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**Research Article**

# Effect of Long-Term Conservation Agriculture Practices on Wheat Root Morphology in the North-Western Indo-Gangetic Plains

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**ABSTRACT**

Effect of Conservation agriculture-based management practices on root architecture of wheat crop was evaluated through a long-term CA based field experiment and samples collected from farmers field of Karnal and Kaithal districts of Haryana, where CA was followed for long term. The treatments examined in field experiment included the permanent broad bed (PBB), PBB with residue (PBB+R), permanent narrow bed (PNB), PNB with residue (PNB+R), zero tillage (ZT), and ZT with residue (ZT+R) and conventional tillage (CT) and in farmers field it was CA and CT where CA means zero tillage with residue retained in field. Root samples were collected during flowering stage of wheat and roots were retrieved using Win–RHIZO software. Results showed that at 0–15 cm soil depth, mean root length density was 2.7 cm cm$^{-3}$ and all the CA-based treatments had shown a 22.7–67.3% increase in RLD over CT. Overall, a 20.6-110.3% and 53-123.3% increase in root surface area density and root mass density was observed under all CA-based treatments over CT. Similarly in farmers field a significant improvement (50.2% in Karnal and 23.5% in Kaithal) in RLD under CA over CT has been reported in the study. In Karnal CA showed S 40% increase in RMD 22% increased in root volume density. Thus, study concluded that CA based practices found to be beneficial for improving root growth of wheat crop.

**Key words:** Zero tillage, Convention tillage, Wheat, Root morphology

## Introduction

The global decline in soil health is a major barrier to achieving good yields in subsistence agriculture and contributes significantly to food insecurity (Lal, 2009). Therefore, it is crucial to develop appropriate tillage and management practices that do not compromise soil quality and the environment for sustainable crop production. Proper tillage can address soil-related constraints, while improper tillage can lead to degradation processes such as soil structure deterioration, accelerated erosion, loss of soil organic matter (SOM) and fertility, and disruptions in water, organic carbon, and nutrient cycles (Lal, 1993).

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Continuous tilling over successive seasons has led to the formation of a subsurface pan and deterioration of soil structure due to the loss of soil organic matter. Recently, conservation agriculture (CA) has been advocated to mitigate such soil physical constraints (Shafeeq *et al.*, 2020). Consequently, various CA practices like permanent bed systems, zero tillage, shallow and reduced tillage, along with residue retention, should be tested to determine the most suitable CA practice for a specific site and cropping system (Das *et al.*, 2018). Conservation agriculture (CA) is a practice that simultaneously maintains crop yields, ensures ecosystem stability, and preserves soil and water resources (Jat *et al.*, 2020). The core principles of CA include minimizing soil disturbance through reduced tillage intensity (zero or minimal tillage), retaining crop residues on the soil surface, and implementing crop rotations and diversification to economically benefit farmers (Verhulst *et al*., 2011). Zero tillage (ZT) has been advocated as a method to preserve and enhance soil structure and fertility in tropical agro-ecosystems (Bolliger *et al*., 2006). Additionally, recycling plant biomass (crop residues) into the soil is a promising strategy for replenishing soil fertility, improving physicochemical properties, and sustaining crop yield (Choudhary *et al*., 2017; Choudhary and Behera, 2019). Surface mulching with crop residues helps reduce soil water loss through evaporation and moderates soil temperature (Arora *et al*., 2008).

Roots act as a crucial link between the soil and the shoot, making root development vital for crop growth. The morphology and spatial distribution of roots are important characteristics for studying root growth and the uptake of water and nutrients by crops (Fageria, 2004; Spedding *et al*., 2004). However, few studies have addressed the impact of tillage systems on root growth due to the difficulty of accessing roots. Mosaddeghi *et al*. (2009) suggests that tillage management influences root development and function, thereby making the root system a bridge between agricultural practices' effects on soil and changes in shoot function and yield. Numerous studies have investigated root length density (RLD), with inconsistent findings regarding the entire soil profile differences between conventional tillage (CT) and no tillage (NT). Some researchers observed higher RLD around flowering under NT compared to CT (Hilfiker and Lowery, 1988; Baligar *et al*., 1998; Holanda *et al*., 1998; Muñoz-Romero *et al*., 2010), while other studies found higher RLD under CT than NT (Barber, 1971; Karunatilake *et al*., 2000; Himmelbauer *et al*., 2012). Additionally, some researchers indicated that RLD was similar under both NT and CT (Raczkowski, 1989; Hughes *et al*., 1992).

