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Effect of Tillage and Nitrogen Levels on Yield and Water Productivity of *Brassica napus* in North West India

Gagandeep Kaur [a], Satinder Singh Brar [a*], C. B. Singh [a] and K. B. Singh [a]

[a] *Department of Soil Science, Punjab Agricultural University, Ludhiana-141004, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In North West India ground water is depleting because of adoption of rice-wheat system. Therefore for saving precious water resources there is need to diversify some area under low water requiring crops and adopt water saving techniques. A field experiment was conducted to evaluate individual and interactive effects of deep tillage, irrigation and nitrogen rates on yield and water productivity of canola (*Brassica napus*). Experimental treatments in main plots were combination of two tillage systems (deep tillage (DT) and conventional tillage (CT)) and three irrigation regimes (no (I_0), one (I_1) and two irrigations (I_2)) and in subplots four nitrogen rates (0 (N_0), 50 (N_{50}), 75 (N_{75}) and 100 (N_{100}) kg ha^{-1} with three replications. Maximum rooting depth was observed with irrigation and 100 kg N ha^{-1}. Root mass density in 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

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*Corresponding author: E-mail: brarpau2010@gmail.com;

at low irrigation frequency resulted in yield similar to low nitrogen rates at higher irrigation frequency. While yield produced under DT with one post sowing irrigation was equivalent to that produced under CT with two irrigations. The results suggest the saving of irrigation water and yield optimisation with high N rate and deep tillage in canola.

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

1. INTRODUCTION

Due to high productivity and profitability, 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 system has led to the depletion of surface and ground waters. Unreliable surface water supplies coupled with excessive groundwater pumpage, due to free electricity and agricultural practices, has led to a long-term groundwater decline of 41.6 cm/yr in the state [1]. The state of development and management of groundwater resources has serious implications for the future of agriculture in the state. Hence, it calls for diversification to low water requiring crops and implementation of 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), [2]. Improving nutrient and water use efficiencies by optimizing field management practices are important strategies to increase economic and environmental sustainability of canola production [3].

India is the world's largest importer of edible oils [4]. 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 inter-related. An encouraging effect of irrigating rapeseed mustard at critical stages has been observed [5]. However, frequent irrigation though sometimes is necessary for yield maximization but it usually lowers the water use efficiency because soil moisture is lost through evaporation from moist soil surface, thus increasing consumptive use [6]. An efficient irrigation water management in brassica can affect seed and oil content enormously and the response to other applied inputs [7]. Therefore, there is a need to make proper irrigation scheduling which will provide irrigation at critical growth stages matching the crop evapotranspiration [8].

Canola is considered as nutrient exhaustive crop with higher nitrogen (N) requirement than cereals and removes a higher amount of nitrogen until flowering with the relatively lower amount taken during reproductive phase [9]. The seed yield in canola depicts positive response to increasing rates of fertilizer N [10,11] as high as 200 kg N ha^{-1} [12]. But excessive use of N fertilizers may promote vegetative growth in the plant at the expense of reproductive growth along with environmental pollution [13] and lower nitrogen use efficiency [14]. Water and nitrogen exhibit interaction effects on rapeseed-mustard growth and yield [15] and their economic analysis is helpful to enhance 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 CITES.

Tillage is the practice for conserving soil water content [16] and control the hydrothermal regime of soil in the root zone [17] through its effects on the shape, size and continuity of soil pores. Deep tillage lowers the mechanical resistance, thus favouring root growth [18]. Several studies [19,20], (Mayer et al 2021); [3] have shown the benefits of deep tillage, irrigation and nitrogen fertilizer as individual factors and little information is available on the interactive effects of these three factors especially on canola crop. It was hypothesized that interaction of irrigation, tillage and nitrogen may lead to better resource use efficiency along with yield. Thus, the present study was carried out with objective to evaluate the individual as well as interactive effects of irrigation regimes, tillage and nitrogen rates on yield and water productivity of canola.

2. MATERIALS AND METHODS

2.1 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 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 76.0 mm (2017-18) and 171.6 mm (2018-19). Pan evaporation during cropping season was less than normal during both 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. CITE.

2.2 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/chiseling 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 crop. The gross plot size and the net plot size 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 same plots in both years of study.

