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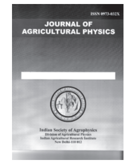

Research Article

Soil Hydro-thermal Environment vis-à-vis Plant Growth of Wheat under Varying Tillage and Residue Management

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ABSTRACT

Effect of no tillage (without residue, NT, and with residue, NT+R) and conventional tillage (without residue, CT and with residue, CT+R) on soil hydro-thermal regime and plant growth in wheat was studied after 6 years of continuous experiment in a sandy loam soil (Typic Haplustept) at ICAR-Indian Agricultural Research Institute, New Delhi. During initial phase of crop growth, NT and NT+R had higher soil water content (SWC) (10-11% higher than CT/CT+R). This effect continued till 2^{nd} irrigation to the crop, and then reduced. Though the effect of CT+R was not observed at the initial stage of crop growth, it was significant on 33 DAS onwards. Variation in SWC over the growing period was mostly contained in top 0-25 cm layer and the tillage as well as crop residue effect was clearly discernible. Soil temperature was moderate with less diurnal variations under NT+R, especially during 35-71 DAS, the most active part of growth. Residue effect was clearly evident in both leaf area index and specific leaf weight values, which were significantly higher in CT+R and NT+R plots. The root weight density in surface 0-10 and 10-20 cm layers were substantially higher in both CT+R and NT+R compared to CT or NT, but in deeper layers it was higher in NT and NT+R. The yield was marginally higher in CT+R followed by NT+R, CT and NT, indicating prospect of no tillage with residue practices in maintaining better soil hydrothermal regime without compromising the grain yield in wheat.

Key words: Soil water content, Soil temperature, Conventional tillage, No tillage, Residue, Root, Wheat

Introduction

Water is the primary constraint to crop production in the semi-arid regions. The availability of water for irrigated agriculture is a serious concern in these areas, due to large increase in demand of water for domestic and industrial purposes. The rainfall is low, and its variability has greatly increased in recent years. Thus, proper management of crops and improvement of its input-use efficiency have become more important today to sustain the food production. Wheat, the second most important *rabi* cereal in India, though mostly irrigated in Indo-Gangetic Plains, a large track of its area is rainfed, and depends heavily on rainfall.

It is widely documented that conservation tillage has in general, positive effect on the soil physical properties like aggregation stability and pore size distribution, which may lead to increase the soil water content (SWC). Greater availability of crop residues and stubbles on the soil surface under conservation tillage practices check the evaporation and improve soil infiltration (Shipitalo *et al*., 2000). However, the hydro-thermal environment as modified by conservation tillage, and its role in improving the available

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soil water are less documented (Bescansa *et al*., 2006).

The no tillage (NT) with crop residue on the soil surface improves water infiltration, reduce erosion and enhance water holding capacity as compared to the conventional tillage (CT) system (Johnston *et al*., 2002; Shaver *et al*., 2002; Shukla *et al*., 2003; Singh and Malhi, 2006). A number of studies clearly established that soil water content was higher in NT than CT (Lampurlanés *et al*., 2001; Mahboubi *et al*., 1993; Starr and Timlin, 2004). Effect of residue retention as mulch on soil water balance, causing increased SWC have been reported both in dry (arid and semi-arid) and wet (sub-humid and humid) regions (Mahboubi *et al.*, 1993; Starr and Timlin, 2004). Changes in microclimate, caused by residue cover often results in reduced heat input into the soil surface which reduces seed zone temperatures and affects crop growth and development. Low soil-surface temperature due to accumulation of crop residues was observed under NT as compared to CT (Fabrizzi *et al.,* 2005; Licht and Al-Kaisi, 2005). This, in turn, reduces the evaporation and increases soil water availability.

The yield under conservation tillage may be improved, which is related to better retention of water through modified pore-size distribution and lower evaporative loss (Baumhardt and Jones, 2002; Jin *et al*., 2009).

