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Influence of soil strength on wheat (*Triticum aestivum*) growth under prolonged tillage

KUMARI CHANCHALA PRIYA[1], INDRA MANI[2], ROAF AHMAD PARRAY[3], P K SAHOO[4], D K SINGH[5], K K BANDYOPADHYAYA[6] and SUSHEEL KUMAR SARKAR[7]

ICAR-Birsa Agricultural University, Ranchi, Jharkhand 834 006, India

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ABSTRACT

Tillage enhances soil physical condition which favors root growth and crop productivity. Though, continuous rotary tillage at same depth leads to the formation of plough pan which slowdown crop productivity. Some serious speculations have been made about rotary tillage that in long run it induces subsoil compaction. This study was conducted at farmers' field in Malhendi , Shamli (UP) to investigate the effect of prolonged use of rototilling with special attention to subsoil compaction. The experimental sites were under rotary tillage (RT) under wheat for last 15 years under rice-wheat cropping system which compared with conventional tillage (CT-cultivator harrow). The crop growth and yield was reduced under RT due high mechanical impedance and BD in deeper layer as compared to CT. In upper soil strata (5-15 cm) the cone index of RT (505kPa-2057kPa) soils are lesser than that of CT (625-2257kPa) while in subsoil layer (45cm) it becomes severe under RT(4578 kPa) compared to CT (2468 kPa). Similar trend found in bulk density under both tillage treatments. The bulk densities observed before tillage at 0-15cm, 15-30 and 30-45cm depth were 1.50 Mg/m^{3}and 1.56 Mg/m^3,1.37 Mg/m^{3}for CT 1.42 Mg/m^3 1.67 Mg/m^{3}and 1.81 Mg/m^3 for RT respectively. The grain yields were (5909 kg/ha) and (4594 kg/ha) under CT and RT tillage system respectively. The CT system well performed in plant height, no of tillers and root growth characteristics, viz. root length density, root volume than that of RT. Performing studies shows that long-term RT induced subsoil compaction which needs some amelioration tillage management.

Key words: Bulk density, Mechanical impedance, Rotary tillage, Subsoil compaction

Soil tillage has vital role in root growth, nutrient uptake and overall crop productivity. Though intensive tillage at same depth causes sub soil compaction and formation of hard pan. Subsoil compaction enhances the soil strength at detrimental level which hindered root growth and leads to reduces nutrients uptake crop production. Rotary tillage has enormous potential for cutting, mixing topsoil and preparing the seedbed directly. It can be is used as both the primary and secondary tillage machine, besides it mixing ability of rotavator is seven times more than that of a plough (Matin 2015). Moreover it saves time (30-35% saving), labour and fuel, thereby reducing cost by 20-25 % (Shiva *et al.* 2014) as well creates 25-30 % higher quality seed beds than conventional tillage methods (Sirisak *et al.* 2010). Besides having several benefits there are certain negative impacts of rototilling in terms of soil compaction. Grubinger (2007) in their study reported that rotary tillage in its long run effects on the destruction of soil aggregate. Besides it, the churning effect of rotary tillage tools in the plough layer destroy the structure by exposing the soil organic matter to air making it dense and compact (Neal *et al.,* 2015). Nigel and James (2004) reported that, too many passes of rotavator operation destruct the soil structure and affects the seedling emergence and root growth. Subsoil compaction restricts the root proliferation and spreading, and thus limits the availability of nutrient and water resources in subsoil to the crops (Bengough *et al.* 2011). Inappropriate soil management, viz overuse of machinery, intensive tillage, short crop rotations, (Batey 2009) are associated with some naturally-formed restrictive layers in soils (Gao *et al.* 2016). The sub soil compaction decreases the agronomic yield due to inhibition of root proliferation (Batey 2009, Mu *et al.* 2016).Since rototilling has become very common in Indo Gangatic plain of India repeatedly use of rotary tillage in this region might cause subsoil compaction which ultimately affects productivity. Keeping in view of above points an investigation carried out to study the extent of compaction

[1]Assistant Professor and Junior Scientist (chanchalapriya.rau@gmail.com), College of Agricultural Engineering, BAU, Ranchi; [2]Head (maniindra99@gmail.com), [3]Scientist (rouf.engg@gmail.com), [4]Principal Scientist (sahoopk1965@gmail.com), [5]Professor (dksingh@iari.res.in), Division of Agricultural Engineering, [6]Principal Scientist (kk.bandyopadhyay@gmail.com), Division of Agricultural Physics, ICAR-IARI, New Delhi; [7]Principal Scientist (susheel@iasri.res.in), Design of Experiments, ICAR-IASRI, New Delhi.

caused by prolonged use of rotary tillage.

