Canola yield and water productivity as affected by irrigation, tillage and nitrogen levels in northwest India

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ABSTRACT

Depleting groundwater resources calls for the need for diversification to low water-requiring crops and the adoption of water-saving techniques. To evaluate individual and interactive effects of deep tillage, irrigation and nitrogen rates on canola yield and water productivity (*Brassica napus*). Treatments included combinations of two tillage systems *viz*; deep tillage (DT) and conventional tillage (CT), with three irrigation regimes *viz*; no (I_0), one (I_1) and two irrigations (I_2) in main plots and four nitrogen rates *viz*; 0 (N_0), 50 (N_{50}), 75 (N_{75}) and 100 (N_{100}) kg ha^{-1} in subplots with three replications. Maximum rooting depth was observed with irrigation and 100 kg N ha^{-1}. Root mass density in the upper 60 cm soil depth was higher under irrigated plots, whereas below 60 cm, it was higher under I_0. Higher root density was recorded under DT and N_{100} plots. Dry matter accumulation significantly increased with irrigation, tillage and N application. Seed yield significantly increased under DT (10%) and I_2 (26.2% over I_0) treatment. Water productivity improved with DT and N_{100}. Oil yield and N uptake increased under DTI_2N_{100}. Higher nitrogen rates at low irrigation frequency resulted in yield similar to low nitrogen rates at higher irrigation frequency. In contrast, the yield produced under DT with one post-sowing irrigation was equivalent to that produced under CT with two irrigations. The results suggest saving irrigation water and yield optimisation with a high N rate and deep tillage in Canola.

Keywords: Irrigation, nitrogen rates, oilseed rape, root growth, tillage, water productivity

Introduction

Due to high productivity and profitability, the rice-wheat (R-W) cropping system is dominant in the alluvial tract of Indo-Gangetic plains. High water demand and low water productivity of conventional irrigated R-W systems have led to the depletion of surface and ground waters. Hence, it calls for diversification to low water-requiring crops and implementing water-saving techniques. Oilseed rape provides management options for irrigators seeking to reduce irrigation requirements and diversification and/or to reduce input costs due to low water requirements (25–35 cm, Rathore *et al* 2017). India is the world's largest importer of edible oils (FAO 2019). Improvement in yield with the judicious utilization of available resources is required to meet the country's demand. Development, water use and yield of oilseed crops are interrelated. An encouraging effect of irrigating rapeseed mustard at critical stages has been observed (Konwar *et al*. 2019). However, frequent irrigation is sometimes necessary for yield maximization. However, it usually lowers the water use efficiency because soil moisture is lost through evaporation from the moist soil surface, thus increasing consumptive use (Shivran *et al*. 2018). Efficient irrigation water management in brassica can affect seed and oil content enormously and ~~also~~ the response to other applied inputs (Rathore *et al*. 2019). Therefore, proper irrigation scheduling needs to be made, which will provide irrigation at critical growth stages matching the crop evapotranspiration (Kar *et al*. 2005).

Canola is considered a nutrient-exhaustive crop with higher nitrogen (N) requirement than cereals and removes a higher amount of nitrogen until flowering, with a relatively lower amount taken during the reproductive phase (Rathke *et al*. 2005). The seed yield in canola depicts a positive response to increasing rates of fertilizer N (White *et al*. 2015; Ma and Herath 2016) as high as 180 kg N ha^{-1} (Brandt *et al*. 2002). However, excessive use of N fertilizers may promote vegetative growth in the plant at the expense of reproductive growth and environmental pollution (Akmal *et al*. 2014) and lower nitrogen use efficiency (Chamoro *et al*. 2002). Water and nitrogen exhibit interaction effects on rapeseed-mustard growth and yield (Mandal *et al*. 2010), and their economic analysis is helpful in enhancing water and N use efficiency. Thus, it calls for optimization of nitrogen application with an appropriate irrigation schedule to meet the crop necessities and higher yield. Coarse-textured soils show low water-holding capacity, poor fertility and rapid development of mechanical resistance to roots leading to nutrient and water stress in growing crops. The degree and duration of nutrient and water stress can be reduced by synchronizing the active root zone with a soil zone containing nutrients and water. Tillage is the practice of managing water content (Sharma *et al*. 1990) and controlling the hydrothermal regime of soil in the root zone (Moroizumi and Horino 2002) through its effects on the shape, size and continuity of soil pores. Deep tillage lowers the mechanical resistance, thus favouring root growth (Arora et al. 2011). Several studies have shown the benefits of deep tillage, irrigation and nitrogen fertilizer as individual factors. Little information is available on the interactive effects of these three factors, especially on the canola crop. It was hypothesized that the interaction of irrigation, tillage and nitrogen might lead to better resource use efficiency and yield. Thus, the present study was carried out to evaluate the individual and interactive effects of irrigation regimes, tillage and nitrogen rates on the yield and water productivity of canola.

Materials and methods

Site description

A multi-factor study was conducted at the Punjab Agricultural University, Ludhiana, situated at 30°54′ N latitude and 75°48′ E longitude at a height of 247 m above mean sea level during the 2017-19 *rabi* seasons. Important soil physical and chemical properties and weather information of the experimental site are given in Table 1 and Table 2, respectively. Total rainfall during the two growing seasons was 76.0mm (2017-18) and 171.6mm (2018-19). Pan evaporation during cropping season was less than ~~the~~ normal during both ~~the~~ years. Mean maximum air temperature varied between 18.5-35.8°C during different growing seasons as against the normal values of 18.2-34.4°C, while mean minimum temperature varied from 5.5-19.9°C compared to the normal value of 5.6-17.1°C, respectively.

Treatments

Combinations of irrigation regimes and tillage systems as main plots and nitrogen rates as subplots were evaluated in a factorial split-plot design with three replications during two-year extensive field trials. Tillage included conventional tillage (CT) - two discs, two cultivators followed by planking operation and deep tillage (DT) - sub-soiling/chiselling ploughed up to 45 cm deep and 50 cm apart followed by CT. Irrigation regimes comprised of no post-sowing irrigation (I_0), one irrigation (I_1); at 4 weeks after sowing (WAS) and two irrigations (I_2); one at 4 WAS and second in December end or first week of January. Four different N fertilizer rates viz., 0 (N_0), 50 (N_{50}), 75 (N_{75}) and 100 kg ha^{-1} (N_{100}) were applied to canola crops. The gross and net plot sizes were 3.9 x 3.3 m^2 and 3.6 x 3.0 m^2, respectively. The experiment was conducted on the same location, and treatments were imposed on the same plots in both ~~the~~ years of study.