Therefore, examining the soil environment's effect on root growth after implementing tillage systems will help select the most suitable tillage regime for a specific crop and growth conditions. While literature reviews exist on root elongation under specific stress conditions (Bengough *et al*., 2011), on reduced or no tillage in North-West Europe (Cannell, 1985; Morris *et al*., 2010; Soane *et al*., 2012), and on plant biotic stress under CT (Sturz *et al*., 1997), very few studies have summarized updated information on the combined effects of soil physical parameters, root morphology, and distribution, and tillage systems on high-revenue cereal crops in temperate climates. This paper aims to elucidate the effects of conservation tillage and CT conditions on root growth of cereals (wheat) under different bed management practices in field experiment and in farmers field of Karnal and Kaithal districts of Haryana.

## Materials and Methods

### *Study area*

The field experiments were conducted in the MB–14B research farm of ICAR–Indian Agricultural Research Institute, New Delhi, India (28°35' N latitude, 77°12' E longitude, and at an altitude of 228.16 m above mean sea level). The fields had an even topography and a sound drainage system. The field experiment was conducted in wheat during *rabi* season in the 14$^{th}$ year of a long-term conservation agriculture (CA). study area experiences a subtropical semi-arid climate characterized by dry, hot summers and cold, moist winters. The maximum temperature ranges from 40 to 46°C in May and June, while January sees the most frigid temperatures, ranging from 5 to 8°C.

Root samples were also collected from the Karnal and Kaithal districts of Haryana during the flowering of wheat 2022–23. Karnal district in Haryana is located on the map with the GPS coordinates of 29°25'05" N latitude and 76°27'40" E longitude with a height of 240 m above the mean sea level with an area of 2520 square kilometers. Kaithal district is located in the northeastern part of Haryana, covering an area of 2,317 square kilometers. It lies between latitudes 29°31' and 30°12' north and longitudes 76°10' and 76°42' east. The climate of the Karnal and Kaithal districts is characterized by dry air, with intense hot summers and cold winters. The cold season starts in the middle of November and extends up to the middle of March. The hot season continues up to June.

### *Experimental details and collection of root samples*

Initially established in the 2010–11 growing season, the field experiment in MB-14B utilized five treatments organized in a randomized complete block design (RCBD) with three replications to compare conventional tillage (CT) against zero tillage on both narrow (PNB) and broad beds (PBB), with and without crop residue. From the second year onward, two additional treatments, i.e., zero tillage with residue retention (ZT+R) and zero tillage without residue (ZT), were introduced on flat land (Table 1). Each treatment was applied to a 30.0 m long and 8.4 m wide strip (approximately 252.0 m²) to facilitate tractor operations for sowing, fertilization, harvesting, and irrigation. These strips were subdivided into three plots of 9.0 m × 8.4 m (approximately 75.6 m²) each, serving as replications.

The current study was also conducted in farmers' field in 60 villages across the two districts, Karnal and Kaithal, specifically from wheat fields under both zero tillage (ZT) with residue and conventional tillage (CT) without residue.

### *Collection of root samples and scanning of root*

For Karnal and Kaithal districts of Haryana, samples were taken from 0–15 cm soil. After removing the above-ground part of the plant, the root auger (7 cm in diameter) was centered at the base of the stem, and the soil was excavated from the specified layers. Root samples were collected from 5 plants in each plot to take care of the maximum possible variability. After collection, the roots were washed, and the scanning was carried out on a root scanner (LA–1600) bed. Root morphology and architecture parameters (total root length, surface area, volume, and average diameter) were retrieved using Win–RHIZO software (Regent Instruments Inc., Canada). Post-scanning, roots were again collected with thoroughness, oven–dried at 65 °C for 48 h, and weighed. The measured root length, surface area, volume, and dry weight were divided by the volume of the core to obtain root length density (RLD), root surface area density (RSD), root volume density (RVD), and root mass density (RMD) for each depth.

### *Statistical analysis*

Root properties were analyzed using ANOVA for a randomized complete block design (RCBD) with three replications (Gomez and Gomez, 1984). Tukey's honestly significant difference (HSD) test was performed as a post hoc mean separation test ($P < 0.05$) employing "*agricolae*" (Mendiburu and Simon, 2007) package in R studio (Version 4.2.1).

