International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(2): 2250-2256

Received: 16-01-2018
Accepted: 19-02-2018

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Impact of tillage and plane of fertilizer application on root attributes and yield of winter wheat

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Abstract
Subsoil compaction occurs due to continuous use of Zero tillage (ZT) or reduced tillage (RT) impeding root proliferation and crop yield over time. In several cases, depth of fertilizer application can modify the distribution of roots in soil profile as well as yield of the crop. This study aimed at evaluation of the effect of deep tillage (DT) and conservation agriculture (CA) on root attributes and yield of winter wheat wherein the machines were modified to place fertilizers either below or in the plane of seeds, respectively. In all the tillage treatments we studied root volume, average root diameter, root length density (RLD), root biomass and specific root length up to a depth of 40 cm and vegetative growth parameters and yield of the crop.
Root volume, root length density (RLD), and root biomass were significantly higher under DT at 10-20 cm; 10-20 cm as well as 20-30 cm; and 30-40 cm respectively, when compared with either ZT or DT. ZT and DT were found to have comparable values for these parameters. Root diameter and specific root length was higher under ZT when compared with either RT or DT, however, the changes between the treatments were insignificant at all depths. The vegetative growth was significantly higher under DT than under ZT or RT, but the straw and grain yield were comparable between the treatments.

Keywords: Conservational tillage, deep tillage, Root growth parameters, Wheat, subsoil hard pan

1. Introduction
Wheat is one of the most ancient crops, grown extensively all around the world. Wheat alone provides over 20% of the daily protein and energy to 4.5 billion people and its straw is used as animal feed and has other significant values to rural population. Accompanying the shrinking land area under cultivation, wheat cultivation has witnessed a global upsurge in demand of over four folds since the industrial revolution [1, 2]. Ancient practices of cultivation were sufficient to cater to smaller needs; however the modern cultivation has accumulated practices such as tillage, use of high yielding varieties, irrigation, and application of fertilizers in order to meet the global production demands.
Strategic manipulation of physical and chemical properties of the soil constitutes an age old practice, adding significantly to the yield and improving nutritional status of the crop. Tillage is intrinsically linked with wheat cultivation and different tillage systems has been extensively reported to affect yield by improving soil structure and the nutrient uptake, however, with contradictory results [3, 4]. Tillage is done chiefly to prepare the seed bed depending on the prevailing cropping system, soil types, practices of crop management etc. It includes all operations of seedbed preparation that optimize soil and environmental conditions for seed germination, seedling establishment and crop growth. Tillage practices in wheat are not only linked with the enhanced gross production but also the productivity, efficiency of agricultural inputs viz. fertilizers, irrigation, and pesticides. Tillage, thus, can modify virtually every aspect of production system including soil aeration and compaction, water and nutrient supply, soil temperature and it critically influences specially root growth. Modification of tillage such as conventional tillage, reduced tillage and no-tillage has evolved over time due to variation in global climate and adoption of specialised cropping systems which has given rise to intense seasonal peaks for land preparation. These practices have been essentially developed to maximize yield and cost: benefit ratio, improve nutrient quality of crop, reduce degradation of soil structure, conserve water and improve biotic activity in the soil.
Conventional tillage practice alleviates soil compaction and incorporates plant residues, organic manures and weed seeds to deeper soil layers.

The typically entails mechanized or traditional ploughing with disking and chisel ploughing operations. Practiced across the globe and dominating the fraction of cultivated land, conventional tillage has been since late considered being unsustainable in long run, due to the degradation of soil structure with the accompanied loss of nutrients from soil, and high cost of operation. The farming community of late is shifting towards a more sustainable way of seed bed preparation called conservational tillage that works on three basic principles i.e. minimal mechanical soil disturbance, permanent soil organic cover, and diversified crop rotation. This includes no tillage, mulch tillage, strip till, ridge tillage and reduced or minimum tillage (CTIC). Over 125 M ha (8% of total) world arable land is presently under conservational tillage system that aims to increase production while sustaining the natural resource base by promoting soil physical structure, biodiversity, and reducing erosion. In the fertile plains of North West India, ZT and RT are being increasingly adopted by the farmers in the rice – wheat cropping system, although with little success.