Crop management

After the harvest of the preceding maize crop, the field with DT plots was deeply tilled (sub-soiled) with a tractor-drawn chiseler in the first week of October and then, the whole field was ploughed twice with a disc harrow. Heavy pre-sowing irrigation (about 10 cm) was applied to ensure adequate moisture in the soil profile for seed germination. The field was then prepared by giving two cultivations with a tractor-drawn cultivator followed by planking at proper moisture conditions to obtain a fine seed bed. Canola (GSC 7) was sown with a seed rate of 3.75 kg ha^{-1} and row spacing of 0.45 m in the 4th and 3rd week of October 2017 and 2018, respectively. The whole amount of phosphorus (30 kg P_2O_5 ha^{-1} as single super phosphate) and potassium (15 kg K_2O ha^{-1} as muriate of potash) was applied at sowing. In plots with I_0 irrigation regime, the total dose of nitrogen fertilizer (as urea) was applied at the time of sowing as per treatment, while in plots with other irrigation regimes, 50 per cent of N as per treatment was applied at sowing and remaining dose of N was applied prior to first irrigation. In N_0 plots, no nitrogen was applied. First irrigation was applied in I_1 and I_2 irrigation regimes on December 2, 2017, and November 16, 2018, growing seasons, respectively. In I_2 regime, second irrigation was applied on December 27, 2017 and January 11, 2019. Parshall flume was used to apply 70 mm of water as flood irrigation. Extra plants were uprooted manually to maintain a plant-to-plant spacing of 0.1-0.12 m within a row. Weeds were controlled by hand weeding. Furthermore, the crop was protected against hairy and cabbage caterpillars by spraying rogor 30 EC @ 1.0 kg ha^{-1}. Pesticide Actara 25 WG @ 0.1 kg ha^{-1} in 250 litres of water was sprayed to control aphids. The crop was harvested manually in the first week of April.

Measurements

Soil penetration resistance expressed as cone index (CI) was measured with a digital cone penetrometer (CP40II; Rimik Electronics, RFM Australia) down to 0.60 m depth from different sites in CT and DT plots. Determining root growth and root mass density (RMD), soil cores were sampled at a flowering stage at 0.15 m depth increments down to 1.80 m soil depth with 0.05 m diameter auger centred at 0.075 m away from plant base (Gajri *et al*. 1994). Roots from each sample were washed in net cloth, cleaned, dried at 65°C and weighed. Dry matter accumulation (DMA) was recorded at 60, 110 and 145 DAS from 0.5 m row length from the second outermost row on either side of each plot. The samples were air dried first and later in an oven at 65±2°C till constant weight. The data of DMA was computed and expressed in t ha^{-1}. Total water use based on irrigation ~~water~~, rainfall and profile water use was computed during both cropping seasons. The water productivity of canola was calculated as a ratio of seed yield to total water use. Seed and stover yield was calculated from area of 6.75 m^2 per plot. N content was determined by the modified micro-Kjeldahl method (Piper 1966), and total N uptake was worked out by multiplying the percent N content and yield. Oil yield was calculated by multiplying the oil content (determined by NMR Analyser) in the seed sample of each treatment with its respective seed yield and expressed in t ha^{-1}.

Treatment effects on various parameters were tested for their statistical significance using ANOVA for a factorial split-plot design and comparisons were made at a 5% significance level. Analysis of variance was carried out for various parameters using the computer programme CPCS 1 (Cheema and Singh 1991).

Results

Soil penetration resistance

Deep tillage caused a reduction in the penetration resistance of soil in the tilled zone and down below (Figure 1). The mean cone index in DT plots and CT plots was 0.4 and 0.6, 1.4

(2.0), 1.6 (2.7), 2.0 (3.0), 2.8 (3.2) and 3.2 (3.2) MPa in 0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4, 0.4-0.5 and 0.5-0.6 m of soil depth, respectively.

Rooting depth and density

Roots in canola plants extended up to 1.8 m depth in irrigated plots; while limited to 1.5 m in I_0 plots. Rooting depth increased with an increase in nitrogen dose as in I_0 plots, N_{100} and N_{75} application forced roots down to 1.5 m deep against 1.2 m obtained in N_{50} and N_0. Likewise, in I_1 plots, roots were obtained up to 1.5 m depth under N_0; however, with the application of N fertilizer, roots in canola plants extended to 1.8 m. Tillage, irrigation and nitrogen substantially affected root proliferation in both the seasons. Root mass density (RMD) was higher in DT than in CT, irrespective of the irrigation regimes during both years (Figures 2 and 3). Differences in RMD of DT and CT in the top 0.3 m soil depth were minimal; after that, the difference increased with a maximum in 0.6 to 0.9 m soil layer and became almost equal in layers below 1.2 m. This ensured water and nutrient uptake by the root in deep-tilled soil. Under different irrigation regimes, the surface layer (0-0.15 m) possessed higher root mass density during both the years (Figures 2 and 3). Root mass density increased with an increase in irrigation frequency up to 0.6 m soil layer. While with an increase in soil depth from 0.6 m in I0 revealed 2.8% and 5.4% higher RMD in comparison to both I_1 and I_2, respectively. Fertilizer N application also affected RMD with a higher impact of 100 kg N ha^{-1} as compared to lower N doses in all irrigation regimes (Figures 2 and 3). Increasing the soil depth eventually led to a minimal difference in RMD when assessed with varied N doses. The highest difference in the root density was noticed in the surface soil layer (0-0.15 m).

Dry matter accumulation

An increase in irrigation frequency resulted in higher dry matter production (Table 3) at different crop growth stages. Two irrigations produced significantly high dry matter by 0.39 and 2.00 t ha^{-1} over one irrigation and 1.35 and 3.78 t ha^{-1} over no irrigation, respectively, at 110 and 145 DAS. Tillage significantly affected the canola crop's dry matter accumulation at all growth stages except 60 DAS. The application of nitrogen also improved DMA significantly at all growth stages. At 145 DAS, N100 treatment increased dry matter by 3.34 t ha^{-1} over N_0.