2.3 Crop Management

After harvest of preceding maize crop, the field with DT plots were deep tilled (sub-soiled) with 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 condition to obtain a fine seed bed. Canola (GSC 7) was sown with seed rate of 3.75 kg ha^{-1} and row spacing of 0.45 m in 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 full 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 plant to plant spacing of 0.1-0.12 m within row. Weeds were controlled by hand weeding. and the crop was protected against hairy and cabbage caterpillar by spraying rogor 30 EC @ 1.0 kg ha^{-1}. Pesticide Actara 25 WG @ 0.1 kg ha^{-1} in 250 liters of water was sprayed for the control of aphid. The crop was harvested manually in the first week of April.

2.4 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 flowering stage at 0.15 m depth increments down to 1.80 m soil depth with 0.05 m diameter auger centered at 0.075 m away from plant base [21]. 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, rainfall and profile water use was computed during both cropping seasons. Water productivity of canola was calculated as 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 modified micro-Kjeldahl method [22] and total N uptake was worked out by multiplying 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 5% level of significance. Analysis of variance was carried out for various parameters using computer programme CPCS 1 [23].

3. RESULTS

3.1 Soil Penetration Resistance

Deep tillage caused a reduction in penetration resistance of soil in the tilled zone and down below (Fig. 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.

3.2 Rooting Depth and Density

Roots in canola plants extended up to 1.8 m depth in irrigated plots; while limiting 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 had substantial effects on root proliferation in both seasons. Root mass density (RMD) was higher in DT as compared to CT irrespective of the irrigation regimes during both years (Figs. 2 and 3). Differences in RMD of DT and CT in the top 0.3 m soil depth was minimal; thereafter difference increased with 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 years (Figs. 2 and 3). Root mass density increased with an increase in irrigation frequency up to 0.6 m soil layer. While with increase in soil depth from 0.6 m in I_0 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 the higher impact of 100 kg N ha^{-1} compared to lower N doses in all irrigation regimes (Figs. 2 and 3). Increasing the soil depth eventually led to minimal difference in RMD when assessed with varied N doses where highest difference in the root density was noticed in the surface soil layer (0-0.15 m).

3.3 Dry Matter Accumulation

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 exerted a significant effect on dry matter accumulation of canola crop at all growth stages except 60 DAS. Application of nitrogen also improved DMA significantly at all growth stages. At 145 DAS, N100 treatment resulted in an increase in dry matter by 3.34 t ha^{-1} over N_0.

3.4 Seed and Stover Yield

The individual effects of irrigation, tillage and nitrogen rates on seed yield of canola were substantial in both cropping seasons but interaction was found non-significant (Table 4). Seed yield recorded during second rabi season (2018-19; 1.59 t ha^{-1}) was higher than that observed during first season (2017-18; 1.36 t ha^{-1}) attributed to favorable weather conditions. Averaged over both seasons, two irrigations recorded 10.8 and 26% higher mean seed yield 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. 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 non-significant but 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 the similar trend as seed yield (Table 4). Mean increase by 14% and 9.1% was observed with increase in irrigation frequency from I_0 to I_1 and I_1 to I_2, respectively. On an average, stover yield of 5.76 t ha^{-1} was obtained with deep tillage which was significantly higher than conventional tillage (5.32 t ha^{-1}). Fertilizer N treatment N_{100} resulted in 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}).

3.5 Total Water Use (TWU) and Water Productivity (WP)

Total water use was higher in second rabi season (2018-19) owing to higher rainfall during the cropping season (Table 5). Total water use increased with increase in irrigation frequency as well as N dose. Deep tilled plots recorded 2.4% higher TWU against conventionally tilled plots. During 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 highest value obtained with N_{100} treatment.

3.6 Total N Uptake

Superior total N uptake was obtained during second growng 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 total N uptake recorded under DTN_{50} treatment was statistically at par to that under CTN_{75} treatment.

3.7 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}.

4. DISCUSSION

4.1 Soil Penetration Resistance

When compared to conventional tillage, deep tillage resulted in a significant reduction in soil mechanical resistance in loamy sand and sandy loam soils under soybeans [24]. This reduction in soil mechanical resistance is attributed to soil loosening associated with tillage. Kaur and Arora [25] 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. The decrease in penetration resistance of the sub soil in canola is also associated with reduction in soil bulk density [26].