Both, no tillage and reduced tillage are sub-types of CA technologies for direct seeding using seed-cum-fertilizer drills to maximise yield, reduce time lag between successive crops and minimise degradation of soil and associated biodiversity. ZT can be advantageous over conventional tillage (CT) systems under certain agro-climatic conditions. These advantages include reduced increased cost: benefit ratio, shortened field time during tillage operations, improved soil aggregate stability and effective nutrient recycling due to incorporation of crop residues over the soil [5-7]. Other soil physical properties benefited by NT systems are increased soil water availability and increased number of biopores that may facilitate root growth [8, 9].

However, recent trends in wheat production suggest that a period of stagnant or even negative growth rate is being observed in most of the wheat growing regions of India. One reason of this decreased growth is the poor fertilizer use efficiency that prevents the crop from achieving its potential yield of over 12.9 Mg ha^{-1}. The amount of fertilizer taken up by the soil is a meagre percentage of what is externally supplied and that too heavily depends upon the crop in question and adopted tillage practices. A study extending over 8 years by Zhang *et al.*, has shown that soil organic matter, and available nitrogen and phosphorus were higher in crop grown under sub soiling tillage than no tillage and conventional tillage practices consequently achieving higher yields [10]. Grain yield also varies with amount of fertilizer, bed size configuration, as is root development. Both of these parameters potentially vary with the state of soil compaction, which in turn, is affected by the tillage system. Prolific root development increases the efficiency of water and nutrients absorption, thus augmenting crop yield. Poor soil structures affect root penetration and functioning, and thus lead to even higher residues of macronutrients at harvest due to under utilization of available soil nutrients. If roots are not able to penetrate the matrix of the aggregates a clustered root distribution in the cracks result, thus poor root growth can be expected in soils having larger cracks [11]. Contradictory reports exist over continuous adoption of NT showing increased soil bulk density, lower soil temperatures, and decreased oxygen diffusion rates, apart from compaction of surface soil layers as compared to conventional tillage [12-14]. The increased topsoil compaction under NT may decrease water infiltration imposing threat of water logging during period of high rainfall. No-tillage is, therefore, less appropriate during wet years or in areas with high rainfall [15, 16]. In some soils, NT has been shown to reduce the growth rate of wheat [17, 18].

Although many studies have been conducted on the effects of tillage systems on soil bulk density and water content, root growth, water-use efficiency, and crop yields under various soil and climatic conditions in different countries, few experiments have been done to determine the effect of tillage systems on root growth of winter wheat under conditions in the Indo-gangetic plains of northern India. This study was conducted to compare the temporal variation of root growth and yield of winter wheat under different tillage systems.

We therefore conducted this study to examine the affect of CA technologies represented by ZT and RT in comparison to subsoil tilling with DT in the context of root growth parameters and yield of winter wheat in the Indo-gangetic plains.

2. Material studied, area descriptions, methods, techniques

2.1. Wheat genotype and site description

The experiment was carried out in winter wheat at the N.E.B crop research centre of Govind ballav pant university of agriculture and technology, Pantnagar (29°30’N, 79°29^0’E; 243.8 m above the mean sea level) in loam textured soil of tarai plains, situated about 30 km southwards to the foothills of the Shivalik range of the Himalayas. The tarai region experiences humid subtropical climate with hot dry summers and cool winters. Winter season extends from November to March. The land where the experiment was carried out was under paddy-wheat cultivation for last many years. In the previous year, the soil was deeply tilled with the Pant ICAR chiseller-cum-fertilizer applicator up to a depth of 25 cm for sowing of direct seeded Basmati rice. Qualitative estimation of soil was done after the seed bed preparation and the physico-chemical parameters are represented in Table 1. 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 uniform length of 8 m. The width of plots varied with treatments with 1.8 m for zero tillage, as well as for reduced tillage and 2.5 m for deep sub-soil tillage per replication.

2.2. Site Management and experimental design

In the present investigation, DPW-621-50 variety of wheat was sown with three different tillage practices. The three set of 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 were placed just below the seeds in slit in a vertical plane. RT 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, DT was performed using Pant ICAR controlled-field-traffick tiller-cum-multi crop seeder in which soil was tilled up to a depth of 20 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 soil surface, in a synchronized vertical plane.