Materials and Methods

Study area

Observations were taken in winter wheat (*Triticum aestivum* L.) in a pigeon pea-wheat system during 2009-10 and 2010-11. The experiment has been running since 2004 at the Indian Agricultural Research Institute, New Delhi (28°37′N, 77°09′E, 228.7 m above mean sea level) with four different tillage and residue management practices. The climate is semi-arid with mean annual rainfall of 750-800 mm. Summer is hot and long, and winter is mild and short with average temperatures of 32-35^{0}C and 13-15^{0}C, respectively. The soil (0-0.15 m) is a typic Haplustepts, sandy loam in texture, mild alkaline in reaction, low in soluble salt and organic matter content, and 8-15% (v/v) in available soil water content.

Treatment consisted of conventional tillage with no residue (CT); conventional tillage where crop residues were incorporated (CT+R); no-tillage where residue were removed (NT); and no-tillage with retention of residue as mulch (NT+R), in a randomized block design (RBD) with three replications (plot size 6 m x 3 m). Under the conventional tillage, the plots were ploughed 4-5 times (2 disc harrowing + 2 cultivators + 1 planking), while in no-tillage, the crop was sown without any tillage operations. All the recommended agronomic cultivation practices were followed.

Monitoring of soil moisture content

Soil water content was monitored throughout the wheat growing period by using a neutron moisture meter (CPN 503 DR HYDROPROBE MOISTURE GAUGE, International INC. USA). Measurements were taken from 5-25, 25-40, 40-60, and 60-90 and 90-120 cm layers. Neutron probe access tubes were permanently installed one in each of the replicated experimental plots for *in situ* soil water content at regular intervals. The neutron probe was initially calibrated against soil water content determined gravimetrically and bulk density of the soil at the experimental site as per standard protocol. Soil water content at 0-5 cm layer was determined gravimetrically.

Soil temperature monitoring

Soil temperature was monitored at 3, 7.5 and 15 cm depths at 3-4 days interval throughout the wheat growth duration by using glass thermometers. The data were recorded twice in a day (at 10.00 and 15.30 h) during crop growth period.

Leaf area index (LAI) and specific leaf weight (SLW)

Leaf area index was measured through LAI-2000 Plant Canopy Analyzer (LI-COR, USA on 52, 63, 71, 80, 87, 95, 102, 107, 113 and 120

DAS. Three plants were harvested every time of LAI measurement and the green leaves were separated and the area was measured with a leaf area meter (model LICOR 3100). The leaves were oven-dried at 65±5^{0}C to constant weight to obtain the SLW.

Root weight density (RWD)

Root samples were collected by using root auger at 70 DAS. Roots were washed, processed and oven-dried at 65±5ºC. The dry root biomass was determined and root weight densities were computed per unit volume of the sampling core.

Crop biomass and yield at harvest

A swath of 1 m^2 crop biomass was harvested for each plot, thrashed in the laboratory to separate grains from the crop residues. The grains and the left-over biomass was recorded.

Statistical analysis

Statistical analyses were carried out by using standard procedures in the SPSS software. The means of treatments were separated using LSD following the analysis of variance test at $P<0.05$ (Gomez and Gomez, 1984).

Results and Discussion

Profile soil water content

The soil water content profile over the whole crop growth period followed distinct trends and the effect of tillage as well as residue management were evident. At initial phase, NT had higher soil water content compared to CT at 0-25 cm, just prior to 1st irrigation (Fig. 1). Similar trend was observed in NT+R compared to CT+R. Once irrigation was given, moisture content of all the treatments reached to nearly 0.29 m^3 m^{-3} in this layer irrespective of tillage or residue management. This was followed by a steady decrease in SWC till the 2nd irrigation (given on 52 DAS). After the irrigation, initially, the decrease occurred in similar rates in all the treatments up to 42 DAS, but a relatively higher rate of depletion in CT was noticed thereafter compared to NT. When the effect of residue is compared, the difference is much larger in conventional tillage *i.e.*, between CT and CT+R than no tillage (between NT and NT+R). On the other hand, NT+R, although recording marginally higher SWC from 33 DAS onward than that in NT, the difference was very less. The soil water depletion during 3rd irrigation cycle was similar between CT and NT or CT+R and NT+R, and no apparent residue effect was noticed.

