

Impact of tillage, irrigation regimes and nitrogen levels on soil moisture dynamics, growth and productivity of canola (*Brassica napus*)

Abstract

A field experiment was conducted at Punjab Agricultural University, Ludhiana, during *rabi* 2018-19 to examine the effects of tillage, irrigation and nitrogen rates on productivity of canola (*Brassica napus*). Combinations of two tillage systems (Deep tillage- DT, and conventional tillage- CT), with three irrigation regimes viz; no irrigation (I_0), one irrigation (I_1) and two irrigations (I_2) in main plots and four nitrogen (N) rates viz; 0 (N_0), 50 (N_{50}), 75 (N_{75}) and 100 (N_{100}) kg ha⁻¹ in sub plots with three replications. Lower soil moisture content was recorded under deep tillage. Root density in upper 60 cm soil depth was higher in I_2 followed by I_1 and I_0 irrigation regimes whereas below 60 cm, it was higher under I_0 . Higher root density was recorded under DT and N_{100} plots. Irrigation and N application significantly improved plant height, relative leaf water content and SPAD value at different stages. Yield attributes and yield was highest under I_2 , deep tillage and N_{100} treatment. Oil content also improved with successive increments of N rate. It may be concluded that, for higher productivity, canola can be grown under deep tillage with sufficient irrigation (I_2) and N fertilization (N_{100}).

Keywords: Canola, soil moisture dynamics, N rates, root length density, yield attributes

Introduction

Rice-wheat (R-W) cropping system in north-western region of India, although ensuring national food security, has indeed resulted in soil degradation and over-use of underground water resources. In addition, conventional practices for crop management in R-W system involve high cost of production and inefficient input utilization (Jat et al. 2014). Diversifying R-W systems with oilseed-based systems and alternative crop save irrigation water and soil management practices may improve the productivity of system, environmental quality and sustaining soil health. Rapeseed and mustard (*Brassica* species; Family *Brassicaceae*), being the second largest edible oilseed crop after groundnut, accounts for 31.4% in the Indian edible oilseed pool (Singh et al. 2014). India has 59.77 lakh ha area under rapeseed mustard with a production of 8430 thousand tonnes (Anonymous 2019). The share of oilseeds is 14.1 percent out of the total cropped area in India; rapeseed-mustard accounts for 3 percent of it (Anonymous 2018). However, high levels of erucic acid and glucosinolates in Indian cultivars have reduced its preference in international market. Canola is an internationally accepted nomenclature for *Brassica* varieties with less than 2% erucic acid in the oil and glucosinolates less than 30 micro moles per gram defatted meal. Canola oil is used for human consumption and seed meal as a rich source of protein for livestock including poultry. It is a magnificent feedstock for bio fuel production. Canola quality oilseed rape (*Brassica napus* L.) varieties have been fairly successful in India.

Yield of oilseed rape is greatly influenced by various agronomic practices such as tillage, irrigation and fertilization. Tillage has been an important aspect of technological advancement in the evolution of agriculture, especially in food production. Among the main factors of crop production, this is an important factor contributing approximately 20% of the increase in crop yield (Ahmad et al. 1996). Mechanical modifications of soil profiles, commonly referred to as deep tillage, could reduce high subsoil strength, promoting deeper rooting and thus, the plant-availability of subsoil resources (Schneider et al. 2017). Irrigation promotes the growth and yield attributes of mustard by supplementing the water requirement of the crop. Better results both in terms of biometric components and seed yield can be achieved by the application of optimum irrigation. Non-availability of sufficient irrigation water as per requirements of mustard crop causes moisture stress at critical stages of growth and development. Irrigation provided at the most critical growth stages (at flower initiation stage and siliquae development stage) produced the maximum growth and yield attributes (Yadav et al. 2010). Rapeseed-mustard group of crops have relatively higher demand for nitrogen than many other crops (Malagoli et al. 2005) and nitrogen fertilizer rate influences canola seed yield and quality (Malhi and Lemke 2007). Excess nitrogen results in greater succulency in plant and thus may lead to higher incidence of insect-pests and diseases. Hence, an optimum dose of N is of utmost importance to maintain high N use and water use efficiency.

Therefore, the current study was conducted to evaluate the effect of tillage, irrigation and N rates on growth, yield and oil content of canola along with soil moisture distribution during growing season.

Materials and methods

Site description

A multi-factor study was conducted during *rabi* season of 2018-19 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. Important physical and chemical properties of the soil are outlined in Table 1. Total rainfall during growing season was 171.6 mm. Pan-evaporation (545 mm) was below long term average (685.9 mm). During the growing season, the mean maximum air temperature ranged from 18.5-35.1 °C to the normal 18.2-34.4 °C; whereas the mean minimum temperature ranged from 5.5-19.5 °C compared to the normal 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. 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 January start. Nitrogen rates were 0 (N_0), 50 (N_{50}), 75 (N_{75}) and 100 kg ha⁻¹ (N_{100}). The gross plot size was 3.9 x 3.3 m² and the net plot size was 3.6 x 3.0 m².

Crop management

The field plots with DT treatment were deep tilled (sub-soiled) with tractor drawn chiseler in the first week of October after harvesting of the preceding maize crop and then the entire field was ploughed twice with a disc harrow. After heavy pre sowing irrigation (10 cm), the field was prepared by giving two cultivations with a tractor drawn cultivator followed by planking at proper moisture condition to obtain a fine seed bed. Canola crop (GSC 7) was sown @ 3.75 kg ha⁻¹ at row spacing of 45 cm on October 18, 2018. The whole amount of phosphorus (30 kg P₂O₅ ha⁻¹ as single super phosphate) and potassium (15 kg K₂O 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 percent of N as per treatment was applied. Prior to the first irrigation the remaining dose of N as per treatment was applied. No nitrogen was applied in N_0 plots. In I_1 and I_2 irrigation regimes, first irrigation was applied on November 16 and in I_2 regime, second irrigation was applied on December 27, 2018. The measured known amount (70 mm) of irrigation water was applied using the Parshall flume. Harvesting of the crop was done manually in the first week of April.

Measurements

Soil cores for determining root growth were sampled at 50 percent flowering with 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 (Gajri et al. 1994). Roots from each sample were washed in net cloth and cleaned. Root length was measured with CI-203 Area Meter and root length density (root length per unit volume of soil) was calculated. Moisture content of 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm profile layers was determined at different stages of crop growth by thermo gravimetric method with three replications of each treatment. Three plants were randomly selected from each plot and plant height was measured at 64, 91, 132, 154 DAS and at maturity of crop from the base to the tip of the plant. Chlorophyll content in leaves of intact plant was measured with Minolta – SPAD 502 Chlorophyll Meter at 49, 64, 103 and 132 DAS. For each observation, second or third fully opened leaf from apex was selected from ten plants for each treatment by taking the precaution that midrib should not come under the sample area/sensor of the instrument. The mean value of 10 readings was reported as SPAD value. Relative leaf water content (RLWC) was measured at 70, 104 and 152 DAS from fully developed 3rd leaf from the top. Among nitrogen treatments, two extremes (0 and 100 kg N ha⁻¹) were taken for measurements. Immediately after cutting, leaves were sealed within plastic bags and quickly transferred to the laboratory. Five circular disks of 2 cm diameter were cut from each leaf and fresh weight (FW) was recorded. Turgid weight (TW)

was obtained after soaking disks in distilled water in petri plates for 24 hours at room temperature (about 20 °C) and under low light condition of the laboratory. After soaking, disks were quickly and carefully blot dried with tissue paper in preparation for determining turgid weight. Dry weight (DW) of the disk was obtained after oven drying at 70 °C till weight becomes constant. Relative leaf water content was calculated by the formula:

$$\text{RLWC (\%)} = \frac{(\text{FW}-\text{DW})}{(\text{TW}-\text{DW})} \times 100$$

The number of primary and secondary branches per plant and siliquae per plant in each treatment was counted at physiological maturity from three randomly selected plants and computed as mean. Total number of seeds in them was counted from twenty-five siliquae collected randomly in each treatment at maturity just before harvesting. Mean number of seeds per siliqua was calculated. After threshing the crop, a representative sample of seeds from each treatment was collected from bulk produce of the whole plot. One thousand seeds were counted and weighed to give thousand seed weight. Grain and stover yield was calculated from harvested net plot area. The oil content in seed (expressed in percentage) was determined with MQC benchtop Nuclear Magnetic Resonance (NMR) Analyser (Oxford instruments, UK) by using non-destructive method of oil estimation as suggested by Alexander et al. (1967).

