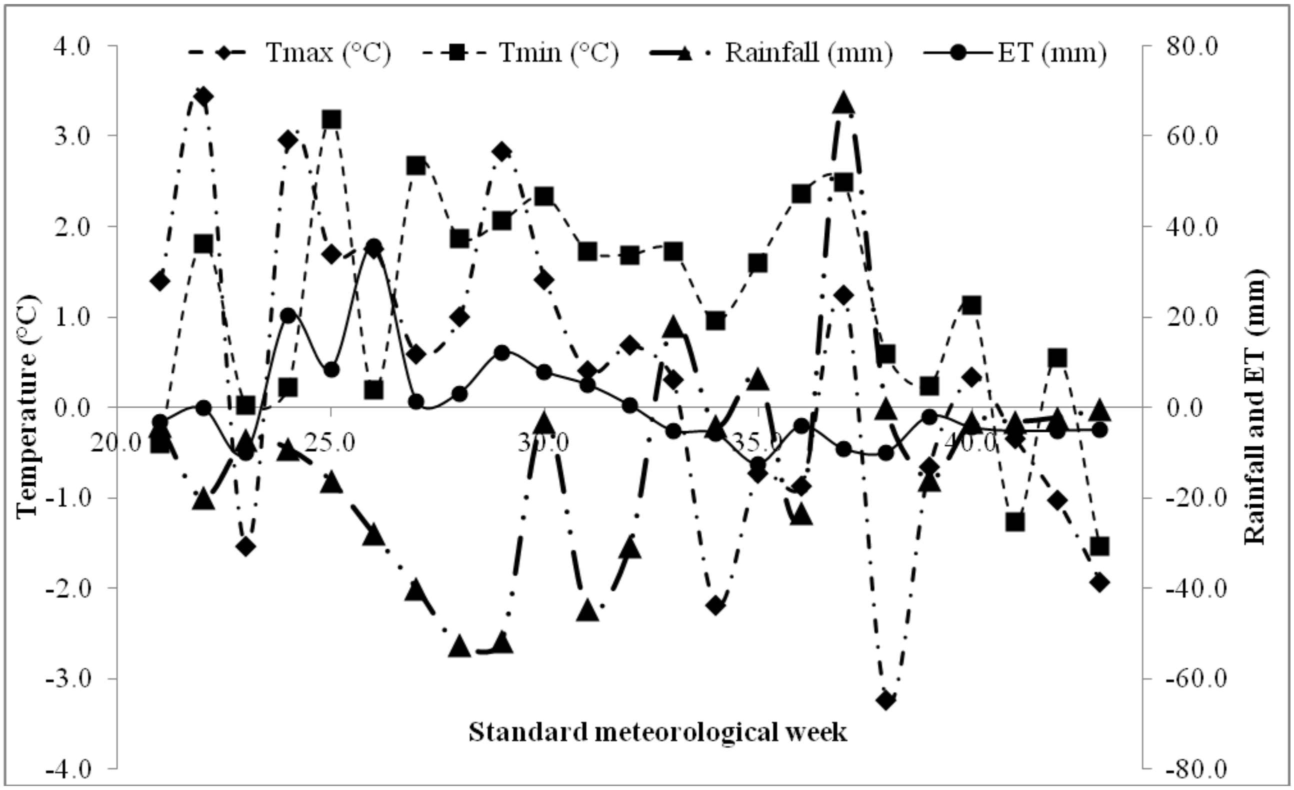

Figure 1 Rainfall, pan evaporation, minimum and maximum temperature deviation from normal data during 2012