At 25-40 cm soil layer, the soil water content profile was nearly the same and the fluctuations in wet and dry periods were considerably less, compared to those at 0-25 cm layer (Fig. 1). No differences were recorded between CT and NT, except during initial period, when NT had higher SWC. Crop residue effect was not visible in either of the tillage systems. Interestingly, variations in SWC profile at 40-60 cm was observed, where NT showed initially higher (significant up to 14 DAS), then lower (up to 42 DAS) and thereafter higher moisture contents on a few days of observation (*e.g.* 14, 18, 42, 49, 52 and 91 DAS). Similar trend, but with reduced magnitude of difference was recorded at 60-90 cm layer.

The soil moisture content profile clearly indicated the effect of tillage, and also residue management in respective tillage practices. Higher SWC in both NT and NT+R just at the initial crop growth indicates the conservation of soil water under NT, in a condition where there is negligible soil surface cover by vegetation, and loss of water takes place mainly through evaporation. After the 1st irrigation, initially no difference in SWC was noticed, appreciable changes were recorded when soil wetness decreased. This clearly brings out the significant role of no tillage in conserving soil water. This is important keeping in view of the crop growth duration, where the soil water extraction by the crop progressively increases, and a better soil moisture status is the most desirable for improving water us efficiency. Considerably higher moisture was recorded in CT+R, compared to CT, which might possibly be attributed to the significantly larger amount of residual and storage pores in CT+R than CT, which might retain more water (Mondal *et al.*, 2013). Marginally lower