Statistical Analysis

Treatment effects on various parameters were tested for their statistical significance using ANOVA for a factorial split-plot design. Regression analysis was done to relate seed yield of canola with nitrogen application rate and yield attributing characters viz; primary branches, secondary branches, siliquae per plant, seeds per siliqua and 1000-seed weight.

Result and discussion

Soil moisture distribution

Distribution of soil moisture in different layers of the root zone reflects water extraction pattern by roots. In general, soil moisture content increased with an increase in soil depth due to lesser evaporation from sub surface. Major contribution for evaporation and greater root activities were responsible for the notably lower moisture content in the upper (0-1.2 m) soil layers (Sarkar and Rana 1999). At 39 DAS, higher soil moisture content was observed under I₁ irrigation regime than I₀ by 3.5 to 1.7 percent of soil moisture content throughout the 180 cm of soil profile (Figure 1). Higher moisture content in I₁ irrigation regime was attributed to application of irrigation water in I₁ prior to sampling. At 70 DAS, difference in soil moisture content between I₁ and I₀ reduced throughout the soil profile with higher values obtained under I₁ irrigation regime than I₀. At 84 DAS, I₂ irrigation regime recorded 8.5, 8.9, 10, 10.1, 10.6, 10.8 and 11.1 per cent soil moisture content against 4.4, 5, 8.1, 9.1, 9.7, 10.1 and 10.7 percent obtained in I₀ in 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm of soil depth,

respectively. Higher moisture content in I_2 irrigation regime than I_1 and I_0 was observed due to application of irrigation water in I_2 before sampling. The differences were lower among soil moisture content in upper soil layers under I_0 , I_1 and I_2 irrigation regimes at 153 DAS due to rainfall however, higher differences were recorded at lower depths. The results were similar to the findings of Mandal et al. (2010) and Zeleke et al. (2014).

Higher soil moisture content was recorded under conventional tillage as compared to deep tillage at all growth stages but most of the difference was observed in lower layers (Figure 2). Denser rooting and increasing dry matter with deep tillage and higher irrigation frequency caused greater extraction of profile stored water. As a consequence, there was less residual water at the end of the growing season in deep tilled plots (Arora et al. 1993). There was no difference between soil moisture content under CT and DT at harvest due to rainfall near harvest.

In general, higher soil moisture content was recorded under N_0 as compared to N_{100} at all growth stages (Figure 3). At 39 DAS, higher values of soil moisture content were obtained under N_0 than N_{100} with maximum difference in 0-60 cm of soil profile. Soil moisture content recorded under N_0 was 4.3, 4.9, 7.6, 9.5, 10, 10.4 and 11.1 percent against 4.8, 5.4, 7.2, 8.9, 9.3, 9.5 and 10.2 percent under N_{100} in 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm of soil depth, respectively. Soil moisture content recorded in 0-30 cm of soil profile at 84 DAS had no difference between N_0 and N_{100} but below 30 cm of soil depth difference was observed being higher under N_0 than N_{100} and thereafter, it reduced with increase in depth. Similar trend was observed at 153 DAS and at harvest. Kumar et al. (2018) observed that 80 kg N ha⁻¹ recorded significantly lower soil moisture content than 40 kg N ha⁻¹ and control in mustard. Increase in nitrogen application rate provided sufficient nitrogen required for plant development enhancing the root growth and above ground biomass. This caused the plant to extract more water from soil profile and hence, resulting in lower moisture content in soil. The findings were in correspondence to the study of Taylor et al. (1991) and Beard et al. (2018).

Root length density

Among irrigation regimes, I_2 recorded highest RLD followed by I_1 and I_0 in upper layers of soil upto 60 cm (Figure 4). Mean increase in RLD under I_2 irrigation regime was 0.34, 0.24 and 0.23 mm cm⁻³ over I_1 and 0.82, 0.48 and 0.44 mm cm⁻³ over I_0 in 0-15, 15-30 and 30-60 cm of soil depth, respectively. In 60-90 and 90-120 cm of soil layers, I_0 irrigation regime recorded maximum RLD of 0.52 and 0.29 mm cm⁻³ which was higher by 10 and 5.1 percent than I_1 and 16.3 and 9.4 percent than I_2 . Below 120 cm soil depth, RLD increased with increase in number of irrigations but difference was smaller. Increased RLD with increase in irrigation frequency are in conformity with the findings of Arora et al. (1993). Root length density was higher in DT as compared to CT with maximum effect observed in 60-90 cm of soil depth (Figure 4). Averaged across nitrogen treatments, DT resulted in RLD of 1.5, 1.3, 0.7, 0.4, 0.2 and

0.1 mm cm⁻³ in 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm of soil depth under unirrigated plots that was 9.6, 5.1, 18, 40, 47.3 and 15.3 percent higher than CT, respectively. In I₁ irrigation regime, increase in RLD under DT plots over CT was 4.8, 5, 16.9, 44.7, 45.6 and 15.9 percent in 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm of soil depth, respectively. The corresponding increase in I₂ irrigation regime was 5.1, 8.3, 13.6, 48.3, 49.4 and 24.3 percent under DT over CT. Arora et al. (1993) reported that below 60 cm depth, DT plots had higher rooting density than CT plots in mustard. Similar results were obtained by Kaur and Arora (2019) in maize crop. With increase in nitrogen dose, RLD increased being highest under N₁₀₀ followed by N₇₅, N₅₀ and N₀. The effect was maximum in upper soil layers and reduced with increase in soil depth. Little difference was observed in deeper layers of soil. Under I₀ irrigation regime, N₁₀₀ recorded 1.6, 1.4, 0.8, 0.6, 0.3 and 0.1 mm cm⁻³ of RLD in 0-15, 15-30, 30-60, 60-90, 90-120 cm and 120-150 cm of soil depth against 1.5, 1.2, 0.7, 0.5 and 0.3 mm cm⁻³ under N₀ in 0-15, 15-30, 30-60, 60-90 and 90-120 cm of soil depth, respectively. In I₁ and I₂ irrigation regimes also, N₁₀₀ resulted in highest RLD as compared to N₇₅, N₅₀ and N₀. Dreccer et al. (2000) reported higher root length density with higher nitrogen dose in oilseed rape. The results were similar to the findings of Liu et al. (2018) and Kaur and Arora (2019). Better root growth may be explained that nitrogen stimulates early root development and their growth (Gour et al. 2019).

Plant height

Irrigation regimes and nitrogen rates significantly influenced the plant height recorded at various growth stages (Table 2). Significant increase in plant height was observed with two irrigations at all growth stages over one irrigation and no post sowing irrigation. Maximum mean plant height recorded was 102.9 cm under I₂ which was significantly higher than I₁ (95.3 cm) and I₀ (80.1 cm) at 91 DAS and corresponding values of about 155, 135 and 111 cm at 132 DAS, 167, 149 and 144 cm at 154 DAS and 188, 170 and 155 cm at maturity, respectively were obtained. Increased in plant height with the application of irrigation water would have been due to availability of higher soil moisture resulting thereby higher leaf water potentials, stomatal conductance, absorption and translocation of nutrients which ultimately reflected in healthy growth of crop. Saud et al. (2016) recorded significantly higher plant height with one irrigation (at flowering stage) than no post sowing irrigation in Indian mustard. Maximum mean plant height of 182 cm was obtained with N₁₀₀ followed by N₇₅ (179 cm), N₅₀ (175 cm) and N₀ (166 cm) at maturity. Similar trend was also observed at other growth stages. Pattam et al. (2017) and Khan et al. (2017) also recorded increase in plant height with increase in nitrogen dose.