2.4. 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 surface with

the help of a new cuboids' shaped auger having dimension 20 cm×20 cm×20. The extracted soil containing the roots was dipped in sodium hexametaphosphate solution (5%) for 24 hrs. 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

2.4.1 Root length, surface area, volume and average diameter

The root samples were scanned using a Hewelett Packard scanner controlled by Win-RHIZO Programme V. 2009C Software (Regent Instruments Inc. Ltd., Quebec, Canada). 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. After scanning, the analysis of the image was done by the programme itself to yield data on root length, surface area, volume and average diameter. After scanning, root samples were oven-dried at 70 ^{0}C for 24 hrs and the dry weights of samples were recorded.

2.4.2. Root Length Density (RLD)

Root length density was calculated as the quotient between root length (RL) and sample core volume (V, cm^3).

RLD (cm/cm^3) = $\frac{RL}{V}$

2.4.3 Specific Root Length (SRL)

The specific root length (SRL) was calculated as the ratio of the root length to the root dry weight.

SRL (cm/cm^3) = $\frac{RL}{V}$

2.5 Statistical analysis

The data obtained from field trials during the course of present investigation were analysed statistically by using simple Randomised Block Design. Standard error of means (SEM) and critical difference (CD) were evaluated at 5% level of significance.

3. Results and Discussion

Root Growth Parameters

Root Volume

Following our study carried on clay loam soil under rice-wheat cultivation we report that root volume between the treatments varied significantly in only 10-20 cm soil depth and differences were insignificant at other depths under investigation (i.e.0-10 cm, 20-30 cm and 30- 40 cm). In all the three treatments, root volume was highest at D1 (0-10 cm) and decreased gradually until D4 (30-40 cm). At 0-10 cm and 20-30 cm depth, the root volume recorded was highest under RT i.e. 14.83 cm³ and 3.85 cm³ respectively. However, at 10-20 cm soil depth, the root volume varied significantly between the three treatments being highest in DT (5.91 cm³) than ZT or RT (3.77 cm³ and 3.34 cm³ respectively) which did not differed significantly among them. At 30-40 cm, the root volume ranged between 2.13 cm³ in RT to 3.79 cm³ in ZT.

Tillage has profound impact on the development and architecture of roots in the soil profile. It is evident that distribution of root in the soil profile will vary according to the physical properties of soil that are prone to amendments by the type and depth of tillage system [19, 20]. Since the experimental site was deep tilled in the last season, it is imperative that some influence of previous treatment was carried forward. With land under zero tillage, length of time is proportional to the evident impact of tillage as suggested by pearson *et al*. (1990) [21]. Zero tillage and reduced tillage may result in accumulation of nutrients at the surface layers leading to comparable root growth as achieved under deep tillage. So, insignificant difference at all depths but 0-10 cm could have been due to rapid initial growth of roots under deep tillage because of deeper placement of fertilizers 5 cm below surface [22, 23].

Average Root Diameter

Root growth is affected by the porosity, mechanical impedance, and soil structure. No-tillage, in long run, leads to increased bulk density and thus the penetration resistance of soil [29]. However, the decrease in root growth has been reported to show a linear, exponential or inverse relationship with increasing penetration resistance [30-32]. We found highest root diameter under ZT at D1, D2, and D4 (0.27 cm, 0.30 cm, and 0.41 cm respectively). At D3, root diameter was slightly higher under RT than ZT (0.36 cm and 0.34 cm respectively). We found no significant effect of tillage on the diameter of wheat roots at all depths under consideration; however, the root diameter was highest under ZT at all depths except at 20-30 cm soil profile. There is little soil manipulation under RT to a shallow depth which may decrease the bulk density and penetration resistance of soil at shallow depths [26].

Root Length Density

There are contradictory reports over the trend observed in root length density (RLD) with the type of tillage. While some authors have reported higher RLD under NT than conventional tillage others have reported insignificant difference or even slightly higher RLD under conventional tillage than NT [27, 28]. Root length of similar genotypes can vary with the soil physical properties as well as the environment. Deep root systems can increase the amount of water and nutrient availability to the crops, particularly under conditions of drought [29]. Tillage systems have potential impact over the number of large biopores per unit surface area, total pore volume, bulk density and air capacity and imply an effect of soil structure on root growth [30]. Since, hard pan is broken only under deep tillage system; we expected profuse root growth under DT when compared with either ZT or RT. Our results were in accordance with the expected trend. Highest RLD was obtained under DT at all soil depths. Since the surface soil under RT is get tilled to some extent, we found that the RLD at 20-30 cm soil depth was higher in RT as compared to ZT. RLD was significantly higher under DT at 10-20 cm and 20-30 cm soil depth. Root growth is more confined to surface layers under ZT, thus the RLD was slightly higher under ZT than RT at 10-20 cm depth [29, 31]. Our data indicate that RLD is not only a function of the depth of tillage but it also varies according to the depth of fertilizer placement. Deeper fertilizer placement stimulated further root growth and retention till the harvest stage. We obtained significantly higher RLD under DT at 10-20 cm and 20-30 cm soil depth as compared to either ZT or RT.