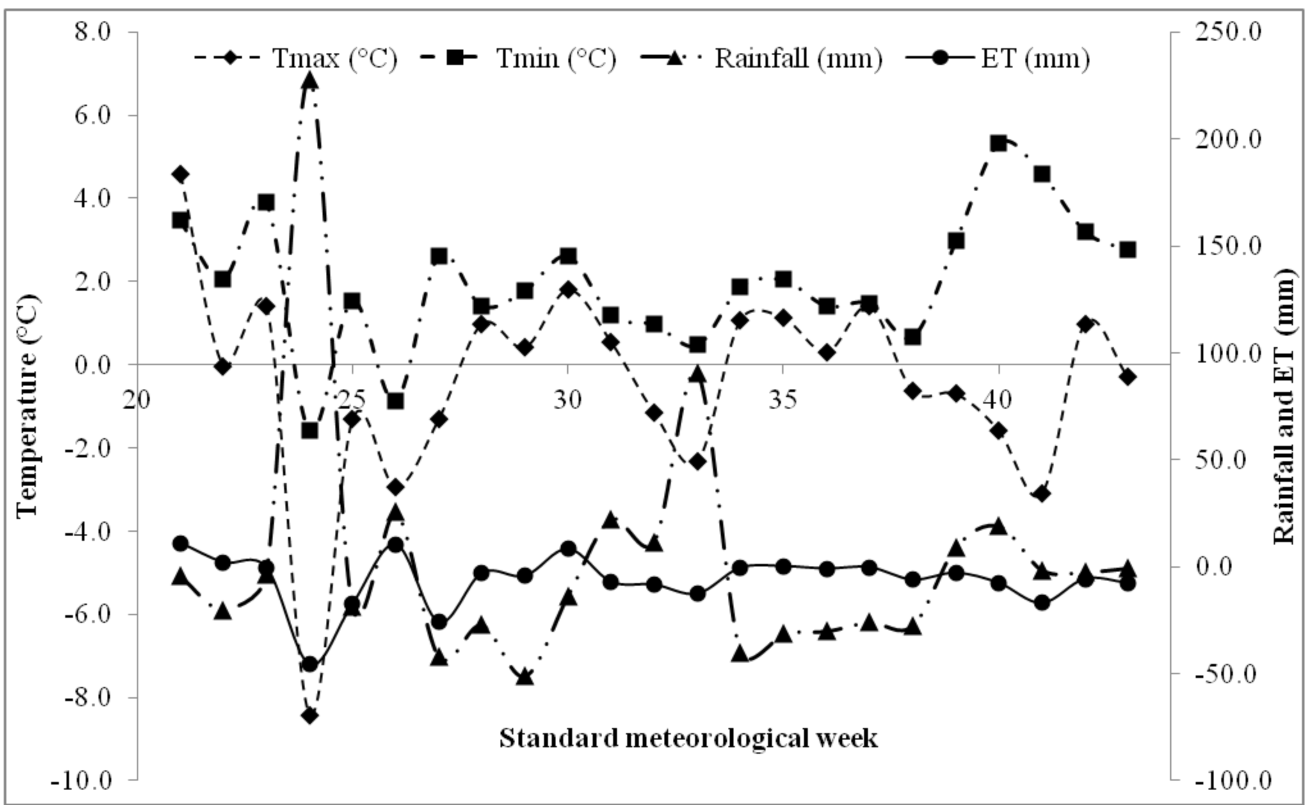

Figure 2 Rainfall, pan evaporation, minimum and maximum temperature deviation from normal data during the year 2013

The statistical analysis of the data regarding electrical conductivity (EC) showed significant increase in the EC of 0-15 and 15-30 cm layer of the soil (Table 1). However, nitrogen fertilization had non-significant effect on the EC. A significant interactive effect of subsoil compaction and nitrogen fertilization in 15-30 cm layer was observed after the harvesting of the maize crop in the year 2013. Significantly higher soil EC was also observed by Glab and Gondek [10] and Motavalli et al. [9] under compacted soils.

Figure 1 pH and EC of experimental site after the crop harvesting in the year 2013

Treatments	**pH**		**EC (dS m^{-1})**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**
C_0	7.63a	7.80a	0.039b	0.038b
C_1	7.61a	7.67ab	0.055a	0.056a
C_2	7.59a	7.60b	0.052a	0.053a
p-value C	0.47	0.029	0.014	<0.01
N_0	7.63a	7.67a	0.045a	0.050a
N_1	7.61a	7.66a	0.055a	0.049a
N_2	7.59a	7.75a	0.047a	0.049a
p-value N	0.47	0.33	0.12	0.97
p-value C X N	0.40	0.72	0.11	0.001

