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Impact of different tillage practices on soil biochemical parameters, root and shoot growth and yield attributes of winter wheat

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Abstract
Higher frequency of heavy machinery on farm land leads to formation of hard pan in soil retarding proliferation of roots. We analysed the growth parameters of root and shoot of wheat sown under no tillage, reduced tillage and deep tillage systems. Physicochemical properties, microbial count of soil, and parameters of shoot and root growth were recorded.
The N, P, K content of soil was almost similar in all the treatments up to 30 cm soil depth. Soil moisture content, plant height, and tiller numbers were significantly higher under deep tillage. However, harvest index and 1000-grain weight were similar in all the treatments. Root length and root surface area at 10-20 cm and root volume at 0-10 cm soil depth were higher under deep tillage. This shows that, both root and shoot growth parameters can be improved by adopting deep tillage practices that can break sub surface hard pan of soil.

Keywords: Different tillage, wheat, deep tillage, soil physicochemical properties, root surface area density, root volume density

Introduction

Wheat is one of the three most important cultivated cereal crops along with rice and maize which meets more than 60% of the energy and 30% of the total protein demand of more than 3 billion people [1, 2, 3]. The genetic variability of wheat enables it to be grown on over 220 million hectare of land under diverse climatic conditions, from temperate, irrigated to dry and high-rain-fall areas and from warm, humid to dry and cold environments with gross production of about 748.8 million tonnes [3]. The demand of wheat production is required to increase from 5 tons/ha from the current 3 tons/ha due to exponentially increasing population [3]. Previous work has been mainly focussed on the development of high yielding varieties by conventional breeding and biotechnology and higher application of agrochemicals. However, recent studies suggest that efforts to increase productivity through these approaches have not yielded in increased biomass production under potential growing conditions [4]. The absolute yield, based on the genetic potential of wheat is 20 tonnes/ha [5]. However, a large gap exists between wheat yields obtained in experimental field and those attained in farmers' field. The highest commercial yield reported is 14 tonnes/ha whereas the average productivity of wheat is still 3 tonnes/ha [3, 6]. The worked out increase in wheat yield is 0.9% calculated between 1961 and 2008. This is much below the desired rate of increase by 2.4% per year to meet the global population demand by 2050 [7]. Even though the use of fertilizers has led to the increased yield of fertilizer responsive cultivars, the nutrient use efficiency of most cereal production systems across the globe is only around 33% [8]. Long term assessment of wheat yield throughout Asia has shown a decreasing trend at recommended doses of N, P, K application [9, 10]. One of the most important reasons of this continued stagnation of yield and low nutrient use efficiency is improper soil management practices; a critical factor having a significant effect on the nutrient availability and water use efficiency of crops [11]. Tillage practices are employed for the preparation of seed bed that reflects in the germination percentage, seedling establishment and yield of the crop. Different tillage methods are developed and adopted for different cropping systems. In the context of north western plains of India where wheat is chiefly grown as a part of rice-wheat cropping pattern, a hard pan at deeper soil depths is usually formed over long run of heavy machines during the period of cultivation. Soil compaction is caused by repeated wheel traffic at the soil surface and formation of a hard pan in subsurface layers [12]. The problem of hard pan formation has been escalated in recent times post green revolution of late 1960's due to the introduction of heavy machinery on the fields to meet the demands of intensive cropping systems leading to compaction of soil and crusting of top layers [13].