Root Biomass

We observed a contrasting difference in distribution of root into the soil profile with respect to RLD and root biomass. Unlike RLD which was significantly higher under DT at 10 cm-20 cm and 20 cm-30 cm soil depth, the root biomass was

significantly higher under DT at 30-40 cm depth. Qin *et al*. (2004) have reported earlier, that NT is associated with an decrease in RLD in the soil layer below 0–5 cm, aptly supported by the work of a long term experiment carried out by Benítez-Vega (2006), in which they reported greater penetration resistance in the topmost 10 cm of soil under NT than under CT, due to the existence of a compacted layer as a result of not using tillage equipment [26, 29]. Similar results are reported by Cassel *et al*. (1995) [30]. An increased topsoil compaction under NT systems may decrease water infiltration thus impairing soil aeration and restricting the length and function of plant roots. Qin *et al*. (2004) also noted that tillage effects disappeared below 30 cm with respect to hangs in RLD. Thus our result explains an supports the earlier findings that tillage does not affects RLD blow 30 cm soil depth but decreased penetration resistance due to deep tillage results in greater proliferation of roots at 30-40 cm soil depth resulting in higher root biomass despite of an insignificant increase in RLD under DT as compared to ZT and RT [26].

Specific Root Length

Specific root length (root length/root weight) is a measure of the fineness of the root system. The larger the ratio of root length to root weight, the more fibrous is the root system. In our study, we have found that total root length decreases with soil depth and so does the root biomass. However the rate with which these changes occur has been found to vary with treatments. We observed significantly higher SRL under DT as compared to ZT or RT at 0-10 cm. at other depths the difference was not significant. At 30-40 cm soil depth, SRL was significantly higher under ZT when compared with DT or RT. Considering the significantly higher root diameter at 30-40 cm soil depth under ZT; it implies that ZT promoted fineness of the roots at greater depths. While at the surface, thicker roots were formed under ZT as compared to DT or RT. As previously mentioned in the text that the experimental site was deep tilled in the previous cropping season, it is reasonable that the soil at greater depths were finer with low penetration resistance and higher moisture content than that of the surface layers. A compensatory root growth has been reported that may account for higher SRL under ZT at greater depths.

Vegetative growth parameters and yield

Table 2 summarizes the data on Vegetative growth parameters and yield of winter wheat as influenced by three different tillage systems. We observed poor early shoot growth in wheat under NT followed by RT, however there was no significant difference between these two treatments for shoot length at any of the growth stage. Shoot length was significantly higher under DT as compared to both ZT and RT during all crop growth stages, particularly at 15 DAS (19.0 cm, 12.9 cm, and 13.8 cm respectively). Poor early shoot growth of wheat under NT and RT may be a direct consequence of lower root growth caused by denser and compacted soil [32]. Tillage practices greatly influence the vegetative growth and yield of the crop. Different tillage practices differentially modify the physiochemical properties of soil and a range of factors cumulatively determine the appropriate tillage system at a time viz. antecedent properties and climate [33-35].

The replacement of conventional tillage with conservation tillage improves crop yields and reduces operational costs, among other economic benefits [36, 37]. However, contrasting results have been achieved by different workers with respect to effect of tillage on grain yield of wheat. Taa *et al*. (2004) observed that wheat yields from reduced and zero-tillage sometimes were lower than those from conventional tillage. Others have found no difference or obtained inconsistent responses of crop yield to tillage systems [38, 39].

Concluding Remarks

Crops share a highly complex relationship with soil at all stages of growth and development. It is imperative to develop a highly controlled environment in order to assess the impact of a particular treatment say, tillage systems over growth and yield of the crop. It is quite impractical till date to conclude at the level of field studies that modulation of soil structure alone is responsible for any observable phenotype. Factors such as biological activity, variation in climate at local and global scale, pests and pathogens, etc. plays a critical role in determining crop performance. Thus, more inclusive and controlled studies are required to reach to a definite conclusion. It may, however, be said that deep tillage in rotation with reduced tillage will be more beneficial in Indo-gangetic plains and areas around the world with higher on-field mechanization and similar soil and climatic conditions.