The data on soil organic carbon content of the soil after the harvesting of maize during both years has been given in **Table 2**. The data revealed that the soil organic carbon was higher in the compacted subsoils than that in uncompacted subsoils. There was an increase in the soil organic carbon of the 0-15 cm layer under higher degree of subsurface compactness after the harvest of the maize in the year 2012 and 2013. The soil organic carbon in both years declined with the increase in the soil depth. The increase in the soil organic carbon in the surface layer of compacted soil may be resulted from more root biomass in surface layer of compacted soil as compared to uncompacted control. The data further revealed that the soil organic carbon was higher in the 15-30 cm soil layer after the maize harvest during the year 2012-13 might be due to the inversion of soil resulted from the imposition of the treatments as the top soil was removed for applying subsoil compaction treatments. De Neve and Hofman [8] also reported depression in C mineralization rate in compacted soil condition which may have led to higher accumulation of organic matter under compacted conditions as compared to uncompacted soils.

Table 2 Effect of subsoil compaction and N fertilization on Soil Organic Carbon (%)

	2012			**2013**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
C_0N_0	0.41	0.11	0.11	0.37	0.17	0.08
C_0N_1	0.42	0.10	0.14	0.36	0.18	0.11
C_0N_2	0.41	0.08	0.10	0.41	0.26	0.13
C_1N_0	0.44	0.27	0.17	0.38	0.26	0.07
C_1N_1	0.49	0.14	0.16	0.42	0.16	0.13
C_1N_2	0.48	0.18	0.12	0.44	0.12	0.09
C_2N_0	0.50	0.28	0.13	0.45	0.23	0.12
C_2N_1	0.55	0.31	0.16	0.48	0.28	0.21
C_2N_2	0.52	0.25	0.12	0.47	0.14	0.11

Effect of subsoil compaction and nitrogen fertilization on Macronutrient status of soil

Nitrogen is considered as one of mobile nutrients in soil and plant system, however, nitrogen content in soil system is influenced by a number of factors including soil physical properties, soil moisture, soil organic carbon status, microorganisms, crops, etc. Nosalewicz and Nosalewicz [11] reported that soil compaction may enhances denitrification processes that resulted in nitrogen losses. The perusal of data showed decrease in ammonical nitrogen with increase in depth. Subsoil compaction had resulted in higher ammonical nitrogen in 0-15 and 15-30 cm layer (**Table 3**), while lower ammonical-N in 30-45 cm layer under C_2 treatment as compared to C_1 and C_0 treatments during the year 2012. However, Nitrate-N content of 0-15 and 15-30 cm layer was higher under C_2 treatment as compared to C_0 and C_1 treatments. Nitrate-N was also lower in 30-45 cm layer under C_2 subsoil compaction level. Nitrogen fertilization had significantly affected the Ammonical and nitrate-N in the soil after the harvest of maize during the year 2012. A significantly higher Ammonical-N was found under N_2 level of N fertilization than that in N_0 and N_1 treatment at 0-15, 15-30, 30-45 cm layer during the year 2012. A positive interactive effect was observed between subsoil compaction and N fertilization at 30-45 cm soil depth for ammonical nitrogen. Nitrate-N was not significantly affected by N application at 0-15 cm depth, however significantly higher Nitrate-N was observed at 15-30 and 30-45 cm layer under N_2 rate of N application as compared to N_0 and N_1 rates. All the interactive effect was no-significant for Nitrate-N during the year 2012.

Table 3 Effect of subsoil compaction and N fertilization on Ammonical (NH_4^+ -N) and Nitrate (NO_3-N) nitrogen content (kg/acre) of soil after the maize harvest in the year 2012 and 2013. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