Hard pan formation reduces the aeration and prevents penetration of roots into deeper soil layers, thus affecting the water and nutrient uptake by the roots [14]. Some soils in arid and semi-arid regions of India are naturally compacted and offer only restricted root growth. In such soils, mechanical loosening is required to improve crop growth. It could be of great benefit to break the hard pan of the soil and recent efforts have been focussed on development of alternative soil management practices such as conservational tillage practices, to reduce the frequency of heavy machinery on the field. Conservation tillage systems are systems of managing crop residues on the soil surface with minimum or no tillage. These are defined as a method of managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment [15]. Conservation tillage is any tillage system that leaves at least 30% of the soil surface covered with crop residue after planting [16]. The systems are frequently referred to as stubble mulching, eco fallow, limited tillage, reduced tillage, minimum tillage, zero-tillage and direct drill. Zero tillage and reduced tillage have in recent years been adopted as efficient technologies for soil conservation. Zero tillage was introduced to save the time required for seed bed preparation under the rice-wheat crop rotation. In recent years, the use of rotavator for field preparation is becoming popular in order to achieve minimal soil manipulation and placement of seed and fertilizer. This equipment makes field ready for cultivation with only one or two operations. Though both zero tillage (ZT) and reduced tillage (RT) are efficient in terms of saving time and cost of operation, neither of them could break the sub soil hard pan. In contrast, continued use of these techniques contributes the formation of a hard pan which restricts root growth and thus reduces the crop yield [17].

Relatively less information is available on the influence of tillage systems or seed-cum-fertilizer drills related to root growth of wheat. This is due to the difficulty associated with the acquisition of root samples from soil and their analysis being tedious and time-consuming. The mere information on root mass in different studies does not produce any concrete information on the total root length, surface area of roots as well as root surface area density and root volume density at different soil depths [18]. Changes in these parameters with the same root mass can dramatically alter root architecture affecting nutrient acquisition and crop growth [19, 20]. Recent reports on the influence of phosphorus and bio-fertilizers on wheat root growth indicate the root length density (RLD) and cation exchange capacity of roots are closely related to specific root length, root diameter and phosphorus content of roots and shoots [21]. Thus, there is need to generate information on the effect of sowing wheat with different types of ferti-seed drills on the shoot and root growth as well as yield of the crop. The aim of this study was to analyse the effects on shoot and root growth and yield attributes of winter wheat sown by three different seed-cum-fertilizer drills.

2. Material and methods

2.1. Site description

The experiment was carried out at the N.E.B crop research centre in govind ballav pant university of agriculture and technology, pantnagar (29°30'N, 79°290'E; 243.8 m above the mean sea level). The experimental site lies in the tarai plains; about 30 km southwards to the foothills of the shivalik range of the Himalayas having loam textured soil. The region experiences humid subtropical climate with hot dry summers and cool winters. Winter season extends from November to March.

2.2. Site Management and experimental design

In the present investigation, DPW-621-50 variety of wheat was sown with three different seed-cum-fertilizer drills. The drills used were Pant Zero-till seed-cum-ferti drill, Roto-till ferti-seed drill, and Pant ICAR controlled-field-traffick tiller-cum-multi crop seeder, providing zero tillage (ZT), reduced tillage (RT) and deep tillage (DT) respectively. In ZT, wheat seeds were drilled directly into the soil with Pant Zero-till seed-cum-ferti drill with a line to line spacing of 20 cm. Fertilizer was placed just below the seeds in the slit in a vertical plane. Reduced tillage was done using Roto-till ferti-seed drill in which the soil was tilled to a shallow depth and the seeds and fertilizer were placed side by side in the same horizontal plane maintaining a line to line spacing of 20 cm. similarly, deep tillage was performed using Pant ICAR controlled-field-traffick tiller-cum-multi crop seeder in which soil was tilled up to a depth of 30 cm. in DT fertilizer were placed at a depth of about 10-15 cm, and the seeds at a depth of about 5 cm from the soil surface, in a synchronized vertical plane. The experiment was laid out in a randomised block design (RBD) with eight replications per treatment. The total plot size was 30.6 m × 17.5 m divided into eight replications per treatment with a uniform length of 8 m. The width of plots varied with treatments with 1.8 m for ZT and RT and 2.5 m for DT.

2.3. Soil Sampling and Analysis

2.3.1 Soil nutrient analysis

Qualitative estimation of soil was done five days after the seed bed preparation and the physicochemical parameters were recorded. Soil samples were collected using a cylindrical soil auger (10 cm x 5 cm), five days after sowing of crop from two different soil depths viz. 0-10 cm and 10-20 cm. Nutrient content was estimated from the soil sample immediately after sample collection using a soil testing kit (Himedia Labs cat. No. K 054) according to manufacturer's protocol.