MATERIALS AND METHODS

Experimental Details: The objective of this experiment is to evaluate the long-term impact of rotary tillage practices on subsoil compaction in rice-wheat cropping system of Indo Gangatic Plain. The study was carried out during 2016-2018 at farmers' fields in Uttar Pradesh (Malhendi) where long-term rotary tillage are being used in rice–wheat cropping system. The region has average temperature range is 28–38°C and average annual rainfall is 869 mm. The mean monthly relative humidity is 67%. The mean wind velocity is 6.70 km/h. The soil was sandy loam with 69.5% sand 13.2% silt and 17.3% clay and carbon percentage 0.51 percent pH 7.76 with other chemical properties as listed in Table 1. The field experiment was laid out in randomized block design with three replications of two tillage systems rotary tillage (RT) and conventional tillage with cultivator-harrow (CT). Five plots of 1 m × 1 m were randomly selected and marked in each replication of tillage treatments and samples collected to study of soils properties and crop response. For all experiments, the cultural practices adopted according to package of practice of the region.

Soil sampling and processing

Soil physical properties: All the soil properties are measured as per standard procedure before tillage (BT), after tillage (AT), 30 DAS, 60 DAS and 90 DAS. Bulk density samples of 0–15, 15–30, 30–45 and 45-60 cm soil layers were taken by using a core auger of 5 cm core diameter. Soil penetration resistance was measured by Daiki 5532 cone penetrometer which could measure, the maximum value of PR up to 5000 kPa; and maximum depth of penetration was 90 cm. Soil moisture was measured using digital soil moisture meter (TDR) at desired depths simultaneously with soil strength measurement and along soil sampling for bulk density.

Biometric observation: A representative hill was selected and tagged in the each marked plot of all replications and treatments for subsequent observations. In each plot, five readings were taken from each one meter square area of previously marked and selected for the tiller number. The grain weight was recorded after cleaning and drying at 14 % moisture content. The grain yields were expressed in kg/ha. Root sampling were taken only once at grain filling stage (100 DAS). A root auger of 7 cm diameter was used to take root samples at 15 cm interval up to 120 cm of soil profile. The root samples were soaked overnight in water containing sodium hexametaphosphate in small amount in a pail (Aggarwal and Sharma 2002). Roots were then separated by carefully passing the decanted water over a fine sieve and root samples scan with RHIZO system.

Statistical analysis: The data were analyzed using the randomized block design analysis in SAS 9.4 (Indian NARS Statistical Computing Portal). Means were compared using significant difference where the analysis of variance was significant at $P<0.05$ (Duncan LSD). Multiple regression equations were developed using bulk density, soil moisture content and Penetration resistance recorded for different depth of soil layers

Table 1 Physicochemical properties of the soil

Property	Values
*p*H	7.76
EC (dS/m)	0.65
Organic carbon (%)	0.51
Bulk density (Mg/m^3)	1.43
Textural class	Sandy loam
Available N(kg/ha)	123
Available P (kg/ha)	20.8
Available K (kg/ha)	245

RESULTS AND DISCUSSION

Effect on soil physical properties

Soil bulk density: Bulk density plays a vital role in root development and indicator of soil health. The bulk density observed before tillage in CT was 1.53 Mg/m^3 and 1.42 Mg/m^3 for that of RT at 0-15cm depth, whereas at 15-30 cm soil depth, rotary tilling had bulk density of 1.67 Mg/m^3 and that of for CT was 1.56 Mg/m^3. In spite at depth of 30-45cm, rotary tilling resulted in bulk density of 1.8 Mg/m^3 and 1.37 Mg/m^3 at below 45 cm. The corresponding values of bulk density observed under CT were 1.48 and 1.35 Mg/m^3. Besides the BD after tillage improved in upper layers of soil strata and was found more effective in RT than CT. BD of soil under RT for 0–15 cm was less than CT at all phase either before tillage or after tillage. However there was higher bulk density after and before tillage under RT than CT at the depths of 15-45 cm, particularly in 30-45 cm depth leading to the compacted soil layer below the tilling depth. The bulk density below 45 cm depth was found less significant. BD of surface soil (0–15 cm) increased gradually from sowing to harvest (Fig 1). Increase in BD with time indicated increase in soil compaction with time, which could be due to settling of soil after tillage or breaking up of the aggregates under the influence of irrigation or rainfall.