Leaf chlorophyll content (SPAD value)

The SPAD value increased up to 103 DAS and decreased thereafter at 132 DAS (Table 2). With increase in number of irrigations, SPAD value increased significantly at all growth stages with mean maximum value of 51.4 obtained with two irrigations followed by 49.3 and 46.7 with one irrigation and

no irrigation, respectively at 103 DAS (Table 2). The improvement in chlorophyll content of leaves under various irrigation levels was probably due to better plant growth and N uptake. It is fact that periodical water stress leads to many anatomical changes like decrease in size of cell and inter cellular space, thicker cell wall, decrease in chlorophyll content and its stability but sufficient moisture condition reverses these anatomical changes by enhancing the turgidity of cells and uptake of nutrients which in turn affects the synthesis of chlorophyll. Sabagh et al. (2017) reported the similar results. Under deep tillage SPAD value was significantly higher than that under conventional tillage and the improvement was 1.6, 1.5, 1.6 and 0.9 at 49, 64, 103 and 132 DAS, respectively. Nitrogen application significantly increased leaf chlorophyll content with maximum value obtained with 100 kg N ha⁻¹ at all growth stages. One of the main components of chlorophyll synthesis is nitrogen. Chlorophyll content increases with increase in nitrogen availability to plant resulting in higher SPAD value in plots with higher nitrogen rates and more number of irrigations. Application of irrigation water and deep tillage maintained optimum soil moisture status in the root zone that accelerated the nitrogen uptake by plant. SPAD value was highest (46.87) and lowest (40.1) with the application of N at the rate of 270 and 90 kg ha⁻¹ as reported by Shengri et al. (2012).

Relative leaf water content (RLWC)

Relative leaf water content (RLWC) increased linearly with increase in growth and highest RLWC was recorded at 152 DAS (Table 3). Irrigation had significant effect on RLWC at all growth stages as depicted in Table 3. At 70 DAS, one irrigation resulted in 3.7 percent significantly higher RLWC than no irrigation. Two irrigations significantly increased the RLWC by 4.5 and 8.3 percent over one irrigation and no irrigation, respectively at 104 DAS. The corresponding increment recorded at 152 DAS was 1.9 and 3.4 percent, respectively. The results indicated that increase in irrigation frequency led to increased relative leaf water content. The high RLWC associated with higher dry matter production rates because cell turgidity is important in relation to the opening and closing of stomata, expansion of leaves and the movement of water and nutrients to the various parts of the plant (Begum and Paul 1993). Relative water content as well as osmotic pressure decreased significantly by prolonging irrigation intervals up to 15 days (Leithy et al. 2015). Relative water content of canola significantly reduced with increasing intervals of irrigation to 45 days as observed by Sabagh et al. (2017). Nitrogen application resulted in significant increase in RLWC throughout the growing period of crop (Table 3). N₁₀₀ recorded 79.4, 83 and 87.4 percent RLWC over N₀ (77.9, 80.7 and 85.4%) at 70, 104 and 152 DAS. The highest value of RLWC was recorded in 100 kg N ha⁻¹ (10.87% increasing over the control) as reported by Namvar and Khandan (2015). It has been shown that increasing nitrogen application will increase the protein synthesis, increase cell wall thickness and cause absorption of extra water by protoplasm and improve the relative water content (Saneoka et al. 2004). Tillage had no significant effect on RLWC of

canola.

Yield attributes and yield

Number of primary and secondary branches

Irrigation regimes, tillage and nitrogen rates significantly affected the production of primary and secondary branches per plant (Table 4). Two irrigations produced maximum number of primary (5.2) and secondary branches (8.2) followed by one irrigation (4.0 and 7.0) and no post sowing irrigation (3.3 and 6.3), respectively. Shivran et al. (2018) reported that three irrigations (30-35 DAS, flowering and siliqua development) produced highest number of primary branches in mustard. Two irrigations (pre-bloom stage + pod filling stage) produced significantly higher number of primary and secondary branches per plant than one irrigation (pre-bloom stage) in mustard (Singh et al. 2016). Significant effect of irrigation regimes on secondary branches was also reported by Rathore et al. (2019) in Indian mustard. This might be due to the reason that better water content in plants enhances growth and better growth produces higher number of branches. Deep tillage increased the production of primary branches by 18 percent and secondary branches by 10.3 percent over conventional tillage. The number of branches plant⁻¹ declined significantly with decreasing the intensity of tillage in Indian mustard (Mishra et al. 2019). Better soil moisture status promoted better root growth resulting in improved shoot growth and higher number of branches. This is in confirmation with the finding of Mondal et al. (2008) and Belal (2013). The plots applied with N₁₀₀ resulted in highest number of primary branches with the mean value of 5.9 which was 1.2, 2.2 and 3.6 higher than N₇₅, N₅₀ and N₀. Similar trend was observed for secondary branches. This agreed with the findings of Akbar et al. (2016) who reported that addition of 100 kg N ha⁻¹ produced maximum (11) number of branches plant⁻¹, while minimum (5) number of branches plant⁻¹ in control plots of canola crop. These results are in line with those reported by Kumar et al. (2018). The reason could be more vegetative growth with increasing nitrogen level which results in more number of branches plant⁻¹ in plots with 100 kg N ha⁻¹ as compared to control plots.

Number of siliquae per plant and grain per siliqua

Two irrigations produced significantly more number of siliquae per plant (371) and grains per siliqua (23.3) as compared to one irrigation (351, 21.2) and no irrigation (328, 19.5), respectively (Table 4). The favourable effect of two irrigations on sink component (number of siliquae and number of grains) could be attributed to better development of the plants in terms of plant height, number of branches and dry biomass production leading to increased bearing capacity due to optimum growth on account of favourable moisture during entire crop growing period (Chauhan et al. 2002 and Pirri and Sharma 2007). Tyagi and Upadhyay (2017) observed that application of two irrigations at 40 and 75 DAS produced significantly the highest number of siliquae plant⁻¹ (101.9) and number of grains siliqua⁻¹ (12) followed by one irrigation at 40 DAS and the lowest under no post sowing irrigation in Indian mustard. Similar

findings were also reported by Jat et al. (2018) and Bharat et al. (2019). Plants in deep tilled plots resulted in 22.3 grains per siliqua which was significantly higher than in conventional tilled plots (20.3 grains per siliqua) whereas for number of siliquae per plant, the value was numerically higher but could not reached at level of significance. Poddar and Kundu (2007) reported that with increase in tillage intensity resulted an increase in number of seeds per siliqua. The nitrogen rates of N_{100} , N_{75} and N_{50} resulted in significant increase in number of siliquae per plant by 26, 16 and 8 percent over N_0 and number of seeds per siliqua by 25, 19 and 7 percent over N_0 . Increasing nitrogen application rate resulted in production of higher number of siliquae per plant (Ren et al. 2017). Similar results were reported by Tufail et al. (2015) and Islam et al. (2018) for number of seeds per siliqua.