2.3.2 Soil moisture content

Soil sample was collected from two soil depths viz. 10-20 and 20-30 cm with the help of an auger (10 cm length and 5 cm radius) five days after sowing and moisture content was determined. 100 g of soil was dried in an oven at 105ºC for 48 hrs. The sample was the weighed over an electric balance and the fraction of weight loss was expressed in terms of percent moisture content of the soil. Moist soil weight

$$\text{Moisture content (\%)} = \frac{\text{moist soil weight} \;\; \text{dry soil weight}}{\text{moist soil weight}} \times 100$$

2.3.4. Shoot biomass and yield parameters

Plant height, number of tillers and shoot biomass were recorded 30 days after sowing and the yield parameters were recorded after harvesting of the crop.

2.3.3 Soil microbial count

Fresh soil samples from 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm were collected from individual plots after five days of sowing. The soil samples were stored at low temperature in deep freeze until experiment. Pour plate serial dilution method was used for estimating the population of the total microbial population in the soil. Soil samples were serially diluted up to 12 folds and aliquots of suitable dilutions were plated nutrient agar medium in triplicates. The characteristic microbial colonies developed in Petri plates of each treatment were counted manually and their mean obtained. The population of these microorganisms in soil was then computed by multiplying the mean colonies with the dilution used for counting the population.

$$\text{Viable counts (per gram soil)} = \frac{\text{Number of colonies X dilution factor}}{\text{Amount plated}}$$

2.3.4 Root Sampling and Analysis

The root samples were collected from four depths viz. 0-10 cm. 10-20 cm, 20-30 cm and 30-40 cm from the soil surface with the help of a cubical auger (20 cm × 20 cm × 20 cm), at maturation stage. The extracted soil containing the roots was dipped in sodium hexametaphosphate solution (5%) for 24 hours. The roots were then isolated and washed under running water and then subsequently collected over a 250-micron sieve and kept into plastic, sealable bags. Samples were immediately kept in the refrigerator at 4 C until further analysis. Root samples were scanned using a Hewlett Packard scanner controlled by Win-RHIZO Programme V. 2009C Software (Regent Instruments Inc. Ltd., Quebec, Canada) [19]. The samples were placed in a Plexiglas tray (200 mm 300 mm) under 4–10 mm standing water level, depending on root size and amount of sample. Root samples were manually spread on the tray before scanning to minimize overlapping.

2.3.4.1 Root length (RL)

The data on root length was obtained after the analysis done by the built-in software program of the Hewlett Packard scanner.

2.3.4.4 Root surface area density (RSAD)

Root surface area density was calculated as the ratio of surface area of the roots at a particular depth to sample core volume.

$$RSAD = \frac{\text{Rootsurface area at a particular depth}}{\text{Sample core volume}}$$

2.3.4.5 Root volume density (RVD)

Root volume density was calculated as the ratio of the volume of roots at a particular depth to sample core volume (V, cm3).

$$RVD = \frac{\text{Root volume at a particular depth}}{\text{Sample core volume}}$$

2.4 Statistical analysis

The data obtained from field trials during the course of the present investigation were analyzed statistically by using ANOVA model for randomised block design. The standard error of means and critical difference (CD) were evaluated at 5% level of significance.