Seed and stover yield

The individual effects of irrigation, tillage and nitrogen rates on the canola seed yield were substantial in both cropping seasons, but the interaction was found non-significant (Table

4). Seed yield recorded during the second rabi season (2018-19; 1.59 t ha-1) was higher than observed during the first season (2017-18; 1.36 t ha-1) due to favourable weather conditions. Over both seasons, two irrigations recorded 10.8 and 26% higher mean seed yields than one irrigation (1.48 t ha^{-1}) and no post-sowing irrigation (1.30 t ha^{-1}), respectively. Deep-tilled plots registered a mean increase of 10% in seed yield over CT. An increase in N fertilizer dose resulted in significant improvement in seed yield in canola, with mean yield varying from 1.04-1.81 t ha^{-1}. Though the interactive effect of factors was insignificant, numerical data showed that deep tillage with one irrigation (2.04 t ha^{-1}) produced at par yield to conventional tillage with two irrigations (2.02 t ha^{-1}) in N_{100} regime in 2018-19. In conventionally tilled plots, two irrigations with 75 kg N ha^{-1} (1.83 t ha^{-1}) gave comparable yield to one irrigation with 100 kg N ha^{-1} (1.88 t ha^{-1}), thus saving either irrigation or N fertilizer. Similar results were obtained in plants with deep tillage.

Stover yield followed a similar trend as seed yield (Table 4). A mean increase of 14% and 9.1% was observed with an increase in irrigation frequency from I_0 to I_1 and I_1 to I_2, respectively. On ~~an~~ average, a stover yield of 5.76 t ha^{-1} was obtained with deep tillage, significantly higher than conventional tillage (5.32 t ha^{-1}). Fertilizer N treatment N_{100} resulted in the highest stover yield (6.69 t ha^{-1}) followed by N_{75} (6.07 t ha^{-1}), N_{50} (5.43 t ha^{-1}) and N_0 (3.98 t ha^{-1}).

Total water use (TWU) and water productivity (WP)

Total water use was higher in the second rabi season (2018-19) due to higher rainfall during the cropping season (Table 5). Total water use increased with increased irrigation frequency and N dose. Deep-tilled plots recorded 2.4% higher TWU than conventionally tilled plots. During the 2018-19 cropping season, tillage influenced irrigation and N effects on total water use by the crop (Table 5). The results suggested that two irrigations alone enhanced water use by 103 mm over 298 mm in I_0N_0, while 100 kg N ha^{-1} increased it by 11 mm, and their combinations increased water use by 120 mm under CT plots. A corresponding increase in water use with these treatments in DT was 111, 25 and 131 mm over 308 mm in I_0N_0. This implies that deep tillage enhanced the irrigation and N effects on total water use. Water productivity was also significantly affected by irrigation, tillage and N fertilizer (Table 5). WP declined with the number of irrigations during both the cropping seasons. A reduction of 11% was observed in water productivity with two irrigations ~~as~~ compared to no irrigation. Deep tillage resulted in 4.49

kg ha^{-1} mm^{-1} of WP, which was higher than conventional tillage by 7.2 percent. Nitrogen application influenced WP positively, with the highest value obtained with N_{100} treatment.

Total N uptake

Superior total N uptake was obtained during the second growing season (81.6 kg ha^{-1}) as compared to the first season (79.0 kg ha^{-1}) (Table 6). Two irrigations (I2)resulted in a significantly higher mean total N uptake of 85.3 kg ha^{-1} as compared to I1 (81.0 kg ha^{-1}) and I0 (74.6 kg ha^{-1}). Deep-tilled plots resulted in an increment of 13.3 % in total N uptake of canola plants in contrast to conventionally tilled plots. The maximum value of total N uptake was recorded under N_{100} treatment (105.6 kg ha^{-1}) followed by N_{75} (89.4 kg ha^{-1}), N_{50} (75.6 kg ha^{-1}) and N_0 (50.6 kg ha^{-1}). The interactive effect showed that the total N uptake recorded under DTN_{50} treatment was statistically at par with that under CTN_{75} treatment.

Oil yield

Irrigation frequency increased oil yield with maximum mean value with two irrigations (0.67 t ha^{-1}) followed by one irrigation (0.61 t ha^{-1}) and no irrigation (0.53 t ha^{-1}) (Table 6). Deep tillage resulted in a significantly % higher oil yield by 10.5 % than conventional tillage (0.57 t ha^{-1}). Oil yield significantly increased with successive increments of N doses up to N_{100}.

Discussion

Effects of Tillage on soil penetration resistance

Compared to conventional tillage, deep tillage significantly reduced soil mechanical resistance in loamy sand and sandy loam soils under soybeans (Arora *et al*. 2011). This reduction in soil mechanical resistance is attributed to soil loosening associated with tillage. Kaur and Arora (2019) also reported that the mean cone index (CI) was 0.6, 1.4, 2.7 MPa in DT plots against 1.4, 3.0 and 3.4 MPa in CT plots for 0-0.2, 0.2-0.4 and 0.4-0.6 m soil depth in maize crop indicating that DT reduced soil penetration resistance.

Effects of tillage, irrigation and N levels on root growth

Both plant genetics and soil parameters determine root growth, and it is highly adaptable to changing environmental conditions (Hodge 2006; Lynch 2011). Higher RMD under DT plots in deeper layers may be attributed to lower soil penetration resistance (Figure 1) by deep ploughing. These results demonstrated that sub-soiling reduces the root distribution at the surface soil and promotes root growth in the deeper layer, thus alleviating root crowding and competition in the topsoil while promoting root growth in the deeper soil layer to improve water and nutrient utilization. These findings are consistent with the studies of Sun *et al*. (2017) and Kaur and Arora (2019) in maize. Caia *et al*. (2014) also reported that loosening the subsoil layer with deep tillage up to 0.5 m increased root length, surface area, dry weight, diameter and the proportion of roots in the 0.4-0.8 m soil layer.

Our results endorse earlier reports on root responses of *Brassica* species to irrigation (Chandra *et al*. 2018). Under restricted irrigation, a relatively drier upper soil profile might cause roots to penetrate in soil faster to lower depths in search of moisture, thus increasing root density in deeper layers (Sarkar and Kar 2000).

