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 the 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 were 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 the 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 the R-W system involve a 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 the 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% of the Indian edible oilseed pool (Singh et al. 2014; Khodabin et al. 2022). India has a 59.77 lakh ha area under rapeseed mustard with a production of 8430 thousand tonnes (Anonymous 2019). The share of oilseeds is 14.1 per cent out of the total cropped area in India; rapeseed-mustard accounts for 3 per cent of it (Anonymous 2018). However, high levels of erucic acid and glucosinolates in Indian cultivars have reduced their preference in the 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 micromoles per gram defatted meal (Bhattarai 2023). Canola oil is used for human consumption and seed meal as a rich source of protein for livestock including poultry (Sohrabi et al.

2023). It is a magnificent feedstock for biofuel production. Canola-quality oilseed rape (*Brassica napus* L.) varieties have been fairly successful in India.

The yield of oilseed rape is greatly influenced by various agronomic practices such as tillage, irrigation and fertilization (Hirzel et al. 2023; Conyers et al. 2023; Pecan et al. 2023). 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 to 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 the requirements of mustard crops causes moisture stress at critical stages of growth and development. Irrigation provided at the most critical growth stages (at the flower initiation stage and siliquae development stage) produced the maximum growth and yield attributes (Yadav et al. 2010). Rapeseed-mustard group of crops have a relatively higher demand for nitrogen than many other crops (Malagoli et al. 2005) and the nitrogen fertilizer rate influences canola seed yield and quality (Malhi and Lemke 2007). Excess nitrogen results in greater succulency in plants and thus may lead to a 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 the growth, yield and oil content of canola along with soil moisture distribution during the growing season.

Materials and method

Site description

A multi-factor study was conducted during the *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 the growing season was 171.6 mm. Pan-evaporation (545 mm) was below the 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/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 the 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 m^2 and the net plot size was 3.6 x 3.0 m^2.

Crop management

The field plots with DT treatment were deeply tilled (sub-soiled) with a tractor-drawn chiseler in the first week of October after harvesting 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 conditions to obtain a fine seed bed. Canola crop (GSC 7) was sown @ 3.75 kg ha^{-1} at a row spacing of 45 cm on October 18, 2018. 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. Before 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, the first irrigation was applied on November 16 and in I_2 regime, the 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 per cent flowering with 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 the plant base (Gajri et al. 1994). Roots from each sample were washed in a 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. The 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 and 154 DAS and maturity of the crop from the base to the tip of the plant. Chlorophyll content in leaves of intact plants was measured with Minolta – SPAD 502 Chlorophyll Meter at 49, 64, 103 and 132 DAS. For each observation, a second or third fully opened leaf from the apex was selected from ten plants for each treatment by taking the precaution that the 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 the 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 ºC) and under low light conditions in the laboratory. After soaking, disks were quickly and carefully blotted dry with tissue paper in preparation for determining turgid weight. The dry weight (DW) of the disk was obtained after oven drying at 70ºC till the weight becomes constant. Relative leaf water content was calculated by the formula:

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

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. The total number of seeds in them was counted from twenty-five siliquae collected randomly in each treatment at maturity just before harvesting. The 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 a 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 a 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 the 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.

Results and discussion

Soil moisture distribution

The distribution of soil moisture in different layers of the root zone reflects water extraction patterns by roots. In general, soil moisture content increased with an increase in soil depth due to lesser evaporation from sub-surface. A 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 I_1 irrigation regime than I_0 by 3.5 to 1.7 per cent of soil moisture content throughout the 180 cm of soil profile (Figure 1). Higher moisture content in I_1 irrigation regime was attributed to the application of irrigation water in I_1 before sampling. At 70 DAS, the difference in soil moisture content between I_1 and I_0 reduced throughout the soil profile with higher values obtained under I_1 irrigation regime than I_0. At 84 DAS, I_2 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 per cent obtained in I_0 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 the 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 a maximum difference in 0-60 cm of the soil profile. Soil moisture content recorded under N_0 was 4.3, 4.9, 7.6, 9.5, 10, 10.4 and 11.1 per cent against 4.8, 5.4, 7.2, 8.9, 9.3, 9.5 and 10.2 per cent 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 the soil profile at 84 DAS had no difference between N_0 and N_{100} but below 30 cm of soil depth difference was observed to be higher under N_0 than N_{100} and thereafter, it reduced with an increase in depth. A similar trend was observed at 153 DAS and 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 the soil profile and hence, resulting in lower moisture content in the soil. The findings were in correspondence with the study of Taylor et al. (1991) and Beard et al. (2018).