3. Results

Soil nutrient status

Tillage affects the nutrient availability in the soil by modulating soil physical properties such as aggregate size, porosity, moisture content, bulk density etc. To know the relative availability of various nutrients in the soil following different tillage operations, we performed qualitative estimation of available nitrogen, potassium, and phosphorus at various depths of soil after 5 days and the data is presented in Table 1. The quantitative values are presented in Table 2. The distribution of $NH4^+$ - nitrogen under ZT increased from low at 0-10 cm depth to medium levels at 20-30 cm, and a reverse trend was recorded in DT where $NH4^+$- nitrogen levels decreased from the medium at 0-10 cm depth to low levels at 20-30 cm depth. $NH4^+$- nitrogen levels were low at all depths in RT. Nitrate-nitrogen levels were very low under all treatments at all depths. K_2O content in soil at 0-10 cm depth was higher under RT and DT as compared to ZT. There was no difference in K_2O levels between ZT and DT at 10-20 cm depth which was lower than RT. At 20-30 cm both RT and DT had higher K_2O content than ZT. Treatments did not vary among each other with respect to phosphate content at any depth and were constant at medium levels at all depths. Organic carbon was higher in DT and RT at 0-10 cm depth. Treatments did not vary with respect to organic carbon at 10-20 cm depth while at 20-30 cm depth ZT had higher organic carbon content than both RT and ZT.

Table 1: Soil physicochemical properties at various depths after five days of sowing under different tillage systems.

Nutrients	0-10 cm			10-20 cm			20-30 cm		
	ZT	**RT**	**DT**	**ZT**	**RT**	**DT**	**ZT**	**RT**	**DT**
$NH4^+N$	L	L	M	L	L	L	M	L	L
NO_3^-N	VL	VL	VL	VL	VL	VL	VL	VL	VL
K_2O	L	M	M	L	M	L	L	M	M
P_2O_5	M	M	M	M	M	M	M	M	M
Organic carbon	M	MH	MH	MH	MH	MH	MH	M	M

V= Very low; L=low; M=Medium; MH=Medium high.

Table 2: Quantitative values of soil nutrients.

Nutrient	Level in soil			
	Very low	**Low**	**Medium**	**Medium-high**
Potassium (kg/ha).	NA*	Less than 112	112-280	NA
Phosphate (kg/ha).	NA	Less than 22	22-56	56-73
Organic carbon (%).	NA	0.1-0.3	0.3-0.5	0.75-1.00
Ammonical nitrogen (kg/ha).	NA	About 15	About 73	NA
Nitrate nitrogen (kg/ha).	About 04	About 10	NA	NA

* NA = Not applicable.

Soil microbial count

Colony forming units (C.F.U counts) per gram soil at three soil depths viz. 0-10 cm, 10-20 cm, and 20- 30 cm was estimated. The data of C.F.U of soil microbes is presented in Table 3. It shows that the C.F.U count was highest in ZT and DT at 0-10 cm and 20-30 cm depth respectively. At depths

10-20 cm and 20-30 cm, the C.F.U count was highest in DT, i.e. 3.70×10^8 and 2.81×10^8, respectively (Table 3).

Table 3: Colony forming units* ($\times 10^8$/g) soil at three different soil depths under different tillage systems.

Treatment	0-10 cm	10-20 cm	20-30 cm
ZT	2.74	3.39	2.39
RT	2.66	3.21	2.42
DT	2.22	3.70	2.81

*(Data is mean of four replications after seven days of sowing).

Soil moisture content

There was no significant difference in the moisture content among the treatments at 0-10 cm. However, at 20-30 cm depth, the moisture content was significantly high under DT (18.5%) than ZT and RT (15.5% and 16.5%, respectively). The data have been represented in Table 4.

Table 4: Soil moisture content at 10-20 cm and 20-30 cm soil depth under different tillage systems.

Treatment	10-20 cm	20-30 cm
ZT	17.5	15.5
RT	18.0	16.5
DT	18.5	18.5
SEM	0.37	0.56
CD (P=0.05)	NS	1.95

*NS = Non-significant.

Initial vegetative growth parameters

The crop responded particularly well under DT with respect to the parameters of initial vegetative growth (Fig.1). Plant height, number of tillers/0.2m2, and shoot biomass/0.2 m2 recorded at 30 days after sowing were significantly high under DT in comparison to both ZT and RT. Plant height was slightly more under ZT than RT but the number of tillers and shoot biomass were significantly high under RT than ZT (Table 5).

Fig 1: Effect of different tillage at initial root and shoot growth 18 days after sowing.

Table 5: Initial vegetative growth parameters of wheat sown under different tillage systems.