Table 1: Characteristics of cropping pattern under different tillage systems

Seed drill	Type of tillage	Plane of fertilizer application	Depth of fertilizer application from the plane of seed (cm)
Pant Zero-till seed-cum-ferti drill	zero tillage	vertical	0
Roto-till ferti-seed drill	reduced tillage	horizontal	0
Pant ICAR controlled-field-traffick-tiller -cum-multi crop seeder	sub-soil tillage	vertical	10-15

Characteristics of cropping pattern under different tillage systems ZT, zero tillage; RT, reduced tillage; DT, deep tillage; SEM, Standard error of mean; CD, Coefficient of deviation; * indicate significance at *P* _ 0.05 probability level; blank is not significant

Table 2: Shoot growth parameters and yield response of winter wheat sown under different tillage systems.

Treatment	Plant height (cm)				Number of tillers/0.2m^2		Shoot biomass (g/0.2 m2)		Straw yield (t/ha)	Grain yield (t/ha)
	15 DAS	60 DAS	90 DAS	120 DAS	60 DAS	90 DAS	60 DAS	90 DAS		
ZT	12.9	43.9	59.2	74.2	121	88	74.1	112.2	8.14	6.45
RT	13.8	44.1	57.8	72.4	138	83	77.3	115.38	9.14	6.10
DT	19	48.1	63.9	80.1	221	127	99.8	155.8	9.24	6.90
SEM	0.56	1.24	1.44	1.38	13.32	4.99	3.45	6.03	0.35	0.24
CD (5%)	1.7	3.78	4.38	4.12	40.4	15.13	10.48	18.3	1.08	0.72

Shoot growth parameters and yield response of winter wheat sown under different tillage systems.ZT, zero tillage; RT, reduced tillage; DT, deep tillage; SEM, Standard error of mean; CD, Coefficient of deviation; * indicate significance at *P* _ 0.05 probability level; blank is not significant

1. Root Volume

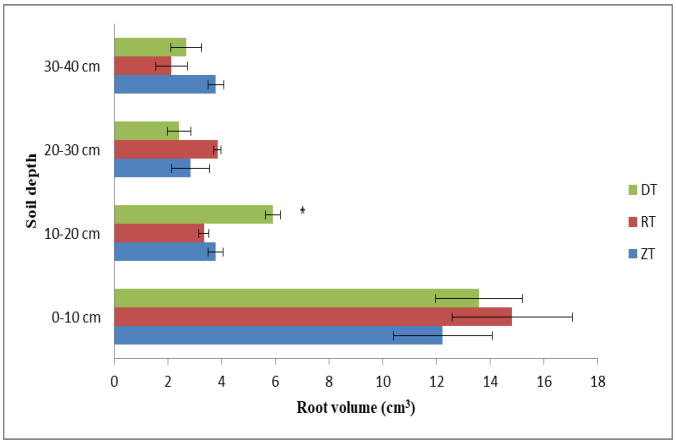

Fig 1: Distribution of root volume with soil depth at harvest of winter wheat as affected by different tillage system. ZT, zero tillage; RT, reduced tillage; DT, deep tillage; * indicate significance at *P* _ 0.05 probability level; blank is not significant

2. Average root diameter

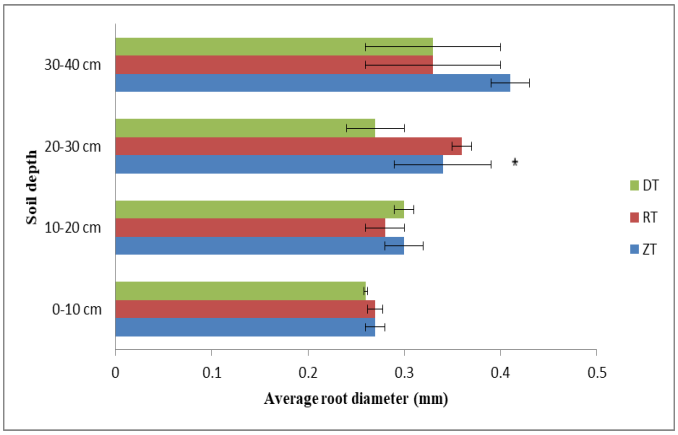

Fig 2: Average root diameter at various soil depths at harvest of winter wheat as affected by different tillage systems. ZT, zero tillage; RT, reduced tillage; DT, deep tillage; * indicate significance at *P* _ 0.05 probability level; blank is not significant.