The N fertilizer application rate is one of the fundamental components of crop management systems that can regulate ~~the~~ root distribution and certain root traits. An increase in rooting density with an increase in N-levels might be due to the favourable effect of nitrogen on above-ground plant biomass (Table 3) that also encouraged root growth. Results endorse the findings of Marcinkevičienė *et al*. (2013), significantly higher root biomass of rape in 0-0.1 m soil layer with mineral fertilization than no fertilization. Plant roots develop more intensively in the upper soil layer with fertilizer application while penetrating deeper without fertilization to contact more soil volume to increase N uptake. Increased root growth with incremented N rates was also reported by Beard *et al*. (2018).

Effects of tillage, irrigation and N levels on DMA and yield

Mishra *et al*. (2019) also recorded the highest DMA with three irrigations, followed by two, one and lowest under no irrigation in mustard. Budzynski *et al*. (2000) also reported higher dry matter accumulation under deep tillage. Subsoil tillage to 0.3-0.45 m soil layer improves soil physical behavior and reduces soil mechanical resistance to root penetration. Importantly, the above-ground stability of plants is enhanced by a well-developed root system (Qamar *et al*. 2013). Sharma *et al*. (2007) observed an increase in dry matter production of mustard with the increase in nitrogen rate, and the highest DMA was recorded at 80 kg N ha^{-1}. This might be due to higher photosynthesis and translocation of assimilates toward reproductive structure owing to adequate soil moisture. The results conformed with Ray *et al*. (2015) and Shivran *et al*. (2018). Deep tillage provided better root growth and moisture extraction that helped the crop initially develop an adequate source (as reflected by high above-ground biomass) compared to CT. Deep ploughing significantly increased the seed yield of mustard over conventional tillage (Pal and Phogat 2005). Our results corroborate ~~with~~ the findings of Ali *et al*. (2019) in Canola. This increase is attributed to the enhanced availability of moisture, which led to a better nutritional environment at the critical crop growth stages, resulting in better vegetative growth. These results endorse the findings of Konwar *et al*. (2019). The increase in stover yield in mustard was 30.3% and 49.4% by 80 kg N ha^{-1} over 40 kg N ha^{-1} and control, respectively (Kumar *et al*. 2018). Tyagi and Upadhyay (2017) concluded that irrigation frequency increased ~~the~~ consumptive water use considerably; 33.1% and 8.3% increase over no-post sowing irrigation with two and one irrigation, respectively. This was expected because irrigation increased the available water in the soil profile and facilitated more water loss through evapotranspiration compared to no irrigation. Similar results were reported by Konwar *et al*. (2019).

Effects of tillage, irrigation and N levels on TWU and Water Productivity

Tyagi and Upadhyay (2017) concluded that irrigation frequency increased the consumptive water use (CU) considerably; 33.1% and 8.34% increase over no-post sowing irrigation with two and one irrigation, respectively. This was expected because irrigation increased the available water in the soil profile and facilitated more water loss through evapotranspiration compared to no irrigation. Similar results were reported by Konwar *et al*. (2019). This implies that deep tillage enhanced the irrigation and N effects on total water use. The results conformed with the findings of Kaur and Arora (2019).

A decrease in WP with the successive increase in the number of irrigations is due to the greater expense of water by evapotranspiration without a proportionate increase in seed yield. While under one irrigation, the crop developed a deep root system. It utilized some moisture from deeper soil layers than frequent irrigation and achieved a higher yield per unit of water, resulting in higher water productivity. Tyagi and Upadhyay (2017) recorded significantly higher WP with ~~the application of~~ one irrigation followed by two irrigations and no-post-sowing irrigation. Tao *et al*. (2015) reported that subsoil tillage in spring maize significantly increased mean WP_{ET} by 14 percent on ~~a~~ sandy loam soil in China. Similar results were also reported by Kaur and Arora (2019). At a specific irrigation level, greater evapotranspiration in fertilized plots was primarily associated with stimulating crop growth and increased DMA with a greater interception of solar radiation (Mandal and Sinha 2004) and increased root biomass. Thus, nutrient application positively influenced WP. The greater increase in seed yield in N_{100}, N_{75} and N_{50} over N_0 and relatively less increase of the corresponding ET have evidently resulted in significantly higher WP, particularly in applying the highest N rate (100 kg N ha^{-1}).

Effects of tillage, irrigation and N levels on total N uptake and oil yield

Rajput (2017) reported that the highest total nitrogen uptake by Indian mustard was observed with 120 kg N ha^{-1}, which was significantly superior over 0, 40 and 80 kg N ha^{-1}. Pal *et al*. (2009) concluded that the oil yield of mustard could be increased by 41 percent with deep ploughing as compared to conventional tillage. These results endorse early reports of N effects on oil yield in Canola (Sukirtee *et al*. 2018).

Conclusion

This study demonstrated that two irrigation and a higher nitrogen rate (100 kg N ha^{-1}) along with deep tillage significantly increased the growth, yield and nitrogen uptake of canola oilseed rape. Two irrigations produced a 10.8 percent higher mean grain yield over one irrigation and 26.2 percent over no post-sowing irrigation. Deep tillage incremented seed yield by 10 percent over conventional tillage. Seed yield significantly increased up to N_{100}, with the highest seed yield production of 1.81 t ha^{-1} among nitrogen rates averaged over two years. Deep tillage and a nitrogen dose of 100 kg ha-1 improved water productivity. Higher nitrogen rates at low irrigation frequency resulted in yield similar to low nitrogen rates at higher irrigation frequency. Deep tillage with one irrigation produced a similar yield as under conventional tillage with two irrigations suggesting saving irrigation water.

Data Availability Statement

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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Table 1 Physico-chemical properties of experimental site

Depth (cm)	Soil separates (%)			Textural class	Bulk Density (Mg m^{-3})	Water holding capacity (%, v/v)		Available N (kg ha^{-1})
	Sand	Silt	Clay			FC	-15 bar	
0-15	79.3	11.7	7.6	Loamy Sand	1.38	14.5	4.0	80.3
15-30	80.6	12.3	6.3	Loamy Sand	1.42	15.0	4.5	77.1
30-60	81.9	9.5	8.5	Loamy Sand	1.47	17.0	6.0	60.3
60-90	83.5	7.7	8.8	Loamy Sand	1.53	17.0	6.8	52.8
90-120	84.3	8.4	7.3	Loamy Sand	1.55	18.0	6.5	55.5
120-150	82.8	8.7	8.5	Loamy Sand	1.57	18.2	6.3	42.1
150-180	81.5	9.8	8.7	Loamy Sand	1.59	18.3	6.4	40.1

Table 2 Monthly mean of daily maximum and minimum air temperature (°C) and monthly cumulative pan evaporation (E_p, mm) and rainfall (RF, mm) in different cropping seasons.