	NH_4^+ -N						**NO_3-N**					
	2012			**2013**			**2012**			**2013**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
C_0	13.02b	10.96b	8.16a	13.16a	10.05b	9.73a	5.33c	8.64b	7.44a	6.66c	4.05b	5.00a
C_1	13.63ab	12.92ab	5.83b	11.84ab	10.73b	7.73ab	8.61b	9.03ab	6.66a	9.50b	5.19a	4.22b
C_2	15.80a	15.34a	6.61c	9.38b	11.96a	6.92b	12.16a	10.20a	3.88b	11.61a	5.76a	3.52c
p-value C	0.044	0.053	<0.001	0.08	0.001	0.034	<0.001	0.04	0.006	<0.001	<0.001	0.001
N_0	10.04c	11.34b	6.22b	9.22a	10.62a	6.87b	8.72a	6.92c	3.94b	8.00b	4.32b	3.30b
N_1	14.10b	12.27ab	6.22b	11.51ab	11.10a	9.54a	8.11a	9.16b	6.61a	9.61a	4.67b	4.88a
N_2	18.32a	15.61a	8.16a	13.66a	11.01a	7.96ab	9.27a	11.84a	7.44a	10.16a	6.00a	4.55a
p-value N	<0.001	0.048	<0.001	0.04	0.48	0.049	0.19	<0.001	0.007	0.008	<0.001	<0.001
p-value C x N	0.58	0.74	<0.001	0.68	0.17	0.47	0.07	0.065	0.083	<0.001	<0.001	<0.001

Ammonical-N was not significantly affected by subsoil compaction at 0-15 cm depth, while significantly higher Ammonical-N was recorded under C_2 treatment as compared to C_1 and C_0 treatments at 15-30 cm depth (Table 3) during the year 2013. Higher ammonical-N was recorded C_0 treatment than that in C_2 and C_1 treatments at 30-45 cm depth. Soil Nitrate-N content was significantly affected by subsoil compaction and nitrogen fertilization at all the depth, however interactive effect of subsoil compaction and nitrogen fertilization were also significant at 0-15, 15-30 and 30-45 cm depth. A significantly higher nitrate-N was observed under C_2 treatment at 0-15 cm depth than that in C_0 and C_1 treatments, while nitrate-N under C_1 and C_2 treatment were not significantly different at 15-30 cm. However, nitrate-N was significantly lower under C_2 than that in C_0 and C_1 treatments at 30-45 cm soil depth. The N_2 level of N application had left more nitrate-N in soil after the maize harvesting in the year 2013 at 0-15, 15-30 and 30-45 cm depth. At 0-15 and 30-45 cm soil depth N_1 and N_2 treatments had statistically similar nitrate-N, while at 15-30 cm soil depth nitrate-N concentration was at par among N_0 and N_1 treatment. The interactive effect of subsoil compaction and nitrogen fertilization on soil nitrate-N was significant at 0-15, 15-30 and 30-45 cm soil depth during the year 2013. The nitrate-N was higher under high degree of subsoil compaction and higher rates of nitrogen application.

Table 4 Effect of subsoil compaction and N fertilization on Available Phosphorus and available Potassium status of soil during the year 2012 and 2013. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

	Available Phosphorus (kg/acre)						**Available Potassium (kg/acre)**					
	2012			**2013**			**2012**			**2013**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
C_0	1.12b	1.32a	1.01a	1.96a	1.24b	0.90a	160.8a	173.2b	153.1b	165.7b	178.1b	171.4a
C_1	1.44a	1.40a	0.43b	2.24a	1.45a	0.64b	159.4a	183.7ab	164.8ab	174.2ab	181.8b	164.3ab
C_2	1.52a	1.12b	0.51b	2.49a	1.50a	0.96a	152.4a	196.6a	180.7a	180.0a	203.0a	159.2b
p-value C	<0.01	<0.01	<0.01	0.11	0.021	0.037	0.09	0.06	0.06	0.02	0.03	0.06
N_0	1.26c	1.31a	0.63a	1.97a	1.55a	0.99a	150.9b	180.8a	165.3a	179.8a	179.2b	157.0b
N_1	1.36b	1.29a	0.62a	2.34a	1.32b	0.76a	158.3ab	186.2a	163.8a	173.3ab	178.5b	162.1b
N_2	1.46a	1.24a	0.71a	2.38a	1.31b	0.74a	163.4a	186.4a	169.5a	166.8b	205.1a	175.8a
p-value N	<0.01	0.52	0.29	0.19	0.023	0.09	0.02	0.77	0.85	0.06	0.02	0.01
p-value C x N	0.068	0.12	<0.01	0.054	0.066	0.22	0.19	0.199	0.71	0.074	0.10	0.61