3. Root Length Density

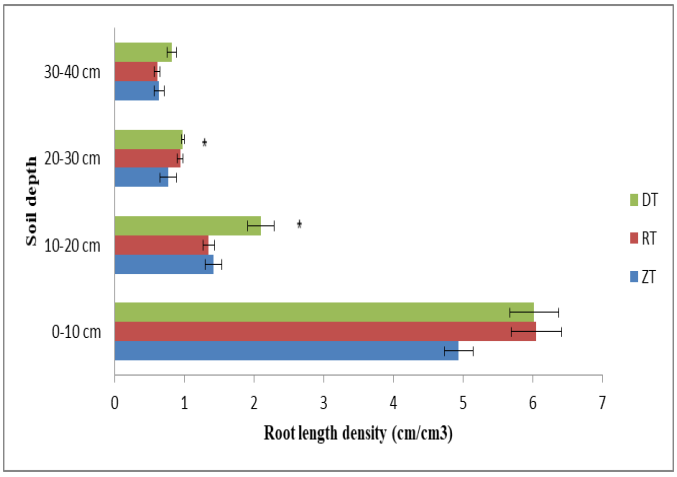

Fig 3: Distribution of root length density with soil depth at harvest of winter wheat as affected by different tillage system. ZT, zero tillage; RT, reduced tillage; DT, deep tillage; * indicate significance at *P* _ 0.05 probability level; blank is not significant.

4. Root Biomass

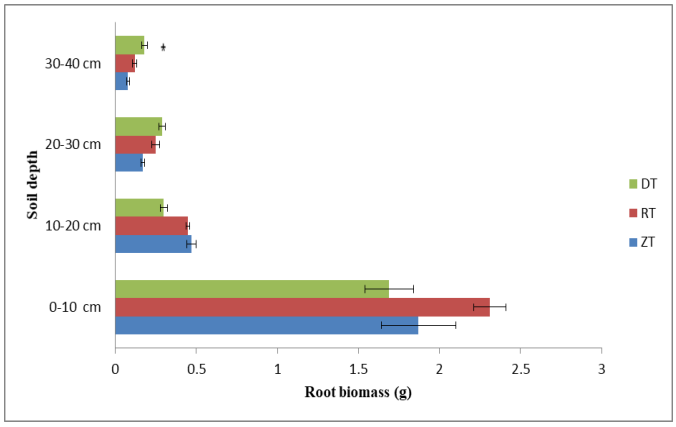

Fig 4: Distribution of root biomass with soil depth at harvest of winter wheat as affected by different tillage system. ZT, zero tillage; RT, reduced tillage; DT, deep tillage; * indicate significance at *P* _ 0.05 probability level; blank is not significant.

5. Specific root length

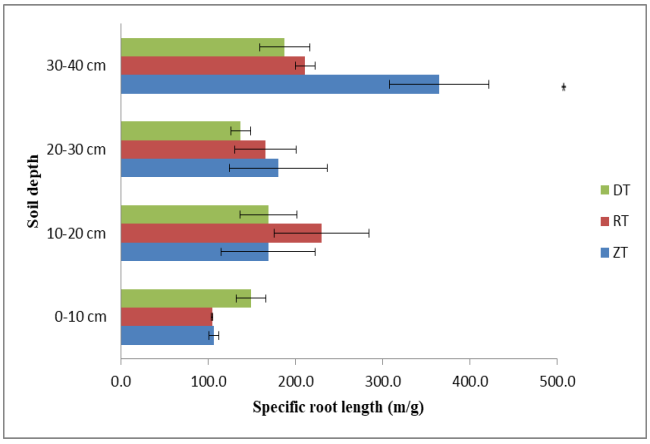

Fig 5: Distribution of specific root length with soil depth at harvest of winter wheat as affected by different tillage system. ZT, zero tillage; RT, reduced tillage; DT, deep tillage; * indicate significance at *P* _ 0.05 probability level; blank is not significant.

Acknowledgement

The authors acknowledge Director, VPKAS, Almora, for allowing us access to the institutional root scanner for the study.

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