## Result and discussion

### *Root morphology of field experiment IARI MB-14B*

The effect of the tillage, residue, and bed management system (IARI MB-14B experiment) had a significant impact on root morphological parameters, i.e., root length density (RLD), root diameter, root surface area density (RSAD), root volume density (RVD), and root mass density (RMD). The root length density (RLD) reflects crop's root distribution and is often used to describe the acquisition of water and nutrients. More studies have

**Table 1.** Details of treatments adopted in the field experiment

| Treatment code | Type of tillage | Type of bed | Residue retention |
|---|---|---|---|
| ZT+R | Zero tillage | Plain/flat land | Yes |
| ZT | Zero tillage | Plain/flat land | No |
| PBB+R | Zero tillage | Permanent broad bed(110 cm bed and 30 cm furrow) | Yes |
| PBB | Zero tillage | Permanent broad bed(110 cm bed and 30 cm furrow) | No |
| PNB+R | Zero tillage | Permanent broad bed(40 cm bed and 30 cm furrow) | Yes |
| PNB | Zero tillage | Permanent broad bed(40 cm bed and 30 cm furrow) | No |
| CT | Conventional tillage | Plain/flat land | No |

been carried out on root distribution than on root morphology. Results showed that at 0–15 cm soil depth, RLD ranged from 3.3 (PBB+R) to 2.0 cm $cm^{-3}$ (CT) with the mean value of 2.7 cm $cm^{-3}$ and was found at par with PNB+R (3.2 cm $cm^{-3}$) (Table 2 and Fig. 1). Results revealed that all the CA-based treatments had shown a 22.7–67.3% increase in RLD over CT, though ZT was found at par with CT. Similarly, at 15–30 cm soil depth, a significant improvement in RLD was reported in residue retention plots over respective non-residue plots. For instance, ZT+R, PBB+R, and PNB+R had registered a 58.4, 26.4, and 59.3% increase in RLD over ZT, PBB, and PNB, respectively. The root system plays an essential role in water and nutrient uptake and plant adaptation to the change in soil management. The analysis of wheat roots showed an increase in root length density (RLD) at 0-15 and 15-30 cm soil depths under residue-treated plots compared to CT. Mondal *et al*. (2019) reported increased RLD in the 0-5 cm soil layer because of more aggregation and reduced BD in the 0-15 cm soil layer. Still, in our study, for all the combinations, the percent change was not significant because of a smaller number of data pairs. A decreasing trend in root length was observed in lower depth (15–30 cm), where the mean RLD was reported as 0.82 cm $cm^{-3}$. Baligar *et al*. (1998) observed that no tillage (NT) resulted in greater root length per plant, root length density (RLD), root weight, and total root length compared to conventional tillage (CT). Similarly, Holanda *et al*. (1998) found that root growth and nutrient uptake were higher under NT than CT. However, other studies, such as Karunatilake *et al*. (2000), indicated that roots were more abundant throughout the soil profile in CT than in NT. The highest value of RSAD was reported under PBB+R (0.61 $cm^2$ $cm^{-3}$) and the lowest under CT (0.29 $cm^2$ $cm^{-3}$) with a mean value of 0.44 $cm^2$ $cm^{-3}$. Overall, a 20.6-110.3% increase in RSAD was observed under all CA-based treatments over CT. At 15–30 cm depth, RSAD ranged from 0.01-0.11 $cm^2$ $cm^{-3}$ with a mean value of 0.06 $cm^2$ $cm^{-3}$. The highest value of RSAD in this depth was obtained in PBB+R, which was 83% higher than PBB. Similarly, among CA-based practices, PBB+R recorded significantly higher RVD (7.66 $cm^3$ $cm^{-3}$). This treatment was found to be statistically similar to ZT+R, PNB+R, and PBB.

**Table 2.** Effect of conventional treatment and conservation agriculture practices on root morphology of wheat in IARI, MB-14 B