Month	2017-18				2018-19				Normal value			
	Temp		E_p	RF	Temp		E_p	RF	Temp		E_p	RF
	Max	Min			Max	Min			Max	Min		
October	33.0	18.5	88.7	0.0	31.3	17.1	96.6	0.0	31.8	16.4	123.4	10.9
November	24.7	11.4	47.4	7.0	27.0	11.8	64.0	2.6	26.6	10.6	81.3	6.7
December	20.8	7.5	50.6	24.0	20.7	5.5	40.0	0.0	20.4	.6.5	53.4	17.6
January	18.7	6.2	46.0	18.4	18.5	6.2	43.1	66.0	18.2	5.6	49.5	28.7
February	22.8	9.1	64.4	27.0	20.1	9.2	46.2	95.6	21.0	7.6	48.4	33.3
March	29.3	13.9	125.3	0.0	25.3	11.8	84.8	7.4	26.6	11.7	118.5	21.0
April	35.8	19.9	218.3	10.0	35.1	19.5	170.3	41.6	34.4	17.1	211.4	27.8
Total	-	-	640.7	86.4	-	-	545	213.2	-	-	685.9	146

Table 3 Dry Matter Accumulation (DMA, t ha^{-1}) of canola crop at various stages as influenced by tillage, irrigation and nitrogen levels in different cropping seasons.

Treatment		60 DAS								110 DAS							
		2017-18				2018-19				2017-18				2018-19			
		N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}			
		0	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**
	I_0	0.13	0.16	0.26	0.34	0.20	0.29	0.35	0.45	0.30	0.57	0.84	1.24	0.43	0.64	0.92	1.26
CT	**I_1**	0.24	0.69	0.76	0.84	0.25	0.74	0.82	0.87	0.89	1.50	1.76	2.51	0.98	1.61	1.88	2.59
	I_2	0.25	0.58	0.75	0.90	0.26	0.65	0.80	0.93	1.36	1.69	2.17	2.98	1.44	1.73	2.25	3.16
	I_0	0.13	0.18	0.26	0.39	0.23	0.27	0.35	0.39	0.37	0.79	0.94	1.36	0.47	0.90	1.02	1.51
DT	**I_1**	0.28	0.65	0.79	0.93	0.35	0.69	0.80	0.95	1.02	1.61	1.95	2.85	1.08	1.67	1.98	3.01
	I_2	0.30	0.59	0.72	0.86	0.32	0.67	0.82	0.92	1.55	2.08	2.35	2.97	1.63	2.12	2.55	3.21

	60 DAS		110 DAS	
Means	Year	17-18=0.50, 18-19=0.57	Year	17-18=1.57, 18-19=1.67
	Tillage	CT= 0.52; DT= 0.53	Tillage	CT= 1.53; DT= 1.71
	Irrigation	I_0=0.27; I_1=0.67; I_2=0.64	Irrigation	I_0=0.85; I_1=1.81; I_2=2.20
	Nitrogen	N_0=0.24; N_{50}=0.51; N_{75}=0.62; N_{100}=0.73	Nitrogen	N_0=0.96; N_{50}=1.41; N_{75}=1.73; N_{100}=2.39
LSD (p=0.05)	Year=NS		Year=0.03	
	Tillage= NS		Tillage= 0.09	
	Year ×Tillage=NS		Year ×Tillage=NS	
	Irrigation=0.05		Irrigation=0.10	
	Year × Irrigation= NS		Year × Irrigation= NS	
	Tillage × Irrigation=NS		Tillage × Irrigation=NS	
	Year ×Tillage × Irrigation= NS		Year ×Tillage × Irrigation= NS	
	Nitrogen=0.03		Nitrogen=0.06	
	Year × Nitrogen= NS		Year × Nitrogen= NS	
	Tillage × Nitrogen= NS		Tillage × Nitrogen= NS	
	Year ×Tillage × Nitrogen = NS		Year ×Tillage × Nitrogen = NS	
	Irrigation × Nitrogen= NS		Irrigation × Nitrogen= NS	
	Year × Irrigation × Nitrogen=NS		Year × Irrigation × Nitrogen=NS	
	Tillage × Irrigation × Nitrogen=NS		Tillage × Irrigation × Nitrogen=NS	
	Year × Tillage × Irrigation × Nitrogen=NS		Year × Tillage × Irrigation × Nitrogen=NS	

Continued….

Treatment		145 DAS							
		2017-18				2018-19			
		N- rate, kg ha^{-1}				N- rate, kg ha^{-1}			
		0	50	75	100	0	50	75	100
	I_0	0.72	1.32	2.14	2.38	0.82	1.43	2.20	2.43
CT	I_1	1.92	2.72	4.26	5.34	1.38	2.92	4.58	5.50
	I_2	3.10	4.24	6.02	7.09	3.40	4.76	6.28	7.47
	I_0	1.65	2.70	2.95	3.78	1.85	2.86	3.18	4.07
DT	I_1	2.08	3.81	5.33	6.13	2.23	4.14	5.88	6.77
	I_2	4.46	5.69	8.23	8.55	4.60	5.91	8.47	8.74
Means	Year	17-18=4.03, 18-19=4.24							
	Tillage	CT= 3.52; DT= 4.75							
	Irrigation	I_0=2.28; I_1=4.06; I_2=6.06							
	Nitrogen	N_0=2.35; N_{50}=3.54; N_{75}=4.96; N_{100}=5.69							
LSD (p=0.05)	Year=0.04								
	Tillage= 0.31								
	Year ×Tillage=NS								
	Irrigation=0.38								
	Year × Irrigation= NS								
	Tillage × Irrigation=NS								
	Year ×Tillage × Irrigation= NS								
	Nitrogen=0.21								
	Year × Nitrogen= NS								
	Tillage × Nitrogen= NS								
	Year ×Tillage × Nitrogen = NS								
	Irrigation × Nitrogen= NS								
	Year × Irrigation × Nitrogen=NS								
	Tillage × Irrigation × Nitrogen=NS								
	Year × Tillage × Irrigation × Nitrogen=NS								

Table 4 Canola yield (t ha^{-1}) as influenced by tillage, irrigation and nitrogen levels in different cropping seasons.