Root length density

Among irrigation regimes, I_2 recorded the highest RLD followed by I_1 and I_0 in upper layers of soil up to 60 cm (Figure 4). The 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 per cent than I_1 and 16.3 and 9.4 per cent than I_2. Below 120 cm soil depth, RLD increased with an increase in the number of irrigations but the difference was smaller. Increased RLD with an increase in irrigation frequency conform 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 per cent higher than CT, respectively. In I_1 irrigation regime, the increase in RLD under DT plots over CT was 4.8, 5, 16.9, 44.7, 45.6 and 15.9 per cent in 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm of soil depth, respectively. The corresponding increase in I_2 irrigation regime was 5.1, 8.3, 13.6, 48.3, 49.4 and 24.3 per cent 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 an increase in nitrogen dose, RLD increased being highest under N_{100} followed by N_{75}, N_{50} and N_0. The effect was maximum in upper soil layers and reduced with an increase in soil depth. Little difference was observed in deeper layers of soil. Under I_0 irrigation regime, N_{100} 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 N_0 in 0-15, 15-30, 30-60, 60-90 and 90-120 cm of soil depth, respectively. In I_1 and I_2 irrigation regimes also, N_{100} resulted in the highest RLD as compared to N_{75}, N_{50} and N_0. 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). A 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 I_2 which was significantly higher than I_1 (95.3 cm) and I_0 (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 plant height with the application of irrigation water would have been due to the availability of higher soil moisture resulting thereby higher leaf water potentials, stomatal conductance, absorption and translocation of nutrients which ultimately reflected in the healthy growth of the crop. Saud et al. (2016) recorded significantly higher plant height with one irrigation (at the flowering stage) than no post-sowing irrigation in Indian mustard. Maximum mean plant height of 182 cm was obtained with N_{100} followed by N_{75} (179 cm), N_{50} (175 cm) and N_0 (166 cm) at maturity. A similar trend was also observed at other growth stages. Pattam et al. (2017) and Khan et al. (2017) also recorded an increase in plant height with an increase in nitrogen dose.

Leaf chlorophyll content (SPAD value)

The SPAD value increased up to 103 DAS and decreased thereafter to 132 DAS (Table 2). With an increase in the number of irrigations, SPAD value increased significantly at all growth stages with a 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 a fact that periodical water stress leads to many anatomical changes like a decrease in the size of cell and inter-cellular space, thicker cell wall and 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 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 the 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 an increase in nitrogen availability to the plant resulting in higher SPAD value in plots with higher nitrogen rates and more irrigations. Application of irrigation water and deep tillage maintained optimum soil moisture status in the root zone that accelerated the nitrogen uptake by the 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 an increase in growth and the highest RLWC was recorded at 152 DAS (Table 3). Irrigation had a significant effect on RLWC at all growth stages as depicted in Table 3. At 70 DAS, one irrigation resulted in 3.7 per cent significantly higher RLWC than no irrigation. Two irrigations significantly increased the RLWC by 4.5 and 8.3 per cent over one irrigation and no irrigation, respectively at 104 DAS. The corresponding increment recorded at 152 DAS was 1.9 and 3.4 per cent, respectively. The results indicated that an increase in irrigation frequency led to increased relative leaf water content. The high RLWC is associated with higher dry matter production rates because cell turgidity is important with 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). The 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 a significant increase in RLWC throughout the growing period of the crop (Table 3). N_{100}