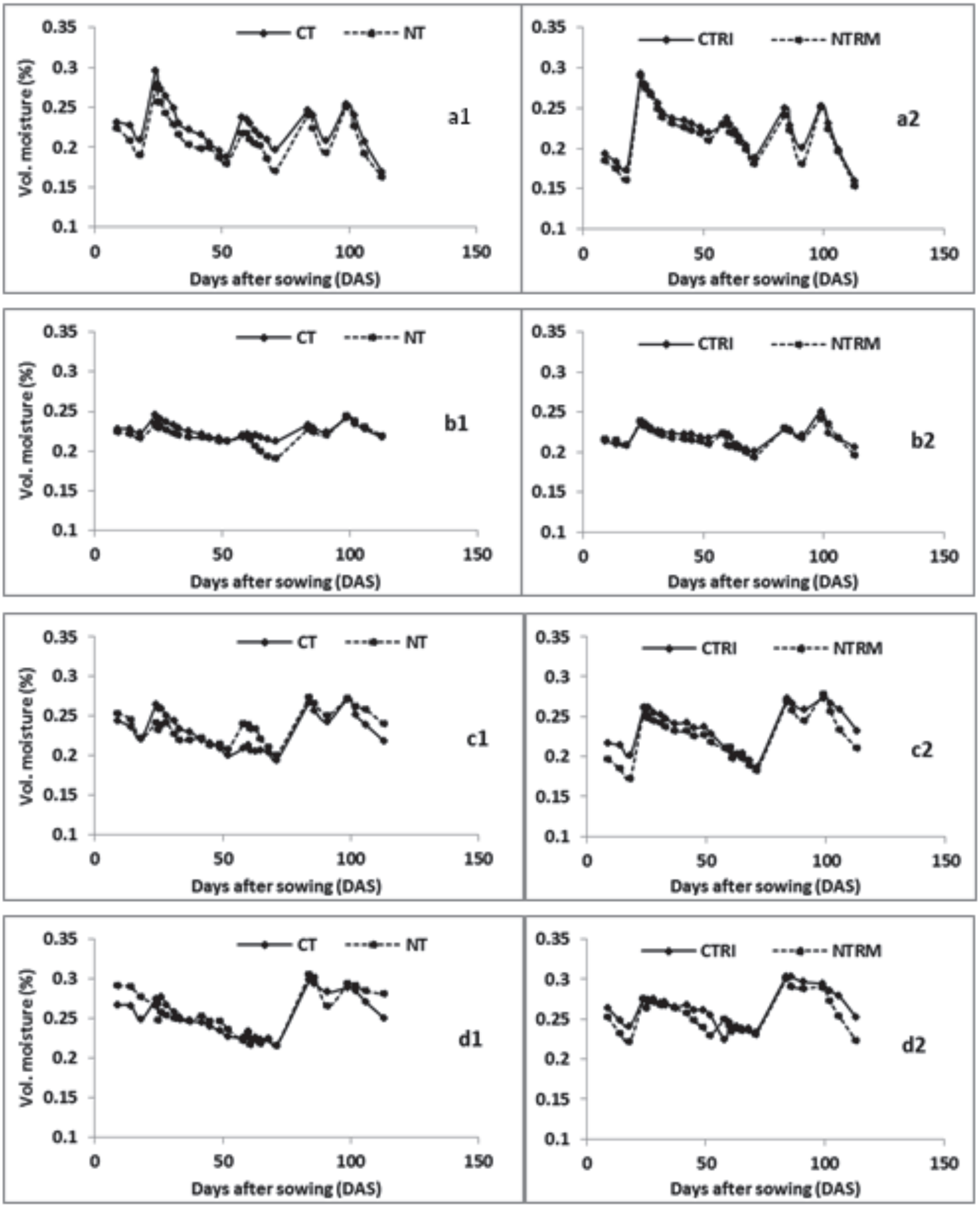

Fig. 1. Profile moisture content over time under various tillage and residue management practices in a) 0-25 cm, b) 25-40 cm, c) 40-60 cm and d) 60-90 cm soil layers