4.2 Rooting Depth and Density

Root growth is determined by both plant genetics and soil parameters, and it is highly adaptable to changing environmental conditions [27]. Higher RMD under DT plots in deeper layers may be attributed to lower soil penetration resistance (Fig. 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 Wang et al. [28] in canola at Wuhan in China. Cai et al. [29] also reported that loosening of 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. Deep tillage including subsoil tillage and deep plowing, has been shown to improve the physicochemical properties of compacted soils, reduce the soil bulk density and penetration resistance in the tilled layer and break the soil plow pan [29,30]. Additionally, in the subsoil, the DT increased the nutrient concentration [30], promoted water storage, regulated the gas, liquid, and solid-phase ratios of the soil, and improved the activity of subsoil enzymes [31,32].

Our results endorse earlier reports on root responses of *Brassica* species to irrigation [33].

Under restricted irrigation, relatively drier upper soil profile might causes roots to penetrate in soil faster to lower depths in search of moisture; thus increasing root density in deeper layers [34]. More water extraction from deeper soil layers under deficit irrigation at vegetative stage of spring canola compared to full season irrigation have also been reported by Katuwal et al. [35].

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 increase in N-levels might be due to favorable effect of nitrogen on above-ground plant biomass (Table 3) that also encouraged root growth. Results endorse the findings of Sarkar et al. [36], significantly higher root biomass of canola with mineral fertilization than no fertilization. Plant roots develop more intensively in the upper soil layer with fertilizer application while penetrate deeper without fertilization to contact more soil volume in attempt to increase N uptake. Increased root growth with incremented N rates was also reported by Beard et al. [37].

4.3 Dry Matter Accumulation, Seed and Stover Yield

Mishra et al. [38] also recorded the highest dry matter accumulation (DMA) with three irrigations followed by two, one and lowest under no irrigation in mustard. Mishra et al. [38] also reported higher dry matter accumulation under deep tillage. Sub soil 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 plant is enhanced by a well-developed root system [32]. Singh et al. [14] observed an increase in dry matter production of mustard with the increase in nitrogen rate and 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 were in conformity with Ray et al. [39] and Shivran et al. [6]. Deep tillage provided better root growth and moisture extraction that helped the crop to initially develop adequate source (as reflected by high above-ground biomass) as compared to CT. Deep ploughing significantly increased seed yield of mustard over conventional tillage [40]. Our results corroborate with the findings of Ali et al. [41] in canola. This increase is attributed to enhanced availability of moisture which led to a better nutritional environment at the critical crop growth stages, which in turn resulted in better vegetative growth. These results endorse the findings of Konwar et al. [5]. The increase for 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 [42]. Nitrogen application increased seed yield of canola by 20% at a high rainfall site and by 77% at a medium rainfall site [12]. Tyagi and Upadhyay [43] 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 this facilitated more loss of water through evapotranspiration as compared to no irrigation. Similar results were reported by Konwar et al. [5]. Singh et al. [14] also reported that in normal rainfall winter season, seed yield of canola was significantly enhanced up to irrigation at 0.9 IW/CPE ratio. However, further appliance of irrigation at 1.2 IW/CPE ratio exhibited higher yield over irrigation at 0.9 IW/CPE ratio, but the difference statistically non-significant. On the other hand, winter season was deficient in rainfall where the seed yield of canola was significantly increased up to irrigation at 1.2 IW/CPE ratio. This could be describes as applying timely irrigation to the critical stages of the crop ensured sufficient moisture availability helping in proper utilization of nutrients and also a formulation and partitioning of photosynthates to the sink. Similar findings were also illustrated by Gupta et al. [44].

4.4 Total Water Use (TWU) and Water Productivity (WP)

Tyagi and Upadhyay [43] 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 this facilitated more loss of water through evapotranspiration as compared to no irrigation. Similar results were reported by Konwar et al. [5]. This implies that deep tillage enhanced the irrigation and N effects on total water use. The results were in conformity with the findings of Kaur and Arora [25].

A decrease in WP with the successive increase in the number of irrigations is due to the greater expense of water by evapo-transpiration without a proportionate increase in seed yield. While, under one irrigation, the crop developed a deep root system and utilized some moisture from deeper soil layers than frequent irrigation and achieved higher yield per unit of water which in turn resulted in higher water productivity. Tyagi and Upadhyay [43] recorded significantly higher WP with one irrigation followed by 2 irrigations and no-post sowing irrigation. Tao et al. [45] reported that sub soil 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 [25].