The perusal of data regarding phosphorus content (**Table 4**) of soil after the harvesting of maize during the year 2012, showed that phosphorus content of 0-15 cm soil depth was significantly higher under C_2 treatment as compared to C_0 treatment, while phosphorus content under C_2 treatment was significantly lower at 15-30 and 30-45 cm soil depth than that in C_0. Significantly higher P content was recorded under N_2 treatment than that in N_0 and N_1 treatment at 0-15 cm soil depth. However, N application had not significantly affected the P content at 15-30 and 30-45 cm soil depth. The interactive effects of subsoil compaction and nitrogen fertilization on soil P were non-significant at all soil depths except 30-45 cm soil depth during the year 2012. During the year 2013, Soil P content was significantly higher under C_2 treatment at 15-30 and 30-45 cm depth; however, the difference among subsoil compaction treatments was non-significant at 0-15 cm soil depth. N_0 treatment had recorded significantly higher soil P at 15-30 cm soil depth, while at 0-15 and 30-45 cm soil depth the difference among N fertilization treatments for soil P was non-significant. The interactive effect of subsoil compaction and nitrogen fertilization on soil P was non-significant during the year 2013. The subsoil compaction and nitrogen fertilization has not significantly affected the available potassium content (Table 4).

Effect of subsoil compaction and nitrogen fertilization on Micronutrient status of soil

The data regarding the Cu, Fe, Mn and Zn concentration in soil (**Table 5**) at 0-15, 15-30 and 30-45 cm soil depth after the harvesting of maize after the completion of the 2-year does not show any trend toward the distribution of Cu, Fe, Mn and Zn content in response to subsoil compaction and nitrogen application. The data further revealed that the available Cu, Fe and Mn content were higher under higher degree of subsoil compaction as compared to no subsoil compaction. However, the available Zn content was found lower in the higher subsoil compacted condition.

Table 5 Micronutrient status of soil after the harvesting of the crop during the year 2013

	Cu (ppm)			**Fe (ppm)**			**Mn (ppm)**			**Zn (ppm)**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
C_0N_0	0.189	0.198	0.229	2.049	1.1554	0.907	0.485	0.358	0.396	3.176	0.705	0.251
C_0N_1	0.217	0.289	0.316	2.815	1.573	1.430	0.797	0.550	0.716	3.338	0.888	0.297
C_0N_2	0.216	0.283	0.299	3.425	2.4086	1.772	0.903	0.738	0.891	7.392	1.269	0.294
C_1N_0	0.362	0.412	0.397	5.325	4.9746	1.222	0.579	0.682	0.694	2.366	1.078	0.246
C_1N_1	0.325	0.338	0.236	4.385	1.2788	0.951	0.581	0.539	0.726	1.732	0.421	0.119
C_1N_2	0.371	0.434	0.311	5.183	3.5046	0.829	0.529	0.667	0.853	1.764	0.758	0.209
C_2N_0	0.326	0.299	0.180	5.015	1.9466	0.858	0.586	0.596	0.615	2.782	0.765	0.195
C_2N_1	0.296	0.269	0.195	4.267	2.0586	1.088	0.615	0.423	0.454	2.890	0.947	0.414
C_2N_2	0.281	0.198	0.168	3.651	1.0828	1.026	0.549	0.527	0.573	2.000	0.423	0.191

Effect of subsoil compaction and N fertilization on N uptake and factor productivity

The data revealed (**Table 6**) that the grain N content was not significantly affected by the subsoil compaction and nitrogen application during the year 2012, however significantly higher grain N content was observed in the treatment C_2 than that in C_0 treatment. The straw N content was not significantly affected by the subsoil compaction and nitrogen application during the year 2012 and 2013. The data on grain and straw N uptake revealed highest N uptake under C_0 treatment and least in the treatment C_2, while highest grain and straw uptake with application of higher dose of N. The total N uptake was significantly affected under higher degree of subsoil compaction (C_2), however data revealed that the total N uptake improved with the application of higher dose of N. The data on the total N uptake followed almost similar trend as the of grain and biomass yield (**Table 7**). The maize yield losses under higher degree of subsoil compaction as compared to uncompacted subsoils might be attributed to limited oxygen, nutrient supply and restricted root expansion [12, 13]. Schuler and Lowery [14] reported corn yield decreased up to 40%, partially due to subsoil compaction on silty clay soil. In a study, Singh and Hadda [15] also reported maize yield reduction of 10-17 per cent due to subsoil compaction.