Treatment	Plant height (cm)*	Number of tillers/0.2 m^2	Shoot biomass (g/0.2 m^2)
ZT	30 ^{a}	148 ^{a}	29.7 ^{a}
RT	29.2 ^{b}	176 ^{b}	33.9 ^{b}
DT	33.5 ^{a,b}	255 ^{a,b}	41.8 ^{a,b}
SEM	0.89	11.99	1.04
CD (P=0.05)	1.7	36.37	3.18

*Numbers followed by same alphabet represent significant difference at p=0.05 between the marked treatments.

Yield parameters

The yield parameters obtained after crop harvest are presented in Table 6. Length of ear head was significantly higher under DT than ZT and RT. There was no significant difference between ZT and DT for 1000 grain weight and harvest index of the crop but both were higher than RT. The ratio between Straw and grain weight was similar for all the three treatments.

Table 6: Yield parameters of wheat sown under different tillage systems.

Treatment	Length of ear head (cm) *	Straw: grain ratio	1000 grain weight (g)	Harvest index
ZT	9.2	1.25 ^{a}	36.0	0.41
RT	8.7 ^{a}	1.49 ^{a}	33.5	0.40
DT	9.6 ^{a}	1.33	36.7	0.41
SEM	0.24	0.57	0.84	0.005
CD (P=0.05)	0.74	0.17	NS	NS

*Numbers followed by same alphabet represent significant difference at p=0.05 between the marked treatments.

Root parameters

Root surface area

The root surface area did not differ among the treatments at 0-10, 20-30, and 30-40 cm soil depths. It was lower at 0-10 cm soil depth which ranged between 0.16-0.20 m². At 10-20 cm there were significant differences in the root surface area among the treatments. The DT had the highest surface area (0.65 m²) whereas ZT and RT recorded a surface area of 0.42-0.47 m² (fig.2).

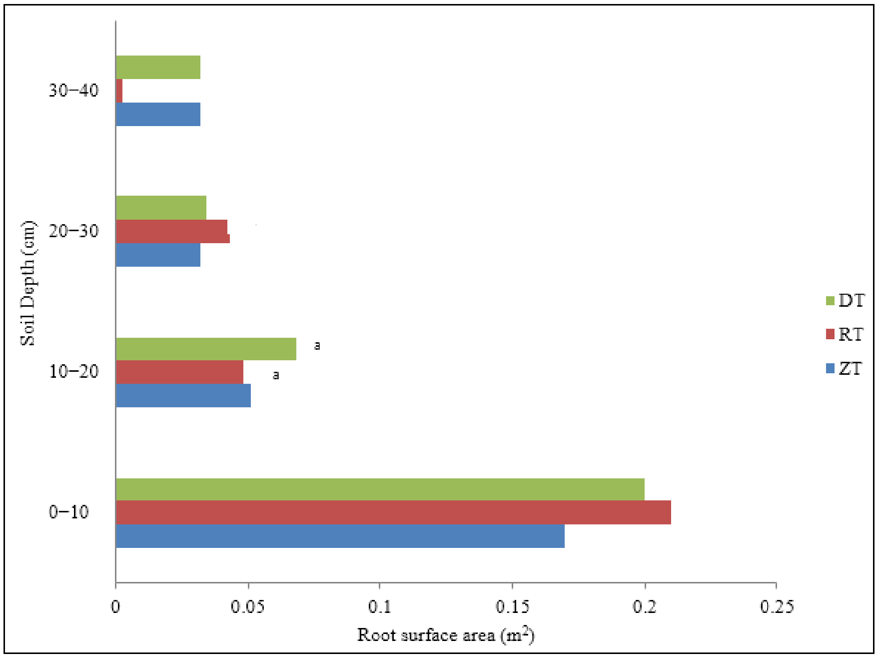

Fig 2: Effect of different tillage systems on root surface area (m^2) at various soil depths.
*Histogram followed by same alphabet in this and subsequent figures represent significant difference at p=0.05 at that particular soil depth, between the marked treatments

Root surface area density

The root surface area density did not differ among the treatments at 0-10, 20-30, and 30-40 cm soil depths. It was lower at 0-10 cm soil depth which ranged between 0.43-0.53 cm^2/ cm^3. At 20-40 cm soil depth root surface area density was higher than 0-10 cm depth. It ranged between 0.06-0.17 cm^2/ cm^3. At 10-20 cm there were significant differences in the root surface area density among the treatments. Highest surface area density (0.17 cm^2/ cm^3 soil) was observed under DT whereas ZT and RT recorded a surface area of 0.13 and 0.12 cm^2/ cm^3 soil respectively (fig.3).