At a specific irrigation level, greater evapotranspiration in fertilized plots was primarily associated with stimulating crop growth and increased DMA with greater interception of solar radiation [46] as well as 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 the case of application of the highest N rate (100 kg N ha^{-1}).

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

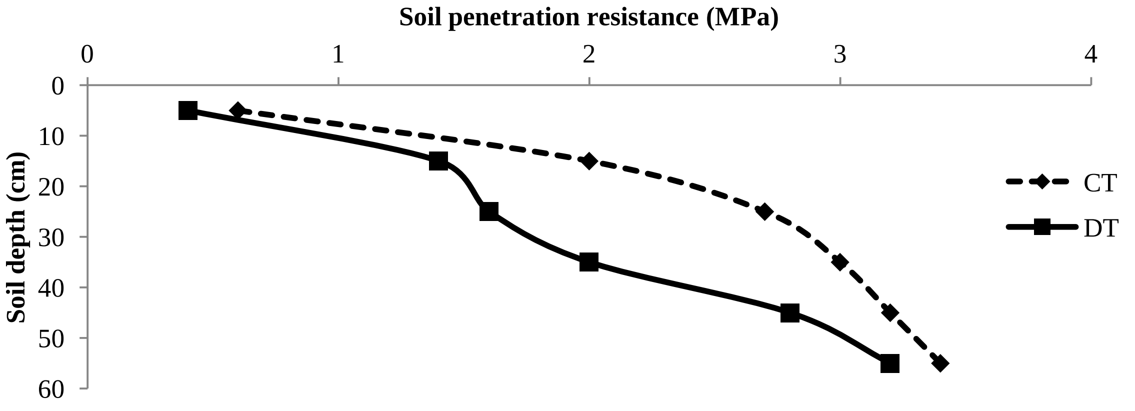


Fig. 1. Effect of tillage on soil penetration resistance (MPa) distribution in 0-60 cm soil layer

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**
CT	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
	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
DT	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
	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
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**
CT	**I_0**	0.72	1.32	2.14	2.38	0.82	1.43	2.20	2.43
	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
DT	**I_0**	1.65	2.70	2.95	3.78	1.85	2.86	3.18	4.07
	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**
	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
	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
	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
	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