Soil penetration resistance: The soil penetration resistance (PR) which measures the soil compaction is influenced by the soil management practices. The results of present investigation revealed that rotary tillage (RT) induces high soil penetration resistance as compared to conventional tillage (CT) especially of sub surface soil (Fig 2). In upper soil strata at depth of 5-15 cm, the cone index of RT (505 kPa-2057 kPa) soils are lesser than that of CT (625-2257 kPa). This could be due to fact that the rotavators excessively pulverize the soil. While in subsoil layer there was high mechanical impedance under RT and the maximum value was 4578 kPa at 45 cm and 2468 kPa in CT at 35 cm depth further below 55 cm there is decrease in impedance and was non-significant to each other. The soil cone index values more than 2 MPa is assumed to be

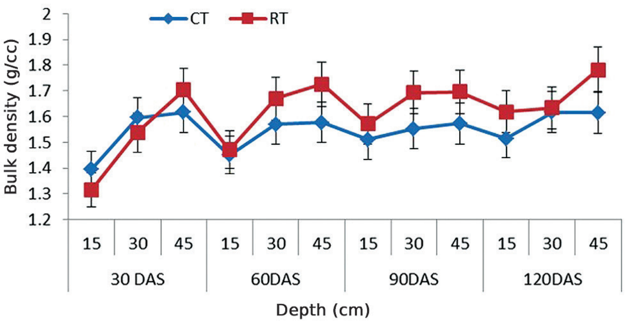

Fig 1 Temporal variation of bulk density at different depths.

yield limiting for all soils (Vepraskas 1994).

Soil moisture retention: The soil moisture retention indicates the total porosity and pore size distribution of the soil. The lower values of soil moisture in sub surface layer sub surface soil layer (30-45 cm) under RT (Fig 3) indicated a low volume of medium-sized water-holding pores due to more compaction. While the higher values of soil moisture in CT System indicated a higher volume of medium-sized water-holding pores due to more aggregation in soil particles. The compaction effect of RT System was found more pronounced at sub surface soil layer (30-45 cm). Distribution of moisture content have different pattern at different depth. This occurred due to variation in water holding macropores lower rates for different depths.

Statistical analysis: In order to evaluate the relative importance of the bulk density (BD) and soil water content (SWC) and soil depth (DEP) on soil penetration resistance (PR), multiple regression analysis had been done. The linear regression of penetration resistance (PR) on other soil properties using data from all the treatments under RT and CT showed that penetration resistance increased linearly with increase in bulk density (BD) and also with decrease in soil water content and soil depth.

Multiple regression equation for:

(1) RT System: $PR = -4813.12 + 4404.42 \times BD - 40.3559 \times SWC - 11.27892 \times DEP$-------3.1
R^2= 0.85 for Rotary Tillage(RT) System (Calculated t-value for *BD*=1.9, *SWC*=-0.45, and DEP=0.70)

(2) CT System: $PR = -1889.77 + 2870.992 \times BD - 52.9793 \times SWC - 16.7318 \times DEP$-------------3.2

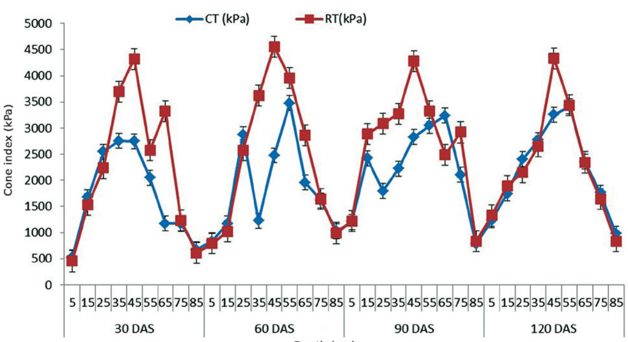

Fig 2 Temporal variation of penetration resistance at different depths.