| Treatment | Root length density ($cm\ cm^{-3}$) | | Root diameter (cm) | | Root surface area density ($cm^2\ cm^{-3}$) | | Root volume density ($cm^3\ cm^{-3}$) | | Root mass density ($mg\ cm^{-3}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0–15 cm | 15–30 cm | 0–15 cm | 15–30 cm | 0–15 cm | 15–30 cm | 0–15 cm | 15–30 cm | 0–15 cm | 15–30 cm |
| ZT+R | $2.95^{b}$ | $1.22^{a}$ | $0.44^{c}$ | $0.40^{c}$ | $0.48^{c}$ | $0.07^{c}$ | $7.35^{abc}$ | $1.00^{b}$ | $0.99^{b}$ | $0.09^{c}$ |
| ZT | $2.21^{d}$ | $0.77^{c}$ | $0.34^{f}$ | $0.30^{f}$ | $0.35^{f}$ | $0.04^{e}$ | $6.91^{c}$ | $0.77^{d}$ | $0.67^{d}$ | $0.05^{de}$ |
| PBB+R | $3.38^{a}$ | $1.10^{a}$ | $0.50^{a}$ | $0.47^{a}$ | $0.61^{a}$ | $0.11^{a}$ | $7.66^{a}$ | $1.22^{a}$ | $1.25^{a}$ | $0.18^{a}$ |
| PBB | $2.71^{bc}$ | $0.87^{bc}$ | $0.41^{d}$ | $0.37^{d}$ | $0.44^{d}$ | $0.06^{cd}$ | $7.21^{abc}$ | $1.01^{b}$ | $0.92^{bc}$ | $0.09^{c}$ |
| PNB+R | $3.24^{a}$ | $0.94^{b}$ | $0.48^{b}$ | $0.43^{b}$ | $0.54^{b}$ | $0.09^{b}$ | $7.47^{ab}$ | $1.12^{a}$ | $1.20^{a}$ | $0.14^{b}$ |
| PNB | $2.48^{c}$ | $0.59^{d}$ | $0.38^{e}$ | $0.34^{e}$ | $0.40^{e}$ | $0.05^{de}$ | $7.14^{bc}$ | $0.88^{c}$ | $0.86^{c}$ | $0.07^{cd}$ |
| CT | $2.02^{d}$ | $0.28^{e}$ | $0.29^{g}$ | $0.25^{g}$ | $0.29^{g}$ | $0.01^{f}$ | $6.93^{c}$ | $0.63^{e}$ | $0.56^{e}$ | $0.02^{e}$ |