Treatment	Seed Yield								Stover yield							
	2017-18				2018-19				2017-18				2018-19			
	N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}			
	0	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**
CT I_0	0.75	1.09	1.28	1.45	0.87	1.34	1.48	1.69	3.26	4.48	4.98	5.42	3.28	4.78	5.25	6.12
CT I_1	0.97	1.21	1.42	1.58	1.03	1.50	1.77	1.88	3.79	4.71	5.71	6.10	3.96	5.48	6.35	7.03
CT I_2	1.03	1.37	1.58	1.76	1.16	1.66	1.83	2.02	4.07	5.76	6.22	6.54	4.34	6.08	6.74	7.33
DT I_0	0.86	1.19	1.36	1.53	0.96	1.43	1.59	1.95	3.66	4.69	5.26	5.51	3.69	5.21	5.89	7.20
DT I_1	1.08	1.34	1.63	1.75	1.13	1.62	1.79	2.04	4.22	5.41	6.13	6.57	4.19	5.90	6.58	7.49
DT I_2	1.24	1.55	1.74	1.89	1.35	1.82	1.97	2.24	4.44	6.06	6.50	6.73	4.85	6.59	7.24	8.23
Means	Year		17-18=1.36, 18-19=1.59						Year		17-18=5.26, 18-19=5.82					
	Tillage		CT= 1.40; DT= 1.54						Tillage		CT= 5.32; DT= 5.76					
	Irrigation		I_0=1.30; I_1=1.48; I_2=1.64						Irrigation		I_0=4.91; I_1=5.60; I_2=6.11					
	Nitrogen		N_0=1.04; N_{50}=1.43; N_{75}=1.62; N_{100}=1.81						Nitrogen		N_0=3.98; N_{50}=5.43; N_{75}=6.07; N_{100}=6.69					
LSD (p=0.05)	Year=0.14								Year=NS							
	Tillage= 0.06								Tillage= 0.19							
	Year ×Tillage=NS								Year ×Tillage=NS							
	Irrigation=0.07								Irrigation=0.23							
	Year × Irrigation= NS								Year × Irrigation= NS							
	Tillage × Irrigation=NS								Tillage × Irrigation=NS							
	Year ×Tillage × Irrigation= NS								Year ×Tillage × Irrigation= NS							
	Nitrogen=0.05								Nitrogen=0.19							
	Year × Nitrogen= 0.08								Year × Nitrogen= 0.27							
	Tillage × Nitrogen= NS								Tillage × Nitrogen= NS							
	Year ×Tillage × Nitrogen = NS								Year ×Tillage × Nitrogen = NS							
	Irrigation × Nitrogen= NS								Irrigation × Nitrogen= NS							
	Year × Irrigation × Nitrogen=NS								Year × Irrigation × Nitrogen=NS							
	Tillage × Irrigation × Nitrogen=NS								Tillage × Irrigation × Nitrogen=NS							
	Year × Tillage × Irrigation × Nitrogen=NS								Year × Tillage × Irrigation × Nitrogen=NS							

Table 5 Total Water Use (mm) and Water Productivity (kg ha^{-1} mm^{-1}) as influenced by tillage, irrigation and nitrogen levels in different cropping seasons.

Treatment	TWU								Water productivity							
	2017-18				2018-19				2017-18				2018-19			
	N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}			
	0	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**
CT **I_0**	250	253	256	257	298	301	305	308	3.02	4.30	4.98	5.65	2.91	4.46	4.85	5.48
CT **I_1**	319	323	327	329	357	359	363	365	3.04	3.74	4.35	4.79	2.89	4.19	4.88	5.16
CT **I_2**	360	367	374	376	401	404	414	417	2.85	3.74	4.24	4.68	2.91	4.12	4.41	4.83
DT **I_0**	249	254	258	259	308	316	325	333	3.43	4.69	5.28	5.92	3.11	4.53	4.89	5.84
DT **I_1**	314	317	321	322	368	371	373	376	3.44	4.24	5.09	5.42	3.07	4.38	4.79	5.41
DT **I_2**	363	371	382	385	420	426	434	440	3.41	4.17	4.55	4.92	3.23	4.27	4.55	5.09
Means	Year		17-18=316, 18-19=366						Year		17-18=4.33, 18-19=4.34					
	Tillage		CT= 337; DT= 345						Tillage		CT= 4.19; DT= 4.49					
	Irrigation		I_0=283; I_1=344; I_2=396						Irrigation		I_0=4.58; I_1=4.31; I_2=4.12					
	Nitrogen		N_0=334; N_{50}=339; N_{75}=344; N_{100}=347						Nitrogen		N_0=3.11; N_{50}=4.24; N_{75}=4.74; N_{100}=5.27					
LSD (p=0.05)									Year=NS Tillage= 0.15 Year ×Tillage=NS Irrigation=0.19 Year × Irrigation= NS Tillage × Irrigation=NS Year ×Tillage × Irrigation= NS Nitrogen=0.15 Year × Nitrogen= NS Tillage × Nitrogen= NS Year ×Tillage × Nitrogen = NS Irrigation × Nitrogen= NS Year × Irrigation × Nitrogen=0.27 Tillage × Irrigation × Nitrogen=NS Year × Tillage × Irrigation × Nitrogen=NS							

Table 6 Effect of irrigation, tillage and nitrogen rates on oil yield (t ha^{-1}) and total N uptake (kg ha^{-1}) of canola