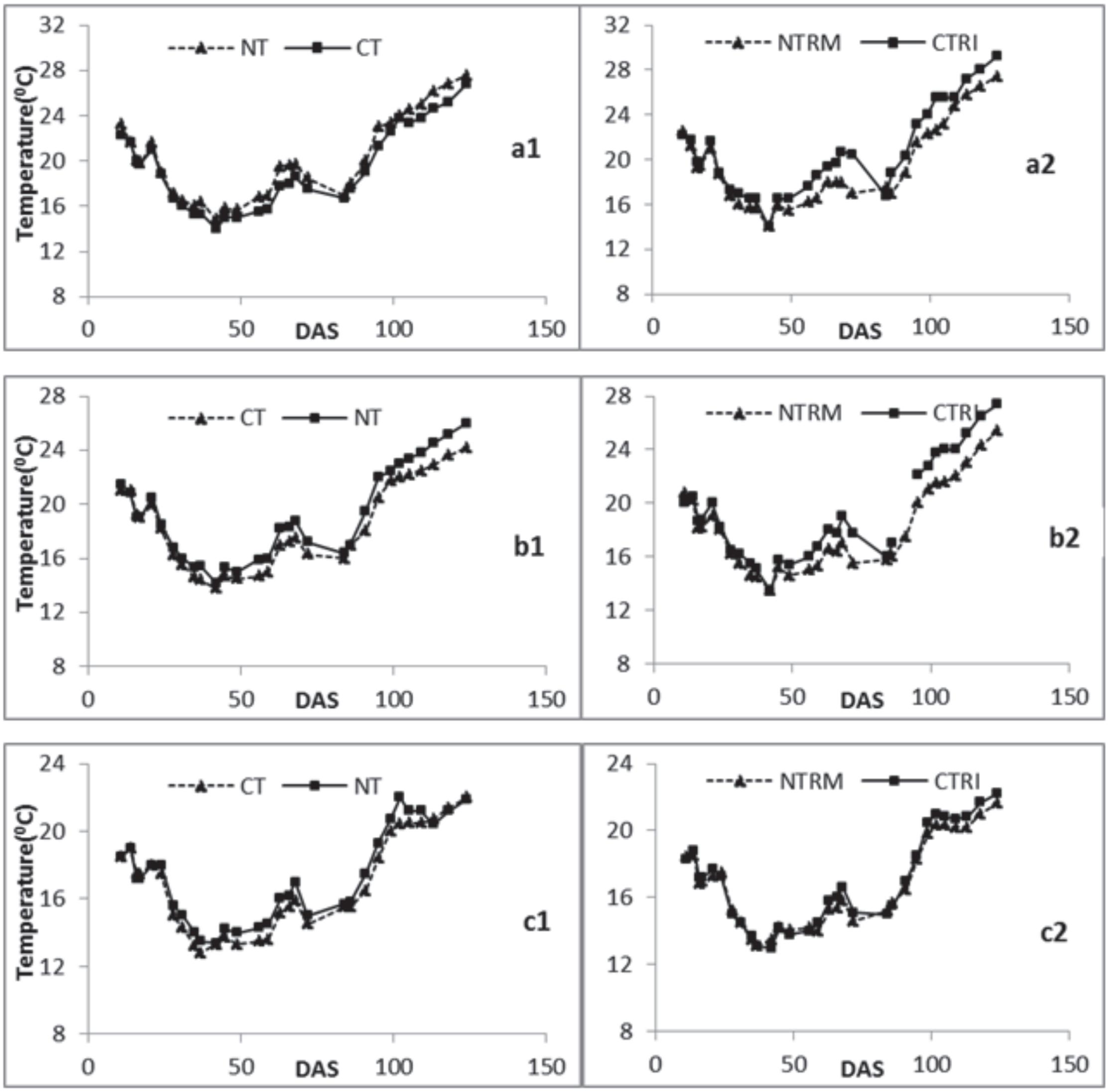

Fig 2. Soil temperature in various treatments at 15.30 h as affected by different tillage and residue management practices throughout the growing period of wheat; a) at 3 cm, b) 7.5 cm and c) 15 cm depths

soil water in NT+R than NT during 2nd irrigation cycle was consistent, possibly due to greater water uptake by the crop under NT+R. Higher SWC was recorded in NT compared to CT (Lampurlanés *et al*., 2001; Mahboubi *et al*., 1993; Starr and Timlin, 2004). Greater availability of crop residues and stubbles on the soil surface under no or minimum tillage in checking evaporation have also been reported (Shaver *et al*., 2002; Johnston *et al*., 2002). However, data on changes in moisture and its availability to crops over its entire period of growth as reported in the present study is scanty (e.g., Bescansa *et al*., 2006).

Soil temperature

The effect of tillage and residue management practices was most prominent at 3 cm depth at 15:30 h (Fig. 2). At this depth, NT showed consistently higher (1-1.5°C) soil temperature at 15:30 h, compared to CT. On the contrary, soil temperature was always lower in NT+R and the difference from CT+R ranged between 1 and 3 °C. Though some treatment difference was initially observed, it was not apparent during 20-30 DAS. The soil temperature started differentiating on 42 DAS onwards and continued thereafter. The relatively warm soil temperature in morning and largely cooling in the afternoon indicated that fluctuations in near surface soil temperature were the minimum under NT+R. At 7.5 cm depth, the trend was the same, except that the effect of tillage and residue was less, compared to 3 cm (Fig. 2). The difference in temperature at 15:30 h between CT and CT+R narrowed down, but the difference between NT and NT+R was more prominent. This was due to further reduction of temperature in NT+R as compared to NT at this depth. At 15 cm soil depth, treatment differences were subtle. At 15:30 h, soil in NT+R was 0.3-0.5°C cooler than CT+R, and even 1-1.5°C cooler than NT and was at par with CT (except some short periods, where it was <1°C warmer).

The NT+R moderated the temperature, especially during 35-71 days (*i.e.,* period of minimum temperature during *rabi* season, and coinciding with the most active phase of wheat growth period). Lowering of soil temperature at 1530 h and warming at 1000 h were recorded under this treatment. Our results are in agreement with others (e.g. Fabrizzi *et al.,* 2005; Licht and Al-Kaisi, 2005). Residue burial in ploughed soil in CT+R reduced the amount of residues left on the soil surface, and therefore has negative consequences in thermal processes. This was evident by increase in soil temperature range between morning and afternoon time (data not presented). Moderation of near surface radiation energy balance and the dynamics of heat exchange processes under NT+R through residue mulch acted as buffer to the quick changes in soil temperature at or near the soil surface.

Leaf area index

At the initial stage, LAI under the treatments was nearly similar, though slightly higher in NT+R (Fig. 3). On 63 DAS onwards, a clear difference in LAI was noted. The trend in LAI increase was practically similar in all the treatments although the rate of increase differed. The increase was sharper in NT+R plots, while it was gradual in CT. The peak value of LAI (3.61) also appeared early in NT+R (95 DAS) compared to NT (102 DAS), CT+R (102 DAS) and CT (107 DAS), although there was no difference in peak LAI values between NT+R and CT+R (3.29), LAI was significantly different in CT (2.81) and NT (2.62). Higher value of LAI in NT+R and CT+R compared to CT and NT throughout the growing period could be attributed to favourable effect of residue. But the effect of tillage on LAI was not prominent as both CT and NT recorded almost similar LAI values.