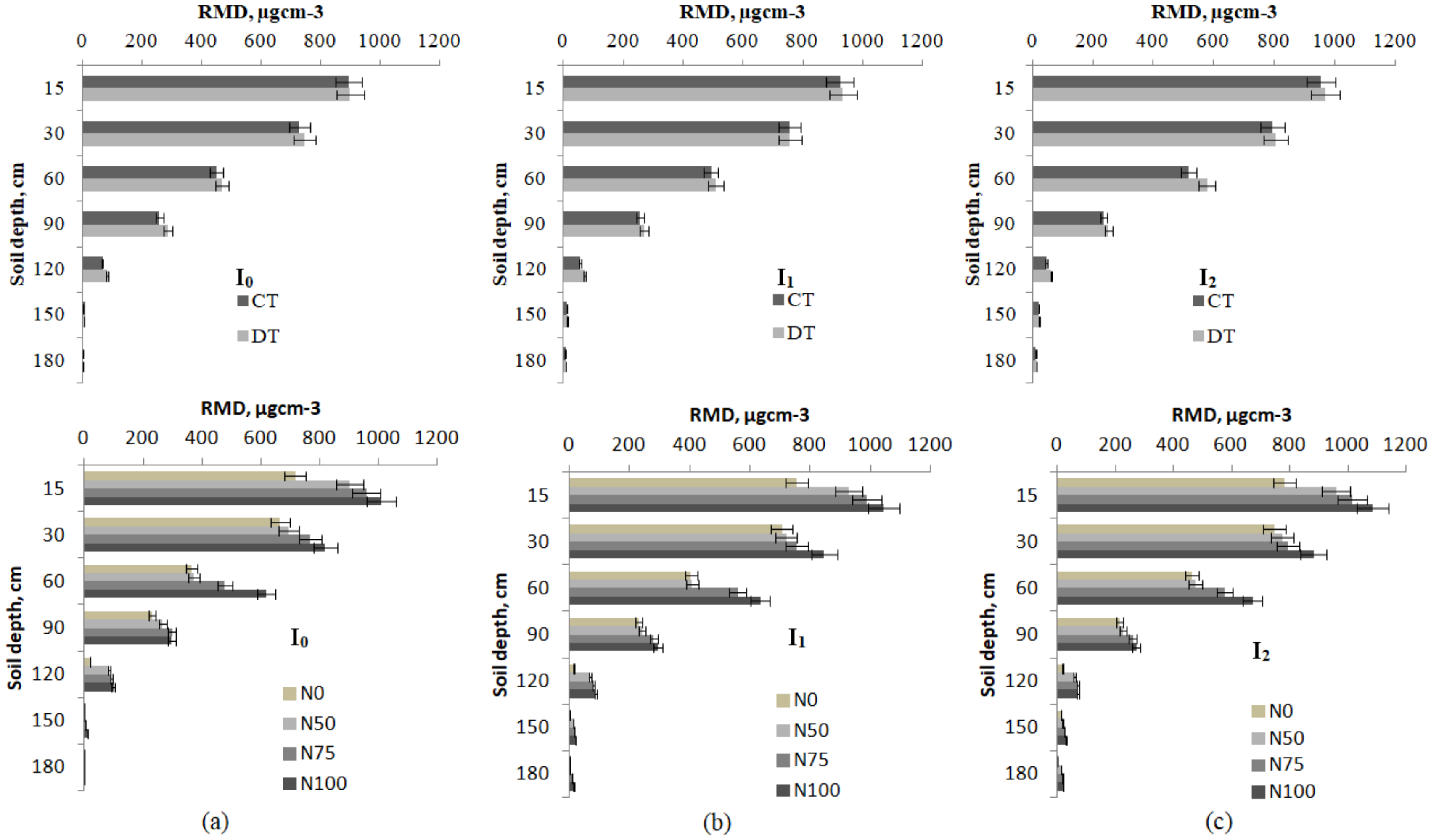
Treatment		**Seed Yield**		**Stover yield**
Means	Year	17-18=1.36, 18-19=1.59	Year	17-18=5.26, 18-19=5.82
	Tillage	CT= 1.40; DT= 1.54	Tillage	CT= 5.32; DT= 5.76
	Irrigation	I_0=1.30; I_1=1.48; I_2=1.64	Irrigation	I_0=4.91; I_1=5.60; I_2=6.11
	Nitrogen	N_0=1.04; N_{50}=1.43; N_{75}=1.62; N_{100}=1.81	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
	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
	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
	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
	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**
CT	**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
	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
DT	**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
	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 Tillage CT= 0.57; DT= 0.63 Irrigation I_0=0.53; I_1=0.61; I_2=0.67 Nitrogen N_0=0.43; N_{50}=0.59; N_{75}=0.66; N_{100}=0.74								Year 17-18=79.0, 18-19=81.6 Tillage CT= 75.3; DT= 85.3 Irrigation I_0=74.6; I_1=81.0; I_2=85.3 Nitrogen N_0=50.6; N_{50}=75.6; N_{75}=89.4; N_{100}=105.6							
LSD (p=0.05)		Year=NS Tillage= 0.023 Year ×Tillage=NS Irrigation=0.028 Year × Irrigation= NS Tillage × Irrigation=NS Year ×Tillage × Irrigation= NS Nitrogen=0.023 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								Year=2.2 Tillage= 3.0 Year ×Tillage=NS Irrigation=3.7 Year × Irrigation= NS Tillage × Irrigation=NS Year ×Tillage × Irrigation= NS Nitrogen=2.2 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							



(a) (b) (c)