Thousand seed weight

Significantly higher mean thousand grain weight was recorded with two irrigations (3.88 g) in comparison to one irrigation (3.35 g) and no post sowing irrigation (2.71 g) as shown in Table 4. Bharat et al. (2019) reported that with increase in irrigation amount, 1000 grain weight increased in Indian mustard. Deep tillage (3.39 g) resulted in significantly higher thousand grain weight than CT (3.24 g). Sub-soiling resulted in 8 percent higher 1000 grain weight as compared to conventional tillage in soybean (Ghosh et al. 2006). Effect of nitrogen rates on 1000 grain weight was significant with maximum mean value obtained with N_{100} (3.69 g) followed by N_{75} (3.50 g), N_{50} (3.24 g) and least with N_0 (2.82 g). The maximum 1000 grain weight was observed from the plot fertilized with 70 kg ha^{-1} , while minimum at 40 kg ha^{-1} as reported by Ali et al. 2019. The results are in line with Hamid and Shaheen (2007) who reported that proper nitrogen level increase the weight of grain due to high uptake of nitrogen which result heavier grain.

Grain and stover yield

Irrigation, tillage and nitrogen rates had substantial effects on grain yield of canola (Table 4). Two irrigations recorded 10 and 9.5 percent significantly higher grain and stover yield than one irrigation (1.6 t ha^{-1} and 1.4 t ha^{-1}) and 25 and 24 percent over no post sowing irrigation (1.4 t ha^{-1} and 5.2 t ha^{-1}), respectively. This might be due to higher photosynthesis and translocation of assimilates toward reproductive structure owing to sufficient soil moisture. The results were in conformity with Ray et al. (2015) and Shivran et al. (2018). The DT plots registered an increase of 9.2 and 9.5 percent higher seed and stover yield over CT, respectively. Deep tillage provided better root growth and better moisture extraction that helped the crop to initially develop adequate source (as reflected by high biomass accumulation) as compared to CT. Pal and Phogat (2005) concluded from their experiment that the deep ploughing significantly increased seed yield of mustard over conventional tillage. Increase in nitrogen dose from N_0 to N_{100} also increased grain yield significantly. N_{100} recorded significantly higher grain yield of 1.97 t ha^{-1} than N_{75} (1.74 t ha^{-1}), N_{50} (1.56 t ha^{-1}) and N_0 (1.08 t ha^{-1}). Increasing N rates improved grain

yield as reported by Ali et al. (2019) in canola.

Oil content

Significant results were obtained for different nitrogen rates while irrigation and tillage had no significant effect (Table 4). Two irrigations resulted in 42.56 percent of oil content which was comparable with one irrigation (42.44 percent) and no irrigation (42.31 percent). Oil content of rain-fed canola and mustard was 7% and 5% lower than the irrigated ones, respectively as observed by Zeleke et al. (2014). Significant effect of number of irrigations on oil content of Indian mustard was also observed by Shivran et al. (2018). Oil content decreased with increase in nitrogen dose. Highest nitrogen dose of 100 kg ha⁻¹ resulted in significantly lower oil content of 42.19 percent against 75 kg N ha⁻¹ (42.41%), 50 kg N ha⁻¹ (42.52%) and 0 kg N ha⁻¹ (42.63%). The possible reason for the decrease in oil content with N increase may be due to the fact that N is the major constituent of protein so it might increase the percentage of grain protein, as a result there might be decrease in the percentage of oil content since it has inverse relationship with protein (Cheema et al. 2001). The results agree with those documented by Olama et al. (2014) and Khan et al. (2018).

Yield attributing parameters and seed yield relationship

The mean value of different yield attributing parameters like primary branches, secondary branches, siliquae per plant, seeds per siliqua and 1000- grain weight were recorded and correlated with grain yield of canola. Regression model was developed with these parameters and grain yield of canola (Table 5). Among these parameters, maximum variation in seed yield was explained by siliquae per plant (89.7 %) followed by number of secondary branches (88.7 %), number of primary branches (78.0 %), seeds per siliqua (77.3 %) and 1000- grain weight (68.3 %).

Conclusion

This study demonstrated that frequent irrigation (two irrigations) and higher nitrogen rate (100 kg N ha⁻¹) along with deep tillage significantly increased the growth, yield attributes, yield and oil content of canola oilseed rape. Two irrigations produced 10 percent higher mean grain yield over one irrigation and 25 percent over no irrigation. Deep tillage incremented seed yield by 9.2 percent over conventional tillage and 100 kg N ha⁻¹ produced highest grain yield. The CT plots retained more soil moisture than DT plots and among N levels, N₀ recorded higher soil moisture content throughout the crop growing season. Root density in upper 60 cm soil depth was higher in I₂ followed by I₁ and I₀ irrigation regimes whereas below 60 cm, it was higher under I₀. Higher root density was recorded under DT and N₁₀₀ plots. It may be concluded that for higher productivity canola can be grown under deep tillage with sufficient irrigation (I₂) and N fertilization (N₁₀₀).

References

Ahmad N, Rashid M, Vaes AG. 1996. Fertilizer and their use in Pakistan, 2nd ed. NFDC.Pub.No. 4/96,

- Islamabad, pp 274.
- Akbar H, Tufail M, Ali S, Jan A. 2016. Nitrogen use efficiency and morpho-phenological traits of canola (*Brassica napus* L.) as influenced by shoots cutting and nitrogen levels. *EC Agric.* 2:530-535.
- Alexander DE, Silvela L, Collins SFI, Rodgers RC. 1967. Analysis of oil content in maize by wide line NMR. *J Am Oil Chem Soc.* 44:555-558.
- Ali W, Anwar S, Khan MH, Iqbal J, Kamal A, Ahmad Z. 2019. Canola yield response to levels and application methods of nitrogen. *Agrotechnol.* 8:189.
- Anonymous, 2018. Package of practices for Rabi Crops of Punjab. pp 44. Punjab Agricultural University, Ludhiana.
- Anonymous, 2019. Production and productivity of rapeseed and mustard in India. <http://www.indiastat.com>
- Arora VK, Gajri PR, Chaudhary MR. 1993. Effects of conventional and deep tillage on mustard for efficient water and nitrogen use in coarse textured soils. *Soil Till Res.* 26:327-340.
- Beard T, Maaz T, Borrelli K, Harsh J, Pan W. 2018. Nitrogen affects wheat and canola silica accumulation, soil silica forms, and crusting. *J Environ Qual.* 47:1380-1388.
- Begum FA, Paul NK. 1993. Influence of soil moisture on growth, water use and yield of mustard. *J Agron Crop Sci.* 170:136-141.
- Belal M. 2013. Effect of irrigation and sowing method on yield and yield attributes of mustard. *Rajshahi Univ J Life Earth Agric Sci.* 41:65-70.
- Bharat R, Kumar J, Rai SK, Gupta R. 2019. Effect of hydrogel and irrigation scheduling on water use efficiency and productivity of Indian mustard (*Brassica juncea* L.) in Jammu region. *J Oilseed Brassica.* 10(2):63-66.
- Chandra K, Pandey A, Mishra SB, Kavita. 2018. Genetic variability of physiological parameters among Indian mustard (*Brassica juncea* L. Czern and Coss) genotypes under non-irrigated and irrigated condition. *Pharma Innovation J.* 7(8):517-525.
- Chauhan DR, Ram M, Singh I. 2002. Response of Indian mustard to irrigation and fertilization with varicose sources and levels of sulphur. *Indian J Agron.* 47:422-426.
- Cheema MA, Malik MA, Hussain A, Shah SH, Basra MA. 2001. Effect of time and rate of nitrogen and phosphorus application on the growth and the seed and oil yield of canola (*Brassica napus* L.). *J Agron Crop Sci.* 186:103-110.
- Dreccer MF, Schapendonk AHCM, Slafer GA, Rabbinge R. 2000. Comparative response of wheat and oilseed rape to nitrogen supply: absorption and utilization efficiency of radiation and nitrogen during the reproductive stages determining yield. *Plant Soil.* 220:189-205.
- Gajri PR, Arora VK, Kumar K. 1994. A procedure for determining average root length density in row