Treatment		Oil Yield (t ha^{-1})								Total N uptake (kg ha^{-1})							
		2017-18				2018-19				2017-18				2018-19			
		N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}				N- rate, kg ha^{-1}			
		0	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**	**0**	**50**	**75**	**100**
	I_0	0.32	0.46	0.54	0.61	0.35	0.53	0.59	0.66	41.66	62.86	74.58	90.52	43.88	67.64	76.77	91.88
CT	**I_1**	0.41	0.51	0.60	0.66	0.41	0.60	0.70	0.74	48.29	65.07	89.33	100.47	48.93	72.99	88.91	101.78
	I_2	0.44	0.58	0.67	0.75	0.47	0.66	0.73	0.80	47.93	77.37	90.57	100.55	51.33	78.91	91.20	104.36
	I_0	0.36	0.51	0.58	0.64	0.38	0.57	0.63	0.76	46.30	73.53	87.95	109.43	49.41	74.68	88.88	113.97
DT	**I_1**	0.46	0.57	0.69	0.74	0.45	0.65	0.71	0.80	52.83	81.06	91.57	110.97	55.55	81.82	94.84	112.33
	I_2	0.53	0.66	0.74	0.81	0.54	0.73	0.76	0.89	59.20	83.87	98.28	112.27	62.30	87.72	100.01	118.65
Means		Year		17-18=0.58, 18-19=0.63						Year		17-18=79.0, 18-19=81.6					
		Tillage		CT= 0.57; DT= 0.63						Tillage		CT= 75.3; DT= 85.3					
		Irrigation		I_0=0.53; I_1=0.61; I_2=0.67						Irrigation		I_0=74.6; I_1=81.0; I_2=85.3					
		Nitrogen		N_0=0.43; N_{50}=0.59; N_{75}=0.66; N_{100}=0.74						Nitrogen		N_0=50.6; N_{50}=75.6; N_{75}=89.4; N_{100}=105.6					
LSD		Year=NS								Year=2.2							
(p=0.05)		Tillage= 0.023								Tillage= 3.0							
		Year ×Tillage=NS								Year ×Tillage=NS							
		Irrigation=0.028								Irrigation=3.7							
		Year × Irrigation= NS								Year × Irrigation= NS							
		Tillage × Irrigation=NS								Tillage × Irrigation=NS							
		Year ×Tillage × Irrigation= NS								Year ×Tillage × Irrigation= NS							
		Nitrogen=0.023								Nitrogen=2.2							
		Year × Nitrogen= NS								Year × Nitrogen= NS							
		Tillage × Nitrogen= NS								Tillage × Nitrogen= NS							
		Year ×Tillage × Nitrogen = NS								Year ×Tillage × Nitrogen = NS							
		Irrigation × Nitrogen= NS								Irrigation × Nitrogen= NS							
		Year × Irrigation × Nitrogen=NS								Year × Irrigation × Nitrogen=NS							
		Tillage × Irrigation × Nitrogen=NS								Tillage × Irrigation × Nitrogen=NS							
		Year × Tillage × Irrigation × Nitrogen=NS								Year × Tillage × Irrigation × Nitrogen=NS							

Fig. 1: Effect of tillage on soil penetration resistance (MPa) distribution in 0-60 cm soil layer

Fig. 2: Effect of tillage and nitrogen rates on depth-wise root mass density (RMD, µgcm^{-3}) of canola under different irrigation regimes during cropping season 2017-18.

Fig. 3: Effect of tillage and nitrogen rates on depth-wise root mass density (RMD, µgcm^{-3}) of canola under different irrigation regimes during cropping season 2018-19.