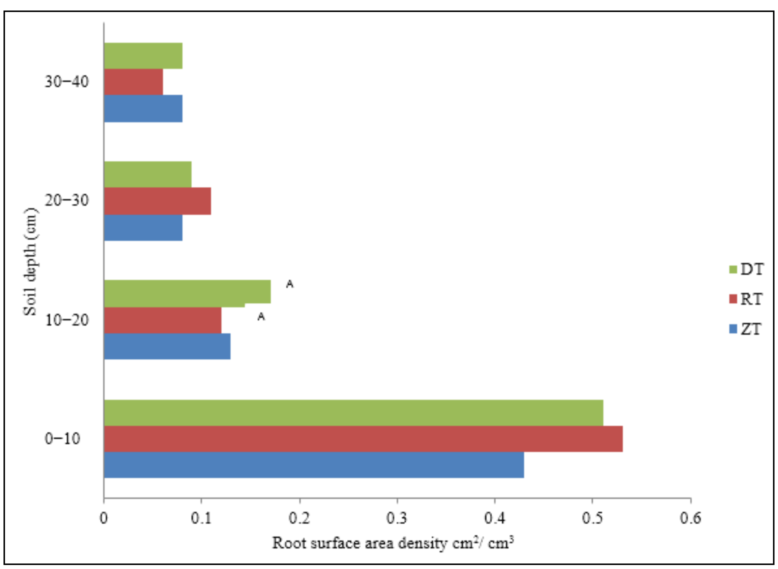

Fig 3: Effect of different tillage systems on root surface area density (cm^2/cm^3) at various soil depths.

Root length

There was no significant difference in root length among the treatments. However, the root length was highest at 0-10 cm depth which gradually decreased in 30-40 cm depth for all the three treatments. The root length varied from 198.02 m in ZT to 241.3 m in DT at 30-40 cm soil depth. At 0-10 cm depth, root length ranged from 27.8 m in RT to 37.9 m in DT (fig.4).

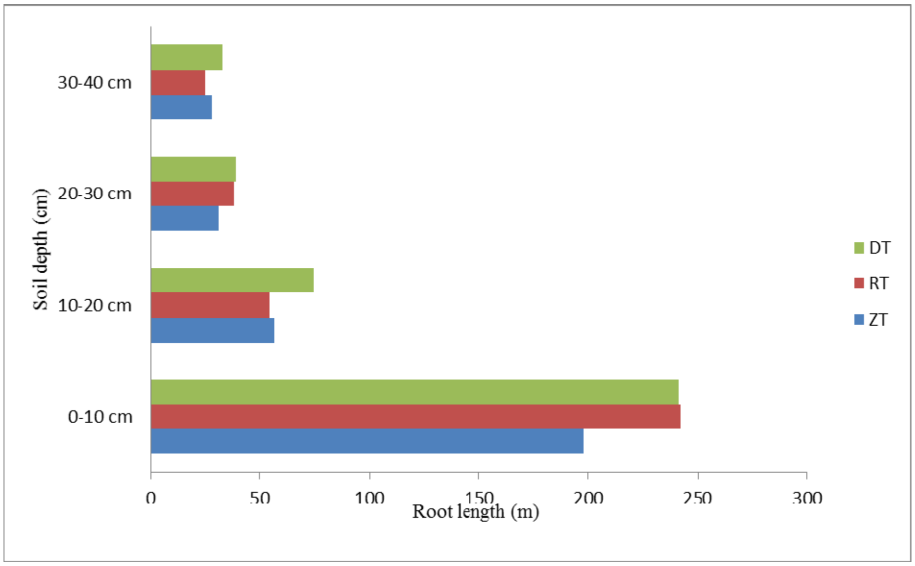

Fig 4: Effect of different tillage systems on root length (m) at various soil depths.