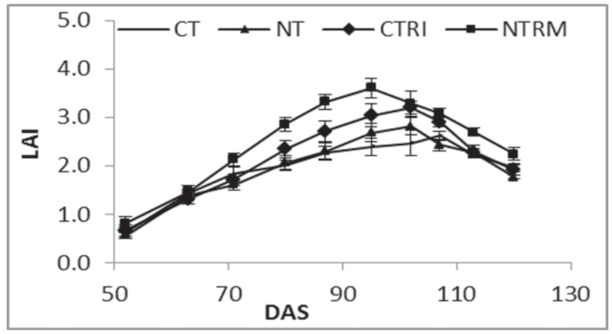

Fig. 3. Change in leaf area index (LAI) under various treatments throughout the growing period

Specific leaf weight

Specific leaf weight reduced slowly up to 95 DAS, and then declined suddenly to almost half of its initial value, followed by a steady decrease and remained constant at maturity (Fig. 4). But unlike LAI, there was no significant difference between the treatments due to tillage only, though residues produced significant differences. The values in CT+R were varying between 14 mg m^{-2} on 52 DAS to 12.3 mg m^{-2} on 95 DAS, while the same was 12.0 and 5.0 mg m^{-2} in CT on similar dates. In NT+R, the corresponding values were 14.6 and 12.0 mg m^{-2} which was significantly different that NT (12.1 and 10.3 mg m^{-2}) on the respective days. No effect of residues was detected thereafter.

Root weight density

A clear and definitive trend in root weight density (RWD) was obtained wherein the tillage effect was best recognized (Fig. 5). In the top layer (0-15 cm), the root growth was highly facilitated by residue addition, and significantly higher RWD values was recorded in CT+R (0.231

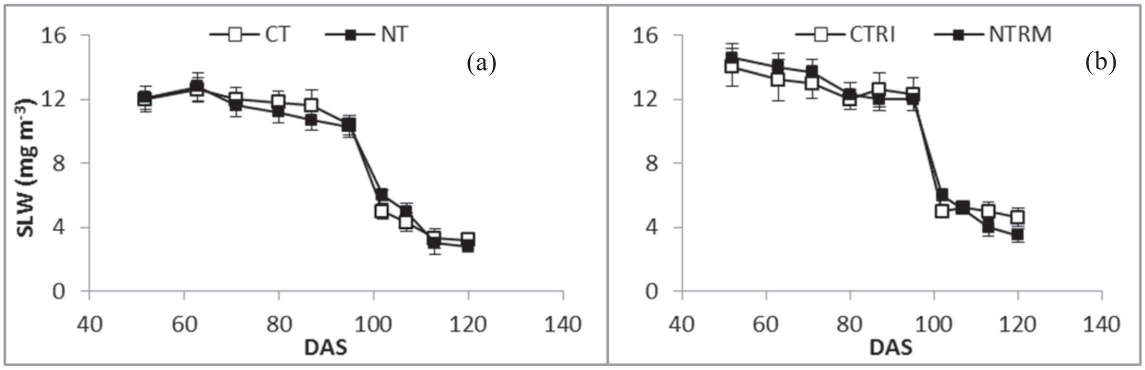

Fig. 4. Specific leaf weight as affected by various (a) tillage and (b) residue management practices