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

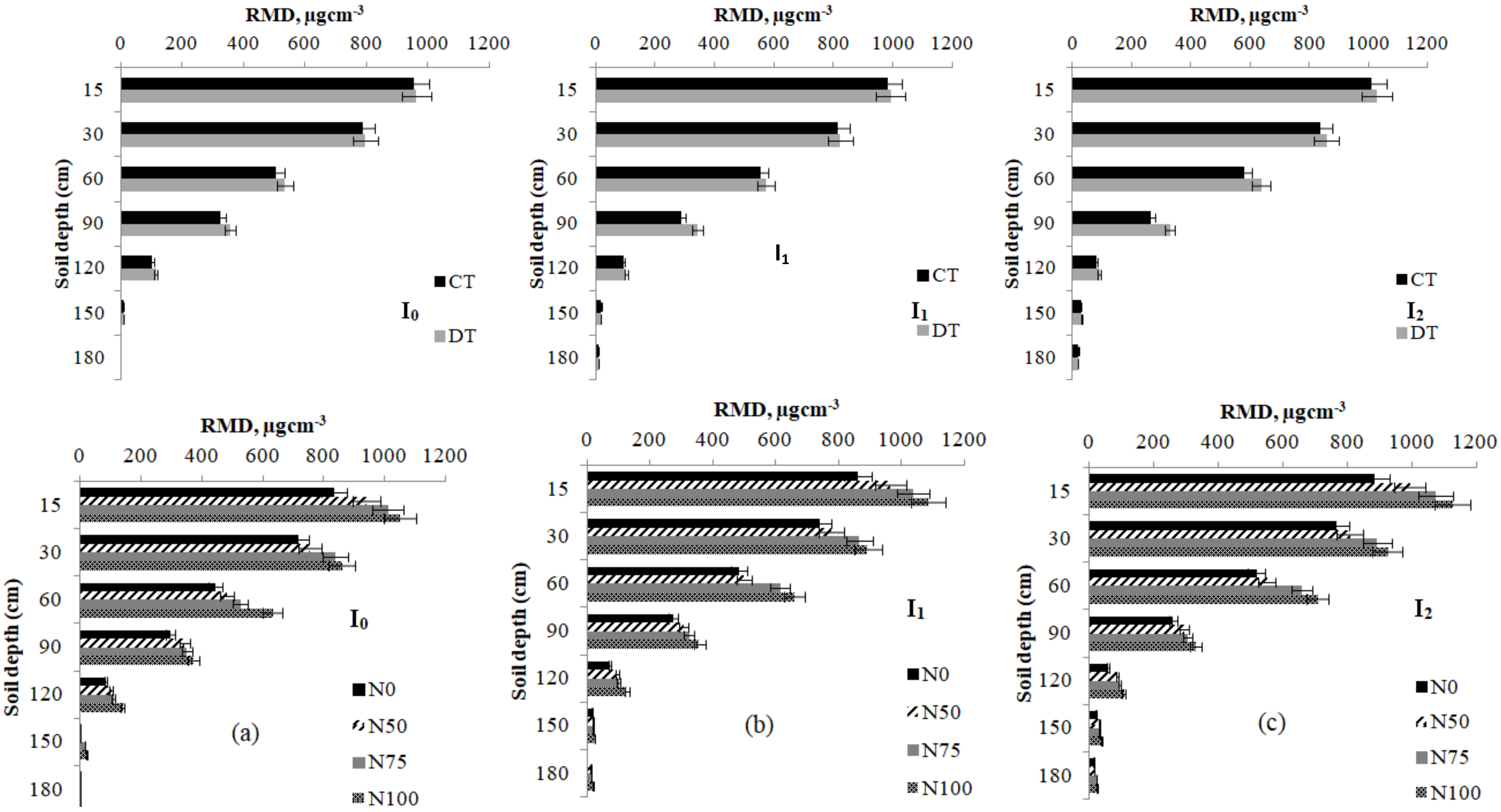


Fig. 3. Effect of tillage and nitrogen rates on depth-wise root mass density (RMD, µgcm^{-3}) of canola under different irrigation regimes during cropping season 2018-19

4.5 Total N Uptake and Oil Yield

Rajput [47] 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. [48] concluded that the oil yield of mustard can 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 [49].

5. CONCLUSION

This study demonstrated that deep tillage, irrigation and nitrogen application rates significantly increased the growth, seed yield and nitrogen uptake of canola. Seed yield significantly increased up to N_{100} and two irrigations. Water productivity improved with deep tillage and nitrogen dose of 100 kg ha^{-1}. Both nitrogen and irrigation are mutually substitute of each other. Depending upon the availability of irrigation or nitrogen fertilizers economic management of these resources can be planned for better returns. Deep tilled plots recorded 2.4% higher TWU against conventionally tilled plots, hence higher crop water productivity. Deep tillage with one irrigation produced similar yield as under conventional tillage with two irrigations suggesting saving of irrigation water.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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