Root volume density

The root volume density did not differ among the treatments at 0-10, 20-30, and 30-40 cm depths. It was lower at 0-10 cm soil depth which ranged between 3.06-3.71 mm^3/ cm^3. At 20-40 cm soil depth root volume density was higher than 0-10 cm depth. It ranged between 0.53-0.96 mm^3/ cm^3. At 10-20 cm there was significantly higher root volume density under DT than ZT or RT (fig 5).

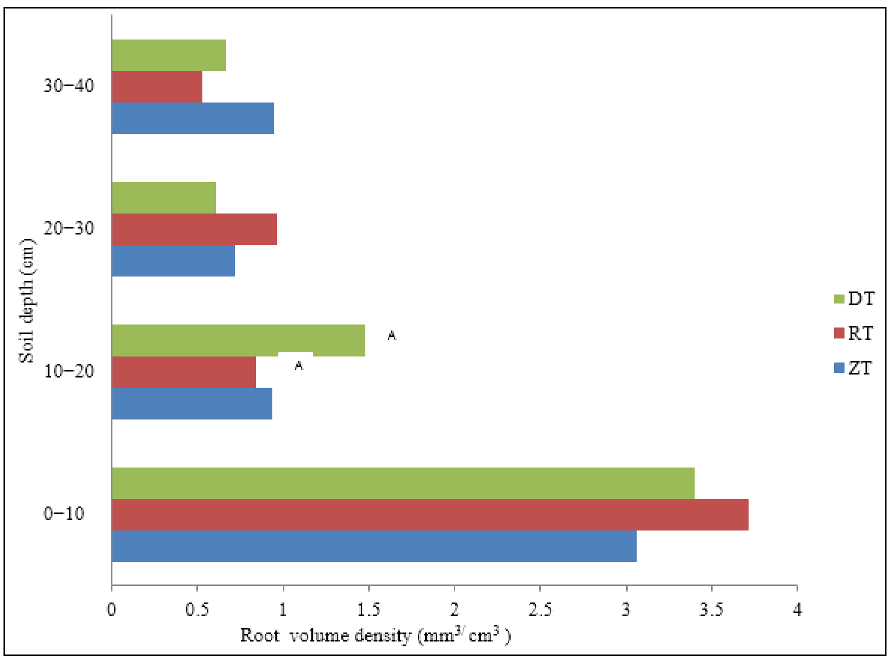

Fig 5: Effect of different tillage systems on root volume density (mm^3/ cm^3) at various soil depths under different tillage operations.

4. Discussion

Tillage systems have profound effect on the physical as well as biochemical properties of the soil [15]. ZT technology is very effective in moderating soil evaporation and minimizing erosion losses [16]. Consistent to the previous findings, our data shows that the $NH4^+$-nitrogen content was highest at 20-30 cm depth under ZT and there was a decreasing trend observed under tilled conditions i.e. both RT and ZT. Soil nitrogen is expected to percolate down the deeper soil layers in well drained and tilled soils hence, the low levels of $NH4^+$-nitrogen and nitrate nitrogen can be explained. The expected trend for phosphorus and potassium could be explained by the related findings that show least variation on soil potassium and phosphorus levels under varying tillage practices. The effect of tillage on microbial count depends both on timing and depth of tillage. The microbial count is correlated to the organic matter content of soil which is higher at the surface layers under ZT. Hence, CFU count was higher at 0-10 cm depth for ZT. However, at deeper soil layers, the availability of nitrogen plays a crucial role in determining the microbial count. Thus, DT shows maximum CFU count at soil depths more than 10 cm. In well drained soils, moisture content tends to be higher with deep tillage since fine textured soils hold more water on dry weight basis at any given depth.