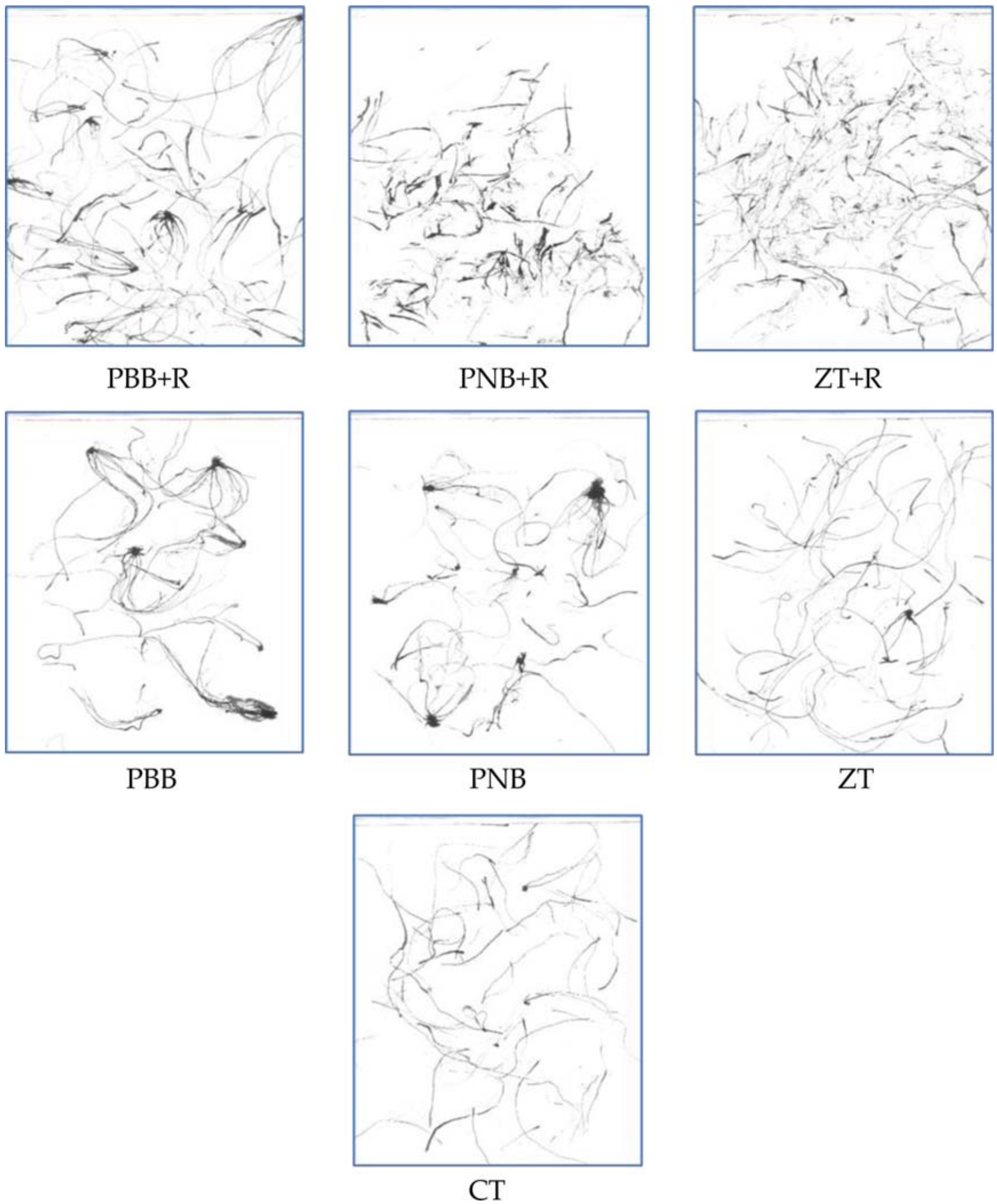


**Fig. 1.** Scanned images of roots in different conservation agriculture based treatments

Residue retention plots had shown a 4.6-6.7% increase in RVD over non-residue plots. Similarly, in 15-30 cm depth, PBB+R and PNB+R showed the highest RVD. In the case of RMD, PBB+R registered the highest value (1.25 mg $cm^{-3}$), which was found at par with PNB+R. There was a 53-123.3% improvement of RMD in CA-based treatments over CT. The individual studies showed a higher RLD and RMD under CA-based management practices over CT (Rai *et al.*, 2019; Shafeeq *et al.*, 2020) because of high structural stability and SOC in the surface layer. The significance of our research findings lies in the improved soil aggregates, soil porosity, and lower BD recorded under the residue plots (PBB+R, PNB+R, ZT+R) compared to CT (Table 2). This aligns with the findings of Cheng *et al*. (1990) and Fiorini *et al*. (2018). The use of crop residue mulch also led to a significant increase in root mass density (RMD). This can be attributed to the better soil aggregates recorded under crop residue mulch, which results in improved porosity and higher soil water availability (Nath *et al*., 2019). The better root length at the subsurface strongly suggested reducing compaction at this layer by adopting CA, providing a clear path for improving crop management. The data not only supports the fact, but also aligns with previous studies, reinforcing the robustness of the research. The reduction in sub-surface compaction, primarily due to higher soil water status and reduced traffic movement, creates a more favorable growing environment for the roots in wheat crops. The thicker roots observed in the 0–15 and 15–30 cm layers under conventional tillage further validate these findings. A more compact subsurface layer may physically restrict root spread, leading to thicker roots under CT (Lipiec *et al*., 2012). These findings, which align with similar responses of roots to hard soil layers reported elsewhere (Iijima and Kato, 2007; Bengough *et al*., 2011), are robust and reliable.

### *Root morphology of Karnal and Kaithal districts*

Fig. 2 illustrates the variation in RLD (cm $cm^{-3}$), RMD (mg $cm^{-3}$), RSAD (cm $cm^{-3}$), RVD ($cm^3$ $cm^{-3}$) at 0–15 cm soil depth under CA and CT in Karnal and Kaithal districts. In Karnal and Kaithal districts, average RLD under CA was reported as 2.91 cm $cm^{-3}$ and 3.63 cm $cm^{-3}$, and under CT it was recorded as 1.94 cm $cm^{-3}$ and 2.94 cm $cm^{-3}$. Results showed that a significant improvement (50.2% in Karnal and 23.5% in Kaithal) in RLD under CA over CT. Similarly, average RMD in Karnal district for CA and CT were reported as 1.61 and 1.15 mg $cm^{-3}$, whereas, results showed S 40% increase in RMD in