- crops by single-site augering. *Plant Soil*. 160:41-47.
- Ghosh PK, Mohanty M, Bandyopadhyay KK, Painuli DK, Misra AK. 2006. Growth, competition, yield advantage and economics in soybean/pigeonpea intercropping system in semi-arid tropics of India: I. Effect of subsoiling. *Field Crops Res*. 96(1):80-89.
- Gour R, Kushwaha HS, Mangal S. 2019. Optimization basal and foliar application of nitrogen for enhancing productivity of mustard [*Brassica juncea* (L.) Czern and Coss]. *Int J Chem Studies*. 7(1):1553-1556.
- Hamid and Shaheen MA. 2007. Response of seed yield, yield components and oil content of canola and nitrogen fertilizer rate diversity. *Environ Arid Land Agric Sci*. 20:21-31.
- Jat AL, Rathore BS, Desai AG, Shah SK. 2018. Production potential, water productivity and economic feasibility of Indian mustard (*Brassica juncea*) under deficit and adequate irrigation scheduling with hydrogel. *Indian J Agric Sci*. 88(2):212-215.
- Jat RK, Sapkota TB, Singh RG, Jat ML, Kumar M, Gupta RK. 2014. Seven years of conservation agriculture in a rice-wheat rotation of eastern Gangetic Plains of South Asia: yield trends and economic profitability. *Field Crops Res*. 164:199–210.
- Kaur R, Arora VK. 2019. Deep tillage and residue mulch effects on productivity and water and nitrogen economy of spring maize in north-west India. *Agric Water Manage*. 213:724-731.
- Keivanrad S, Zandi P. 2014. Effect of nitrogen levels on growth, yield and oil quality of Indian mustard grown under different plant densities. *Cercetari Agronomice Moldova*. 47:81-95.
- Khan S, Anwar S, Kuai J, Noman A, Shahid M, Din M, Ali A, Zhou G. 2018. Alteration in yield and oil quality traits of winter rapeseed by lodging at different planting density and nitrogen rates. *Scientific Reports*. 8:634.
- Khan S, Anwar S, Kuai J, Ullah S, Fahad S, Zhou G. 2017. Optimization of nitrogen rate and planting density for improving yield, nitrogen use efficiency and lodging resistance in oilseed rape. *Front Plant Sci*. 8:532.
- Kumar K, Kumar Y and Katiyar NK. 2018. Effect of plant geometry, nitrogen level and antitranspirants on physiological growth, yield attributes, WUE and economics of mustard (*Brassica juncea*) under semi-arid conditions of western Uttar Pradesh. *J Pharmacogn Phytochem*. 7(2):226-229.
- Leithy SM, Leila BA, Abdallah EF, Gaballah MS. 2015. Response of canola plants to antitranspirant levels and limited irrigation. *Am Eurasian J Sustain Agric*. 9(4):83-87.
- Liu W, Ma G, Wang C, Wang J, Lu H, Li S, Feng W, Xie Y, Ma D, Kang G. 2018. Irrigation and nitrogen regimes promote the use of soil water and nitrate nitrogen from deep soil layers by regulating root growth in wheat. *Front Plant Sci*. 9:32.

- Malagoli P, Laine P, Rossato L, Ourry A. 2005. Dynamics of nitrogen uptake and mobilization in field grown winter oilseed rape (*Brassica napus*) from stem extension to harvest. *Annals Bot.* 95: 853-861.
- Malhi SS, Lemke R. 2007. Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and nitrous oxide gas emissions in a second 4-yr rotation cycle. *Soil Till Res.* 96:269-283.
- Mandal KG, Hati KM, Misra AK, Bandyopadhyay KK. 2010. Root biomass, crop response and water-yield relationship of mustard (*Brassica juncea* L.) grown under combinations of irrigation and nutrient application. *Irrig Sci.* 28:271-280.
- Mishra J, Singh RK, Yadaw D, Das A, Sahoo S. 2019. Effect of tillage and irrigation frequency on growth of Indian mustard [*Brassica juncea* (L.) Czernj and Cosson]. *Int J Chemical Studies.* 7(1): 2127-2130.
- Mondal N, Hossain S, Bhuiya S. 2008. Tillage and mulching effects on conservation of residual soil moisture, yield attributes and yield of mustard (cv. Daulat.). *Bangladesh J Agric Res.* 33(4):597-606.
- Namvar A, Khandan T. 2015. Inoculation of rapeseed under different rates of inorganic nitrogen and sulfur fertilizer: impact on water relations, cell membrane stability, chlorophyll content and yield. *Archives Agron Soil Sci.* 61(8):1137-1149.
- Olama V, Ronaghi A, Karimian N, Yasrebi J, Hamidi R, Tavajjoh M, Kazemi MR. 2014. Seed quality and micronutrient contents and translocations in rapeseed (*Brassica napus* L.) as affected by nitrogen and zinc fertilizers. *Archives Agron Soil Sci.* 60(3):423-435.
- Pal D, Phogat VK. 2005. Effect of deep tillage and gypsum on yield and N, P, K and S uptake by mustard. *J Indian Soc Soil Sci.* 53(1):134-136.
- Pattam K, Pannu RK, Dhaka AK, Sharma KD. 2017. Effect of dates of sowing and nitrogen levels on growth and yield of Indian mustard. *Int J Curr Microbiol App Sci.* 6(9):1029-1036.
- Pirri I, Sharma SN. 2007. Effect of sulphur on yield attributes and yield of Indian mustard (*B. juncea*) as influenced by irrigation. *Indian J Agric Sci.* 77:188-190.
- Poddar P, Kundu AL. 2007. Influence of tillage systems and different dates of sowing on growth, productivity and economics of *Rabi* rapeseed after *Kharif* paddy. *Environ Ecol.* 25(3):644-647.
- Rathore SS, Shekhawat K, Dass A, Premi OP, Rathore BS, Singh VK. 2019. Deficit irrigation scheduling and superabsorbent polymer- hydrogel enhance seed yield, water productivity and economics of Indian mustard under semi- arid ecologies. *Irrig Drain.* 68:531-541.
- Ray K, Sengupta K, Pal AK, Banerjee H. 2015. Effects of sulphur fertilization on yield, S uptake and quality of Indian mustard under varied irrigation regimes. *Plant Soil Environ.* 61(1):6-10.
- Ren T, Liu B, Lu J, Deng Z, Li X, Cong R. 2017. Optimal plant density and N fertilization to achieve