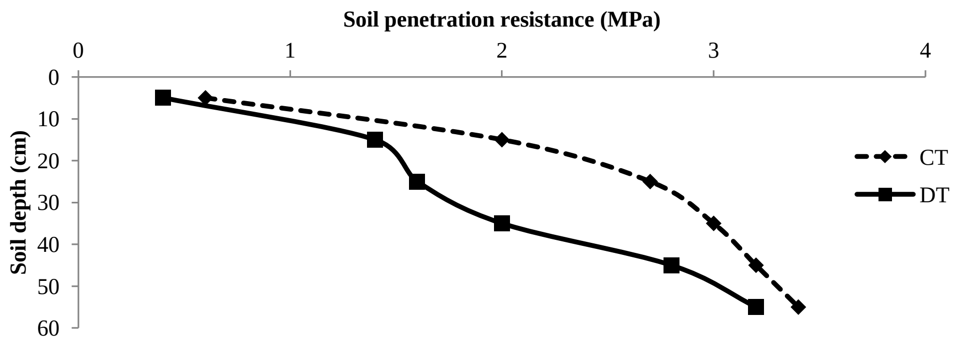
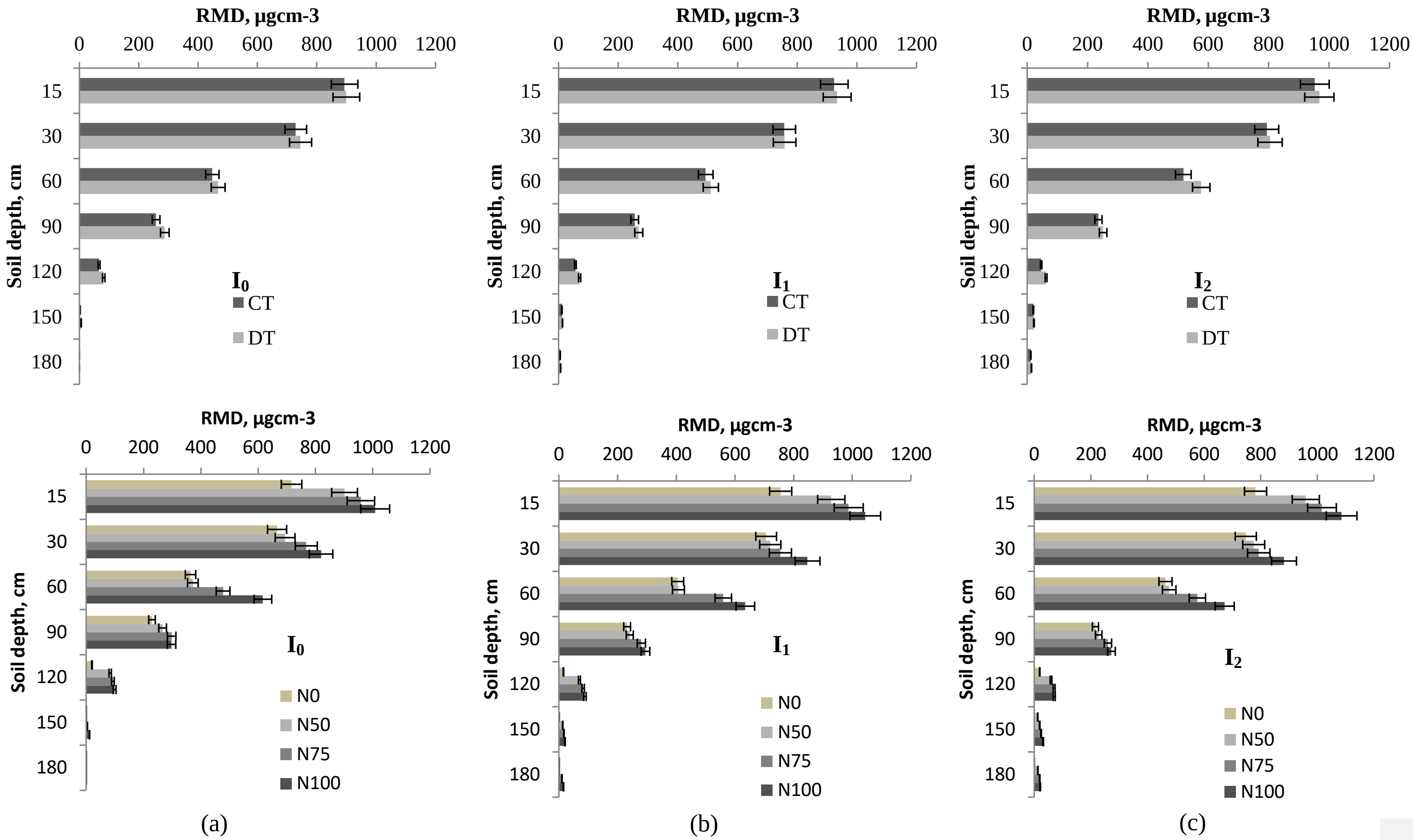
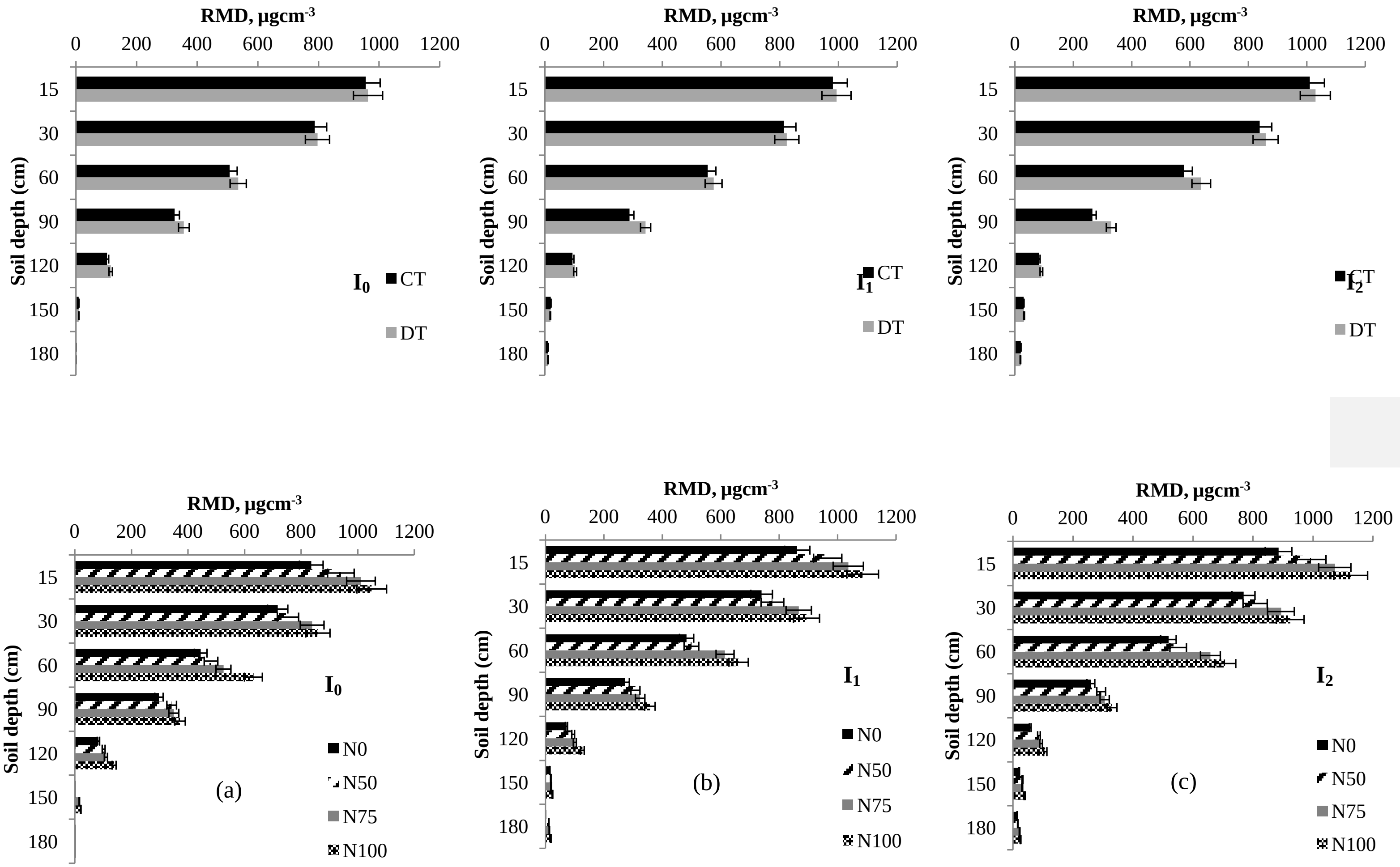


Fig. 1: Effect of tillage on soil penetration resistance (MPa) distribution in 0-60 cm soil layer

Fig. 2: Effect of tillage and nitrogen rates on depth-wise root mass density (RMD, µgcm-3) of canola under different irrigation regimes during cropping season 2017-18.





RMD, µgcm-3
0 200 400 600 800 1000 1200
Soil depth (cm)
15
30
60
90
120
150
180
I0
I1
I2
CT
DT
N0
N50
N75
N100
(a)
(b)
(c)

Fig. 3: Effect of tillage and nitrogen rates on depth-wise root mass density (RMD, μgcm^{-3}) of canola under different irrigation regimes during cropping season 2018-19.