Table 6 Effect of subsoil compaction and N fertilization on grain and yield N content during the year 2012 and 2013. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

	Grain (%)		**Straw (%)**		**N uptake grain (kg ha^{-1})**		**N uptake straw (kg ha^{-1})**		**Total N uptake (kg ha^{-1})**	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
C_0	1.673a	1.697a	0.635a	0.638a	105.64a	93.17a	108.09a	95.7a	213.75a	188.87a
C_1	1.702a	1.723a	0.639a	0.649a	97.52b	75.93b	102.18ab	89.9b	199.70b	165.83b
C_2	1.713a	1.764a	0.646a	0.658a	91.14c	73.25b	95.26b	86.5b	186.39c	159.75b
p-value C	0.21	0.08	0.63	0.33	<0.01	<0.01	0.04	<0.01	<0.01	<0.01

N_0	1.694a	1.723a	0.625a	0.640a	91.46c	74.78b	91.19b	85.08c	182.65c	159.86b
N_1	1.686a	1.731a	0.645a	0.649a	97.00b	80.231ab	103.45a	90.78b	200.45b	171.02ab
N_2	1.707a	1.731a	0.649a	0.656a	105.8a	87.34a	110.89a	96.23a	216.74a	183.57a
p-value N	0.63	0.94	0.12	0.51	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
p-value C X N	0.92	0.85	0.71	0.74	0.41	0.94	0.99	0.14	0.94	0.75

Table 7 Grain yield, biomass yield and partial factor productivity (PFP_N) of maize under different subsoil compaction and nitrogen treatments. Different letters in each column of experimental factors show significant differences at < 0.05 probability level

Treatments	Grain yield ($t\ ha^{-1}$)		Biomass yield ($t\ ha^{-1}$)		Partial Factor Productivity ($Kg\ ha^{-1}\ kg^{-1}$ N applied)	
	2012	2013	2012	2013	2012	2013
C_0	6.31a	5.49a	16.99a	15.00a	82.0a	71.5a
C_1	5.74b	4.39b	15.96ab	13.83b	74.3b	56.8b
C_2	5.33b	4.16b	14.69b	13.13b	69.5b	54.0b
p-value C	0.002	0.0003	0.016	0.0004	<0.01	<0.01
N_0	5.40a	4.35b	14.53b	13.28b	86.4a	69.5a
N_1	5.76ab	4.65ab	16.12a	13.98b	73.4b	59.2b
N_2	6.21a	5.05a	17.00a	14.72a	66.1c	53.7b
p-value N	0.01	0.038	0.009	0.003	<0.01	<0.01
p-value C X N	0.65	0.99	0.96	0.44	0.79	0.79

The partial factor productivity (PFP_N) reveals the information on productivity of treatment. The data on partial factor productivity (Table 7) shows decline in PFP_N with application increase in the bulk density of subsoil, similarly with the application of higher doses of the nitrogen.

Conclusion

The present investigation revealed that the subsoil compaction has no significant effect on the soil pH, EC, however macro and micro-nutrients were affected in response to the subsoil compaction and nitrogen fertilization. The soil organic carbon was found higher in the compacted subsoils than that in uncompacted subsoils. The subsoil compaction had resulted in higher ammonical N in 0-15 and 15-30 cm layer, while lower ammonical-N in 30-45 cm layer under C_2 treatment than C_1 and C_0 treatments. The grain and biomass yield were significantly higher in the low subsoil compaction level (C_0) and higher rate of N application(N_2). The data also showed that the partial factor productivity (PFP_N) declined under higher degree of subsoil compaction and also under higher nitrogen application rates.

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