- higher seed yield and lower N surplus for winter oilseed rape (*Brassica napus* L.). *Field Crops Res.* 204:199-207.
- Sabagh AEL, Abdelaal KAA, Barutcular C. 2017. Impact of antioxidants supplementation on growth, yield and quality traits of canola (*Brassica napus* L.) under irrigation intervals in north Nile delta of Egypt. *J Exp Biol Agric Sci.* 5(2):163-172.
- Saneoka H, Moghaieb REA, Premachandra GS, Fujita K. 2004. Nitrogen nutrition and water stress effects on cell membrane stability and leaf water relations in *Agrostis palustris* Huds. *Env Exp Bot.* 52:131-138.
- Sarkar S, Rana SK. 1999. Role of tillage on productivity and water use pattern of rice-wheat cropping system. *J Indian Soc Soil Sci.* 47(3):532-534.
- Saud RK, Singh BP, Pannu RK. 2016. Effect of limited irrigation and nitrogen levels on growth, yield attributes and yield of Indian mustard (*Brassica juncea* L.). *Agric Sci Digest.* 36(2):142-145.
- Schneider F, Don A, Hennings I, Schmittmann O, Seidel SJ. 2017. The effect of deep tillage on crop yield—What do we really know?. *Soil Till Res.* 174:193-204.
- Shengri AH, Gharineh MH, Bakhshandeh A, Fathi G, Karmollachaab A. 2012. Effect of terminal heat stress and nitrogen on morphophysiological characteristics, ANUE and yield of canola (*Brassica napus* L.). *Int J Agric Crop Sci.* 4:284-288.
- Shivran H, Kumar S, Tomar R, Chauhan GV. 2018. Effect of irrigation schedules on productivity and water use efficiency in Indian mustard (*Brassica juncea* L.). *Int J Chem Studies.* 6(4):15-17.
- Singh PK, Singh AK, Singh RK. 2016. Effect of different dates of sowing and irrigation scheduling on growth and yield of mustard (*Brassica juncea* L.). *Res Environ Life Sci.* 9(2):200-202.
- Singh VV, Bhagirath R, Singh M, Meena ML, Chauhan JS. 2014. Generation mean analysis for water stress tolerance parameters in Indian mustard (*Brassica juncea* (L.) Czern & Coss) Crosses. *J Breeding Genetics.* 46(1):76-80.
- Taylor AJ, Smith CJ, Wilson IB. 1991. Effect of irrigation and nitrogen fertilizer on yield, oil content, nitrogen accumulation and water use of canola (*Brassica napus* L.). *Fertilizer Res.* 29:249-260.
- Tufail M, Akbar H, Ali S, Jan A, Khan A. 2015. Nitrogen levels and shoots cutting influenced on oil contents, yield and yield attributes of Canola. *Pure App Bio.* 4(1):31-37.
- Tyagi PK, Upadhyay AK. 2017. Growth, yield and water use efficiency of Indian mustard (*Brassica juncea* L.) as influenced by irrigation frequency and row spacing. *J Oilseed Brassica.* 8(1):27-36.
- Yadav RP, Tripathi ML, Trivedi SK. 2010. Yield and quality of Indian mustard (*Brassica juncea*) as influenced by irrigation and nutrient levels. *Indian J Agron.* 55(1):56-59.
- Zeleke KT, Lucketts DJ, Cowley RB. 2014. Response of canola (*Brassica napus* L.) and mustard (*B.*

juncea L.) to different watering regimes. Exp Agric. 50(4):573-590.

UNDER PEER REVIEW

Table 1. Physico-chemical properties of experimental site

Depth (cm)	Soil separates (%)			Textural class	Bulk Density (Mg m ⁻³)	Water holding capacity (% v/v)	pH (1:2 soil:water suspension)	EC (dS m ⁻¹)	Organic carbon (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
	Sand	Silt	Clay									
0-15	79.3	11.7	7.6	Loamy Sand	1.38	42.7	8.25	0.19	0.30	80.3	31.8	164.9
15-30	80.6	12.3	6.3	Loamy Sand	1.42	43.5	8.50	0.18	0.22	77.1	25.4	133.3
30-60	81.9	9.5	8.5	Loamy Sand	1.47	40.4	8.46	0.14	0.15	60.3	19.3	111.4
60-90	83.5	7.7	8.8	Loamy Sand	1.53	41.7	8.44	0.13	0.09	52.8	17.9	103.3
90-120	84.3	8.4	7.3	Loamy Sand	1.55	41.3	8.54	0.12	0.05	55.5	15.7	102.8
120-150	82.8	8.7	8.5	Loamy Sand	1.57	41.4	8.56	0.11	0.01	42.1	7.7	101.3
150-180	81.5	9.8	8.7	Loamy Sand	1.59	41.2	8.57	0.13	0.01	40.1	5.1	103.2

Table 2. Effect of irrigation, tillage and nitrogen rates on plant height and SPAD value of canola at various growth stages

Treatment	Plant height (cm)					SPAD			
	64 DAS	91 DAS	132 DAS	154 DAS	At maturity	49 DAS	64 DAS	103 DAS	132 DAS
Irrigation									
I ₀	18.4	80.1	110.6	144.1	154.1	42.7	43.9	46.7	44.6
I ₁	28.5	95.2	134.0	149.4	169.8	44.6	46.4	49.3	46.7
I ₂	29.1	102.9	154.9	166.7	188.3	44.6	46.4	51.4	49.1
CD (0.05)	2.7	4.5	11.2	16.7	7.5	1.3	1.5	1.2	1.4
Tillage									
CT	24.8	92.5	132.5	152.6	170.4	43.2	44.8	48.3	46.3
DT	25.8	93.0	133.9	154.2	171.0	44.7	46.3	50.0	47.3
CD (0.05)	NS	NS	NS	NS	NS	1.0	1.2	1.0	NS
Nitrogen rate									
N ₀	18.9	83.2	117.2	143.6	161.7	40.7	42.3	45.8	43.7
N ₅₀	25.4	91.6	134.6	151.4	169.8	43.5	44.5	48.2	46.0
N ₇₅	27.6	96.9	138.5	157.2	173.7	44.9	46.7	50.6	48.0
N ₁₀₀	29.3	99.1	142.3	161.3	177.8	46.7	48.7	51.9	49.5
CD (0.05)	1.2	2.4	4.6	3.9	2.8	1.1	1.3	0.9	0.7

Table 3. Effect of irrigation, tillage and nitrogen rates on relative leaf water content (RLWC, %) of canola

Treatment	RLWC (%)		
	70 DAS	104 DAS	152 DAS
Irrigation			
I ₀	76.6	77.9	84.6
I ₁	79.4	80.7	85.9
I ₂	79.3	84.4	87.5
CD (0.05)	1.7	0.8	2.2
Tillage			
CT	78.2	80.9	85.6
DT	78.6	81.1	86.4
CD (0.05)	NS	NS	NS
Nitrogen rate			
N ₀	77.7	79.9	84.9
N ₁₀₀	79.2	82.1	87.1
CD (0.05)	0.6	0.7	0.7

Table 4. Effect of irrigation, tillage and nitrogen rates on yield attributes, yield and oil content of canola

Treatment	Primary Branches	Secondary Branches	Siliqua per plant	Grain per siliqua	1000 grain weight (g)	Grain yield (t ha ⁻¹)	Stover yield (t ha ⁻¹)	Oil content (%)
Irrigation								
I ₀	3.26	6.26	328	19.5	2.71	1.41	5.18	42.31
I ₁	3.98	6.98	351	21.2	3.35	1.60	5.87	42.44
I ₂	5.24	8.24	371	23.3	3.88	1.76	6.43	42.56
CD (0.05)	0.23	0.25	28	1.1	0.17	0.12	0.43	NS
Tillage								
CT	3.82	6.82	344	20.3	3.24	1.52	5.56	42.41
DT	4.50	7.50	356	22.3	3.39	1.66	6.09	42.47
CD (0.05)	0.19	0.21	NS	0.9	0.14	0.10	0.35	NS
Nitrogen rate								
N ₀	2.28	5.28	310	18.9	2.82	1.08	4.05	42.63
N ₅₀	3.69	6.70	334	20.3	3.24	1.56	5.67	42.52
N ₇₅	4.74	7.74	361	22.4	3.50	1.74	6.34	42.41
N ₁₀₀	5.93	8.93	394	23.7	3.69	1.97	7.23	42.19
CD (0.05)	0.30	0.31	8	0.7	0.08	0.10	0.29	0.09

Table 5. Yield attributing parameters and grain yield relationship

Dependent variable (Y)	Independent Variable (X)	Regression equation	R²
Seed yield	Primary branches	4.18X-5.83	0.780*
do	Secondary branches	2.12X+0.55	0.887*
do	Siliquae per plant	0.10X-18.31	0.897*
do	Grain per siliqua	1.21X-10.19	0.773*
do	1000- grain weight	5.21X-1.69	0.683*