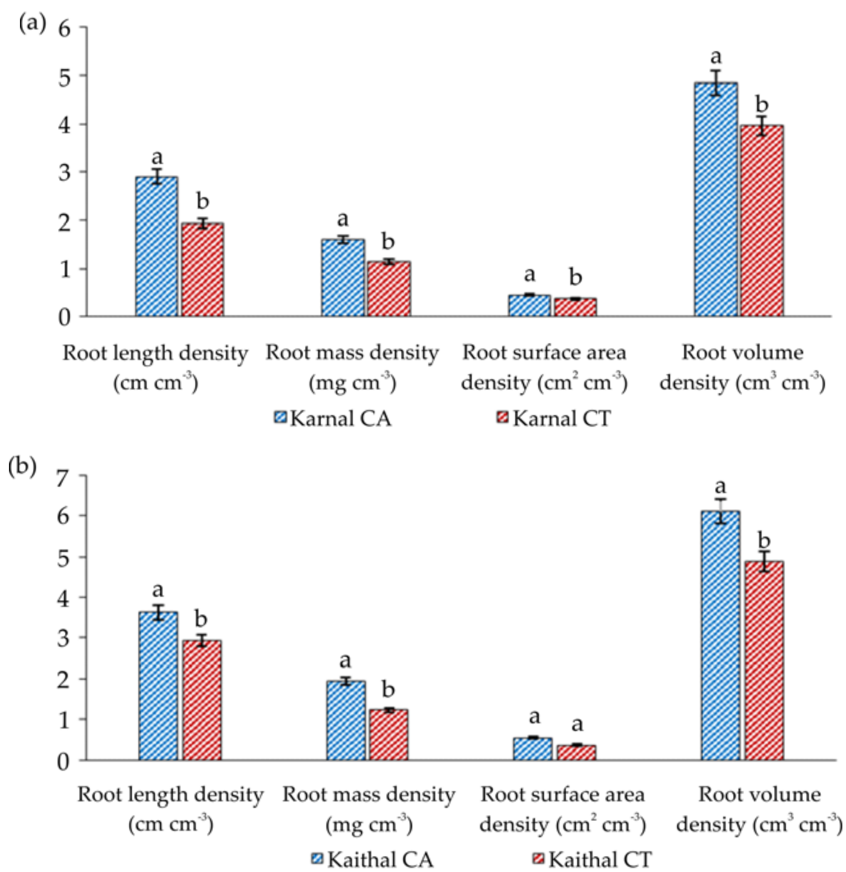


**Fig. 2.** Effect of conventional treatment and conservation agriculture based management practices on root morphology in Karnal (a) and Kaithal (b) at 0–15 cm soil depth

CA over CT. Similarly, RMD in CA and CT were registered as 1.94 and 1.23 mg $cm^{-3}$ in Kaithal district. The root mass density increased significantly in CA by 0.71mg $cm^{-3}$ compared to CT. Results also revealed that RSAD and RVD in Karnal district under CA were 0.45 $cm^2$ $cm^{-3}$ and 4.85 $cm^3$ $cm^{-3}$. Similarly for CT, RSAD and RVD were registered as 0.54 $cm^2$ $cm^{-3}$ and 6.11 $cm^3$ $cm^{-3}$. Root surface area density in Karnal district under CA and CT were found at par though RVD increased in CA by S 22% over CT. Root surface area density and root volume density in Kaithal district were 0.54 $cm^2$ $cm^{-3}$ and 6.11 $cm^3$ $cm^{-3}$, respectively under CA and 0.36 $cm^2$ $cm^{-3}$ and 4.89 $cm^3$ $cm^{-3}$, respectively under CT. In Kaithal district, RSAD in CA and CT was found at par, but RVD in CA was increased by 1.22 $cm^3$ $cm^{-3}$ as compared to CT.

Under CA-based practices, RMD, RVD, and root surface area density (RSD) showed a significant increase over CT at 0–15 cm soil depth (Table 2). This finding, which is consistent with the work of Martinez *et al*. (2008) and Bag *et al*. (2020), as well as several other pot and field experiments in wheat (Xue *et al*., 2014; Hossain *et al*., 2008; Weligama *et al*., 2010), has significant practical implications. Wang and Ma (1992) observed that the initial root growth at the surface under CT may be marginally higher due to the effect of ploughing. However, this growth was no longer visible later, leading to improved root growth under CA-based practices at the flowering stages of the crops.

## Conclusion

Residue incorporation in CA influences crop development by impacting root growth and function. As a result, the root system acts as a link between the effects of agricultural practices on soil and changes in shoot function and yield. However, there are few studies that have explored root morphology in the field, particularly concerning the effects of different tillage systems. Present study showed 22.7–67.3% increase in RLD under CA based treatments over CT. The highest value of RSAD, RMD and RVD was reported highest under PBB+R and subsequently all the residue retained plots showed improvement over CT. It is concluded that adoption of conservation agricultural practices along-with residue retention could be helpful for sustainable wheat cropping. permanent bed with crop-residue (PBB+R) was found promising as an effective management practice which helps in enhancing and root architecture wheat crop.

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