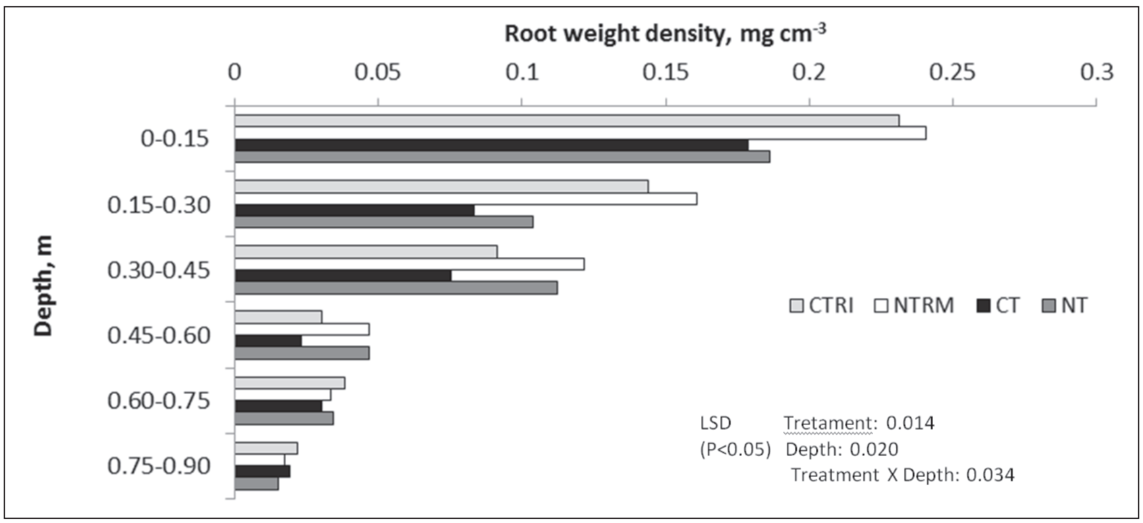

Fig. 5. Depth-wise root weight density in different tillage and residue management practices

mg cm^{-3}) and NT+R (0.241 mg cm^{-3}), compared to 0.178 and 0.186 mg cm^{-3} in CT and NT, respectively. The tillage differences were, however non-significant. Similar trend extends to 15-30 cm layer. But at 30-45 cm, NT resulted in significantly higher RWD (0.122 mg cm^{-3}) than CT (0.091 mg cm^{-3}), and was higher in NT+R (0.112 mg cm^{-3}) compared to CT+R (0.075 mg cm^{-3}). Similar results were obtained at 45-60 cm layer also, but the difference reduced. No difference was noticed at 60-90 cm layer.

The root growth in the entire soil profile (0-0.9 m) clearly indicated effect of tillage alone or in combination with crop residue left over on surface or incorporated into the soil. Residue retention in NT+R as mulch as well as its incorporation in CT+R since last 6 years, could significantly affect the root growth in wheat (Acharya and Sharma, 1994; Gajri *et al.*, 1994), which was nearly 30% higher than CT or NT. The effect of residue extended to next layers also, but tillage effect was more evident at deeper layers. Significantly higher RWD in NT+R or NT clearly reveals that no tillage triggers roots to extend to deeper layers, despite the fact that there was more compaction at the surface in NT/NTRM and similar compaction (hard pan) as CT/CTRI in the sub-surface. This extended root system under no tillage might be attributed to the formation of more number of biopores (macropores), which facilitated roots to grow and extend down the profile.

Yield and biomass at harvest

The CT+R recorded the maximum grain yield, which was 12, 14, 17% higher compared to

NT+R, CT and NT. The lowest yield in NT and 2% less yield compared to NT+R indicates that residue should be left in no tillage system in order to obtain the full benefit of NT. Biological yields followed the similar trend as in grain yield. Greater LAI or deeper root penetration could not result in larger biomass or grain yield in NT or NT+R; the reason could be other factors like management practices or inherent soil fertility difference. Though CT+R recorded highest biological and grain yields, NT+R recorded yield at par to CT. The yield benefit, also referring to a single year data, signifies that NT+R, which is often hailed as better practice from soil and water conservation point of view, can have great potential in achieving yields at par or near to yields obtained in conventional tillage. The CT+R could also be selected as a viable option in modifying soil physical environment in a better way and leads to higher productivity.

Conclusions

In the present study, the effect of either tillage or residue management could be clearly distinguished. The NT+R and NT showed initially higher water content compared to CT and at later stage of crop growth, no apparent difference was perceived. Higher soil water depletion took place from 45-60 cm layers in NT and NT+R plots, possibly due to greater roots at this depth. Though CT+R resulted in the highest grain and biological yield, better crop growth in NT+R was achieved. The yield was only marginally lower than CT+R. Variation in management practices, including competition with weeds in untilled plots must be realized.

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