Tillage practices modify the root zone and are correlated with the crop yield [15]. Modification of soil aggregation and compaction of soil following operation of heavy machinery under no tillage or reduced tillage are chief determinants of root growth under such tillage systems [17, 22]. Contradictory reports exist on the amount of root mass under ZT than RT or NT. However, there might be an increase in root mass in ZT as compared to RT or DT that can be attributed to root proliferation in cracks, bio pores and worm channels [23, 24, 25]. Reports of hard pan formation at about 0.15 m depth due to repeated use of tractor-driven cultivators hinders the movement of water and air and inhibits the root growth of plants [26]. Root development and distribution in the soil profile are of great importance for water and nutrient uptake by plants. Root growth in the sub-soil is greatly affected by tillage. Continuous use of conventional tillage operations can create hard pans in the sub-soil, which can be detrimental to root proliferation below the plough layers [27]. Roots are usually extracted by using cylindrical cores or auger. In the present study, a rectangular root sampler was designed having dimensions 20 cm×20 cm× 20 cm. In wheat, row to row spacing is maintained at 15-20 cm. This space is assumed to be equally occupied by the roots of adjacent rows, thus the rectangular root sampler was designed to extract roots which will be a representative of the root mass in a particular volume of the soil. Thus, it was possible to estimate root growth parameters per unit volume of the soil. Root growth is determined both by plant genetic character and by soil physical and chemical properties. Among the tillage systems practiced in wheat, conventional tillage systems disturbs the soil structure, its physical and chemical properties and distribution of roots. No-tillage or zero tillage systems have been reported to give comparable yields as that under conventional tillage. On the contrary, reduced growth rate of wheat under ZT has been ascribed to reduction in root growth and nitrogen uptakes [28]. Root growth as well as their capacity to acquire water and nutrients from soil is a key determinant of plant growth and yield. In the present study, the surface area of roots was maximum at 10-20 cm soil depth as compared to the upper layers (0-10 cm) or the layers below (20-40 cm). Among the treatments, it was higher with the DT as compared to ZT and RT. In all the treatments, the root length was higher in the upper 10 cm soil depth and thereafter decreased with soil depth. Available literature indicates that root growth parameters such as length, volume, dry weight and density are higher with tilled raised furrows than ZT. In the present study, higher root surface area, root length and root length density under DT could be explained due to pulverization and loosening of soil at greater depths thus facilitating better penetration of roots to deeper soil layers promoting greater proliferation of root. On the other hand, compactness of soil under ZT offers penetration resistance to root proliferation thereby reducing their growth. This retards root proliferation under ZT. This explains our result on the root growth parameters which did not vary among treatments in the uppermost layer of the soil. Deeper root systems and greater RSAD and RVD in the subsoil have possible effects on the acquisition of water and nutrients from the subsoil to promote the root system and growth in the middle and lower soil layer that helps to efficiently enhance root system's absorption of water and fertilizers, resulting in the increased grain yields. This implies that the root systems in the middle and lower soil layers play vital roles in determining wheat grain yields. The improved P uptake per unit root length could be due to increase in the root surface area per unit root length. Species with a relatively small initial investment in biomass per unit root length may be at an advantage at exploiting pulses of water or nutrients in the soil. In a comparison of two arid-land grass species of similar shoot: root biomass ratio, shoot architecture and shoot photosynthetic rates, the species with the smaller diameter roots had more rapid root proliferation and also more rapid root invasion into disturbed soil zones. The replacement of conventional tillage with conservation tillage improves crop yields and reduces operational costs, among other economic benefits [29]. Cereal grain response to conservation tillage practices is variable [30]. Higher yield is usually attributed to increased water conservation or utilization by the crop, especially in arid and semi-arid regions; lower yield is attributed to greater disease and weed infestations and N immobilization [31]. In this study, the crop yield components such as total biological yield and straw yield were higher under DT whereas number of tillers per square meter and harvest index were similar under both ZT and RT.

5. Conflict of interest

Authors declare there is no conflict of interest for this study.

6. Acknowledgement

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