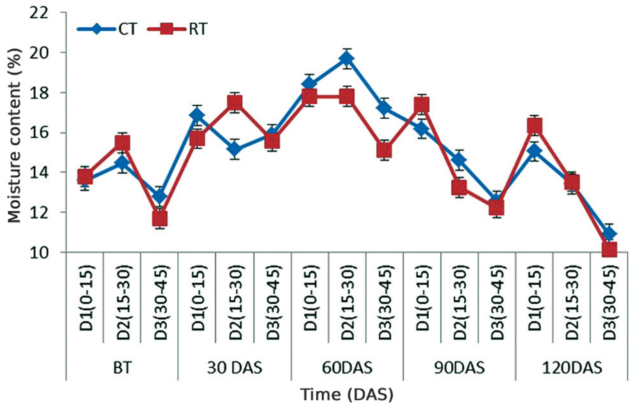

Fig 3 Soil moisture content variation at different depth and time.

R^2= 0.83 for Conventional tillage (Cultivator Harrow – CT) System
(Calculated t-value for *BD*=2.7, *SWC*=-0.73, and DEP=1.54)

Multiple correlation: In above described regression model (equations 3.1 and 3.2) for predicting PR (dependent variable) as a function of SWC, BD and DEP (input variables) showed that a correlation of -0.037 to -0.083 existed between PR and SWC, 0.82 to 0.83 between PR and BD and 0.0.42 to -0.57 between PR and DEP. Similar trends were reported by Grunwald *et al*. (2001).

Rooting characteristics: The mechanical impedance has significant role on early emergence and root development. Results assess the effects of different mechanical impedance due to subsoil compaction under RT System. Proportions of root growth revealed that; the maximum root dimensions were observed for plants grown under CT, than that of RT. The results are in agreement with Loades *et al*. (2013). The root length density was decreased after 15 cm depth of soil due to high mechanical impedance caused by subsoil compaction under rototilling. Approx. 65-70% roots were confined in the upper layer and only 30-35% below 30 cm of soil layer. Root length density for 0-15 cm and 15-30 cm layer was significantly lower under RT than that of CT. Again, root volume density in 0–30 cm of conventional system was mainly as compared due to rotary tillage system the fact that favorable mechanical impedance and upper 0–20 cm of CT were looser than that of rotary tillage system.

Vegetative characteristics: There was decrease in plant height was observed under RT than that of CT. At the time of harvesting maximum plant height of 109 cm was observed in CT, whereas in highly compacted plot under RT the same was 103 cm. Whereas in 30 DAS, 60 DAS and 90 DAS plant height were 32.6 cm, 49.5cm and 86.6 cm respectively while that of under RT were 30.5 cm, 43.6 cm and 83.3 cm respectively. Conventional tillage has significantly increased yield of wheat due to significant increase in grains/spike and test weight as compared to rotary tillage system. Similar results were reported by Schillinger (2001).Similar to other plant growth factor yield of wheat in RT decreased than that of CT. The yield were found 59.09 q/ha and 45.94 q/

ha under CT and RT respectively while test weights were found 49.48 and 38.21g . The no. of spikelets were found 292 and 268 under CT and RT respectively. The results thus indicated that surface soil of CT was less compacted and lesser mechanical impedance was offered to growing roots results in higher RLD which favored increased vegetative growth under CT.

The results from the study showed that the high PR and BD affected both the above- and below-ground growth of winter wheat. However moderate subsoil compaction produced the highest yield which was consistent with the result of who also reported that moderate soil compaction allowed the crop root to extract adequate resources. However, when soil BD was increased to threshold value, further increase in BD in the plough pan tended to reduce soil water availability and increase the root penetration resistance, thereby, adversely affected root growth. The experiment was conducted with a view of assessing the effects of prolonged use of rotary tilling on soil structure, soil strength and also, their effect on crop root growth. The effect of large number rotary tilling passes resulted increased the soil bulk density and cone index at the soil depths of 15-30 cm, leading to the compacted soil layer below the tilling depth. Results indicated that prolonged use of RT causes a hardpan in the subsurface layer which leads to decrease in yield because it affects the root growth. In this situation some other measures like sub soiling along with RT needed to sustainable option.

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