* Significance at 5% level

UNDER PEER REVIEW

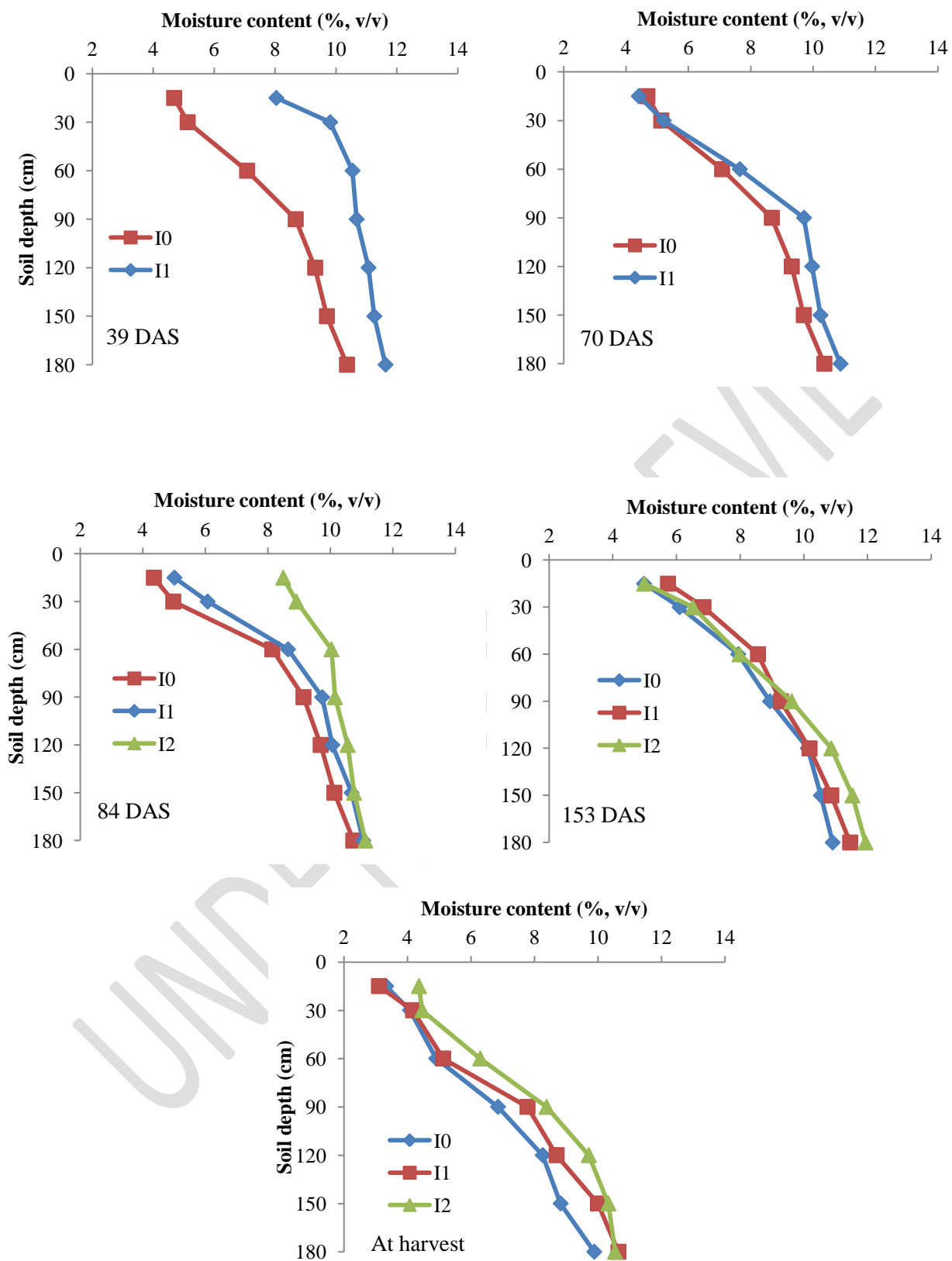


Figure 1. Effect of irrigation on depth-wise volumetric soil moisture content during growing season of canola.

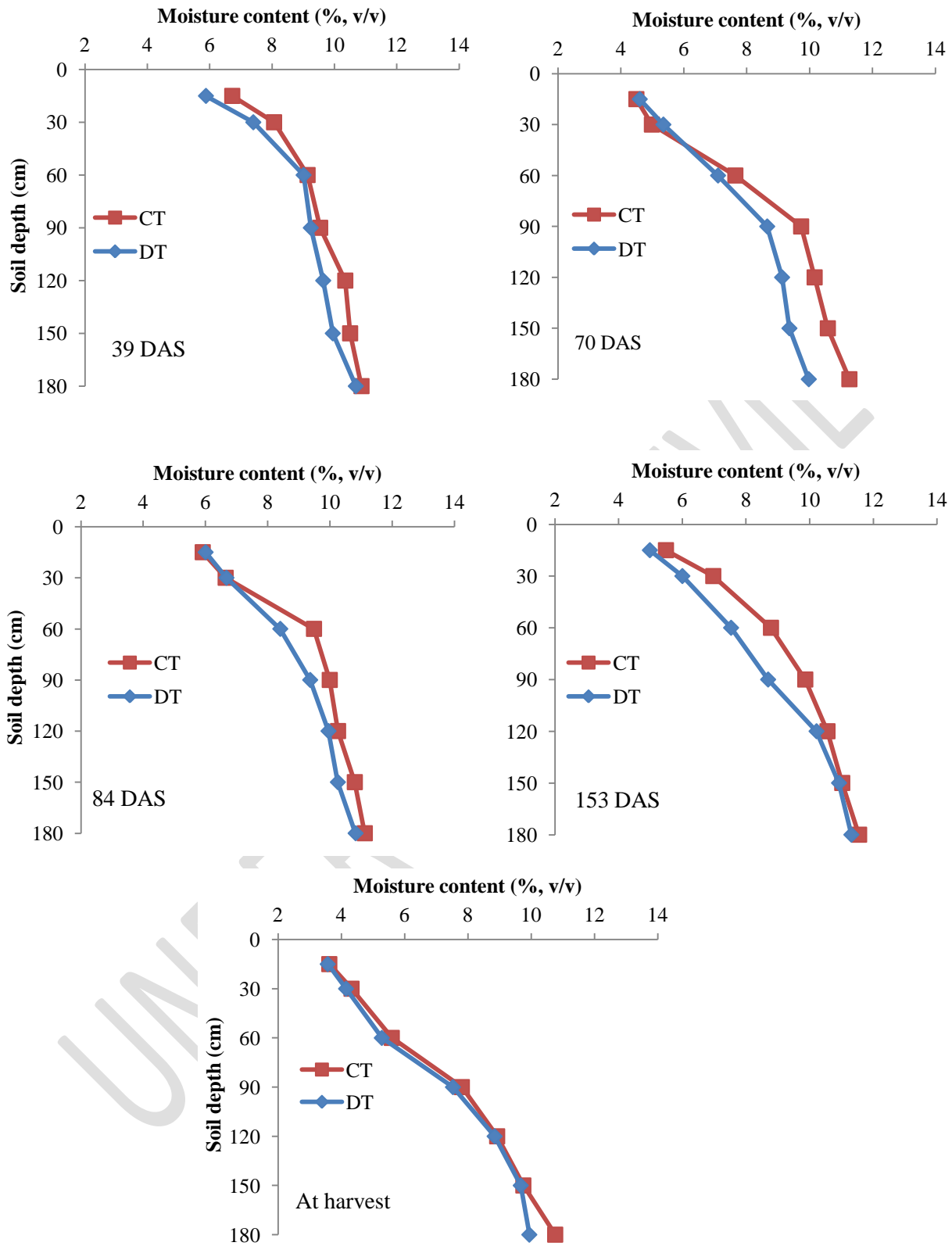


Figure 2. Effect of tillage on depth-wise volumetric soil moisture content during growing season of canola.

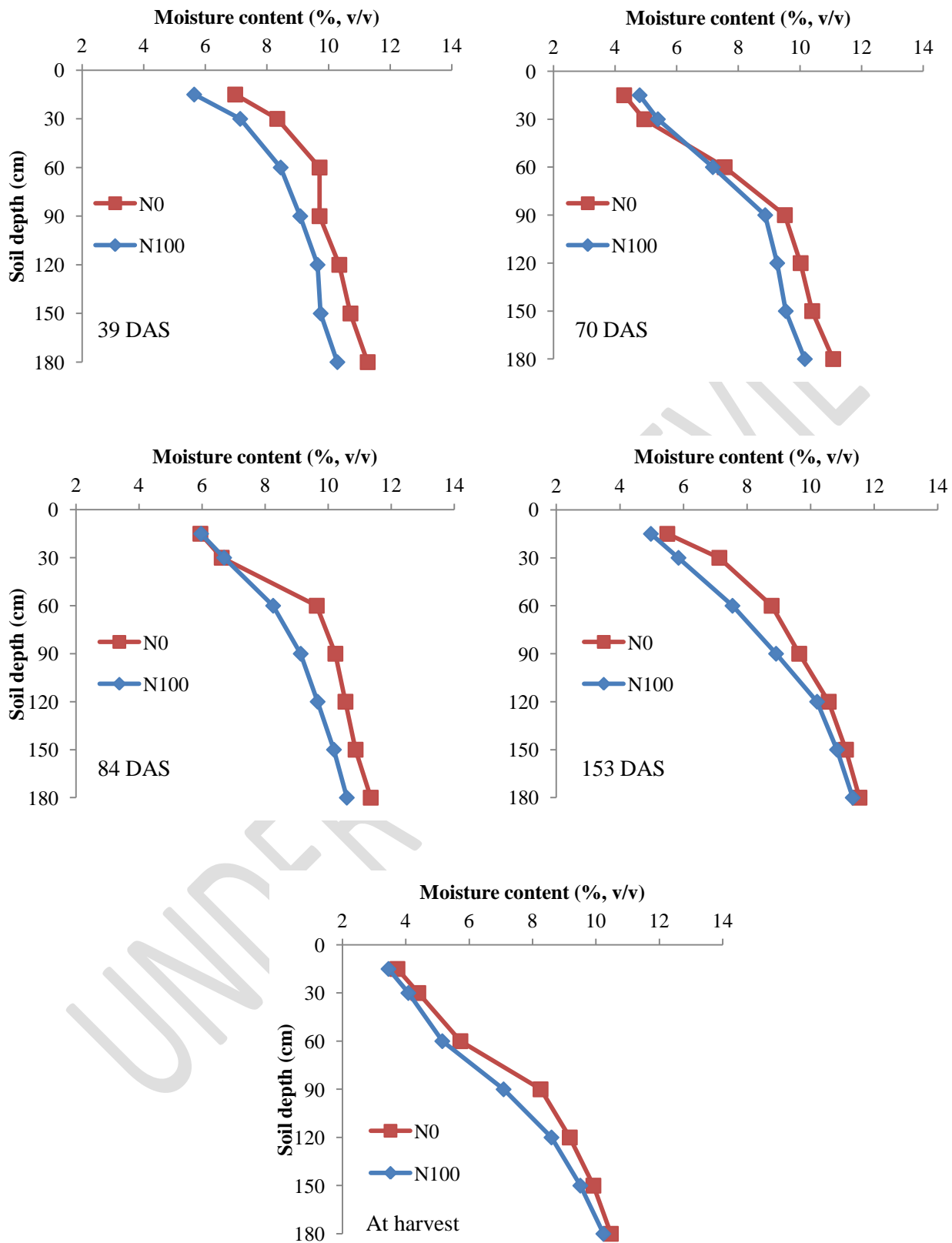


Figure 3. Effect of nitrogen application on depth-wise volumetric soil moisture content during growing season of canola.

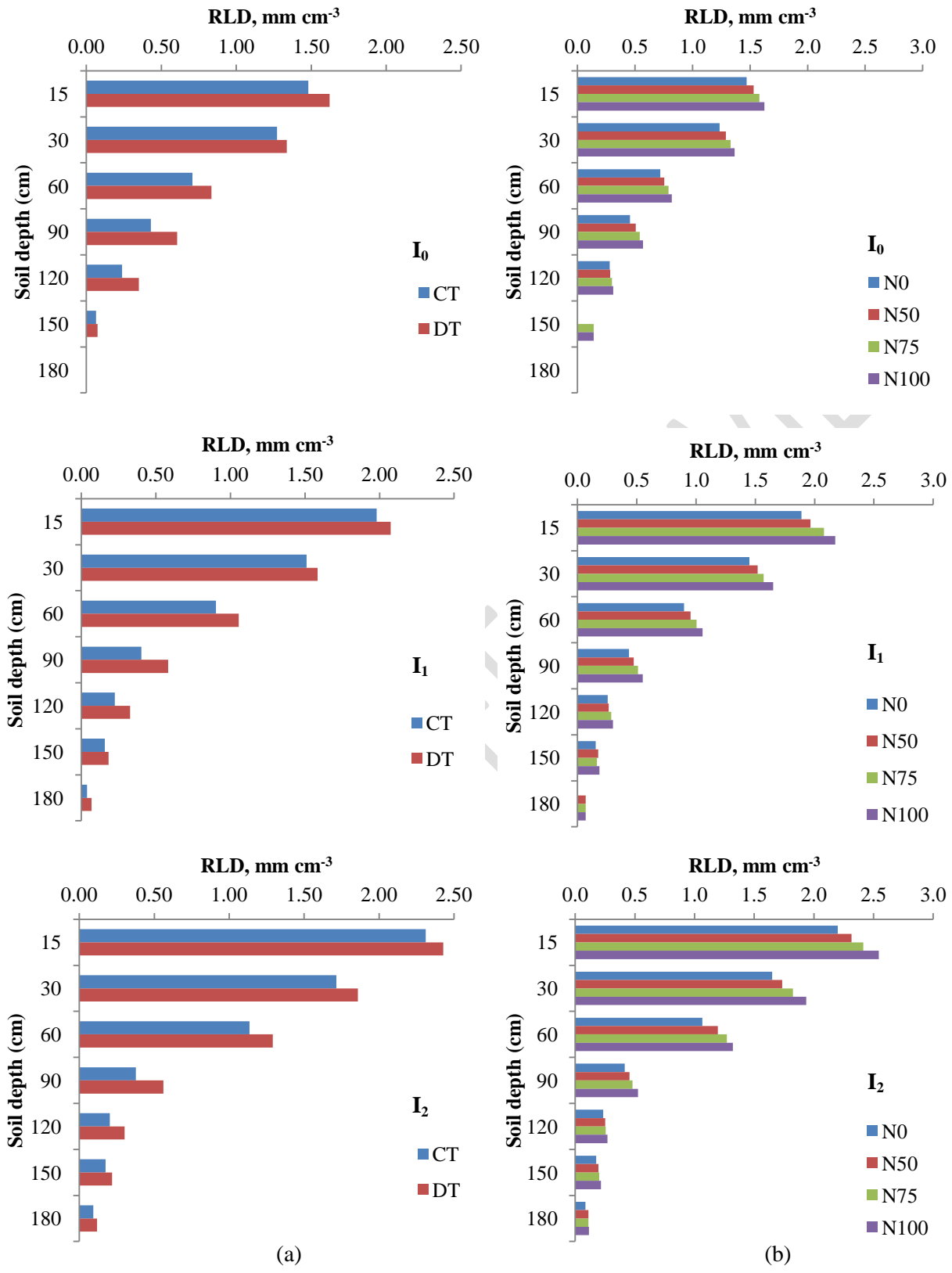


Figure 4. Effect of (a) tillage and (b) nitrogen rates on depth-wise root length density (RLD, mm cm⁻³) of canola under different irrigation regimes.