recorded 79.4, 83 and 87.4 per cent RLWC over N_0 (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% increase over the control) as reported by Namvar and Khandan (2015). It has been shown that increasing nitrogen application will increase 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 the 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 the 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 the highest number of primary branches in mustard. Two irrigations (pre-bloom stage + pod filling stage) produced a significantly higher number of primary and secondary branches per plant than one irrigation (pre-bloom stage) in mustard (Singh et al. 2016). A 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 a higher number of branches. Deep tillage increased the production of primary branches by 18 per cent and secondary branches by 10.3 per cent 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 a higher number of branches. This is in confirmation with the finding of Mondal et al. (2008) and Belal (2013). The plots applied with N_{100} resulted in the highest number of primary branches with a mean value of 5.9 which was 1.2, 2.2 and 3.6 higher than N_{75}, N_{50} and N_0. A similar trend was observed for secondary branches. This agreed with the findings of Akbar et al. (2016) who reported that the addition of 100 kg N ha^{-1} produced a maximum (11) number of branches $plant^{-1}$, while a 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 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 the 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 the application of two irrigations at 40 and 75 DAS produced significantly the highest number of siliquae plant^{-1} (101.9) and several 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 several siliquae per plant, the value was numerically higher but could not be reached at a level of significance. Poddar and Kundu (2007) reported that with an increase in tillage intensity increased number of seeds per siliqua. The nitrogen rates of N_{100}, N_{75} and N_{50} resulted in a significant increase in the number of siliquae per plant by 26, 16 and 8 per cent over N_0 and the number of seeds per siliqua by 25, 19 and 7 per cent over N_0. Increasing nitrogen application rate resulted in the production of a 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 an increase in irrigation amount, 1000 grain weight increased in Indian mustard. Deep tillage (3.39 g) resulted in a significantly higher thousand-grain weight than CT (3.24 g). Sub-soiling resulted in 8 per cent higher 1000 grain weight as compared to conventional tillage in soybean (Ghosh et al. 2006). The effect of nitrogen rates on 1000 grain weight was significant with the 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 the 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 increases the weight of grain due to high uptake of nitrogen which results in heavier grain.

Grain and stover yield

Irrigation, tillage and nitrogen rates had substantial effects on the grain yield of canola (Table 4). Two irrigations recorded 10 and 9.5 per cent significantly higher grain and stover yield than one irrigation (1.6 t ha^{-1} and 1.4 t ha^{-1}) and 25 and 24 per cent 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 conformed with Ray et al. (2015) and Shivran et al. (2018). The DT plots registered an increase of 9.2 and 9.5 per cent higher seed and stover yield over CT, respectively. Deep tillage provided better root growth and better moisture extraction that helped the crop initially develop an adequate source (as reflected by high biomass accumulation) as compared to CT. Pal and Phogat (2005) concluded from their experiment that deep ploughing significantly increased the seed yield of mustard over conventional tillage. An increase in nitrogen dose from N_0 to N_{100} also increased grain yield significantly. N_{100} recorded a 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 per cent of oil content which was comparable with one irrigation (42.44 per cent) and no irrigation (42.31 per cent). The 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). A significant effect of several irrigations on the oil content of Indian mustard was also observed by Shivran et al. (2018). Oil content decreased with an increase in nitrogen dose. The highest nitrogen dose of 100 kg ha^{-1} resulted in a significantly lower oil content of 42.19 per cent 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 because N is the major constituent of protein so it might increase the percentage of grain protein, as a result, there might be a decrease in the percentage of oil content since it has an 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 the grain yield of canola. The regression model was developed with these parameters and the grain yield of canola (Table 5). Among these parameters, the 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 per cent higher mean grain yield over one irrigation and 25 per cent over no irrigation. Deep tillage incremented seed yield by 9.2 per cent over conventional tillage and 100 kg N ha^{-1} produced the highest grain yield. The CT plots retained more soil moisture than DT plots and among N levels, N_0 recorded higher soil moisture content throughout the crop growing season. 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. 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}). The study demonstrated that frequent irrigation (two irrigations), higher nitrogen rate (100 kg N ha^{-1}) along with deep tillage had no negative influence on plant establishment and have likelihood of crop yield improvement for irrigated canola production in Punjab.

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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)	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	R^2
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

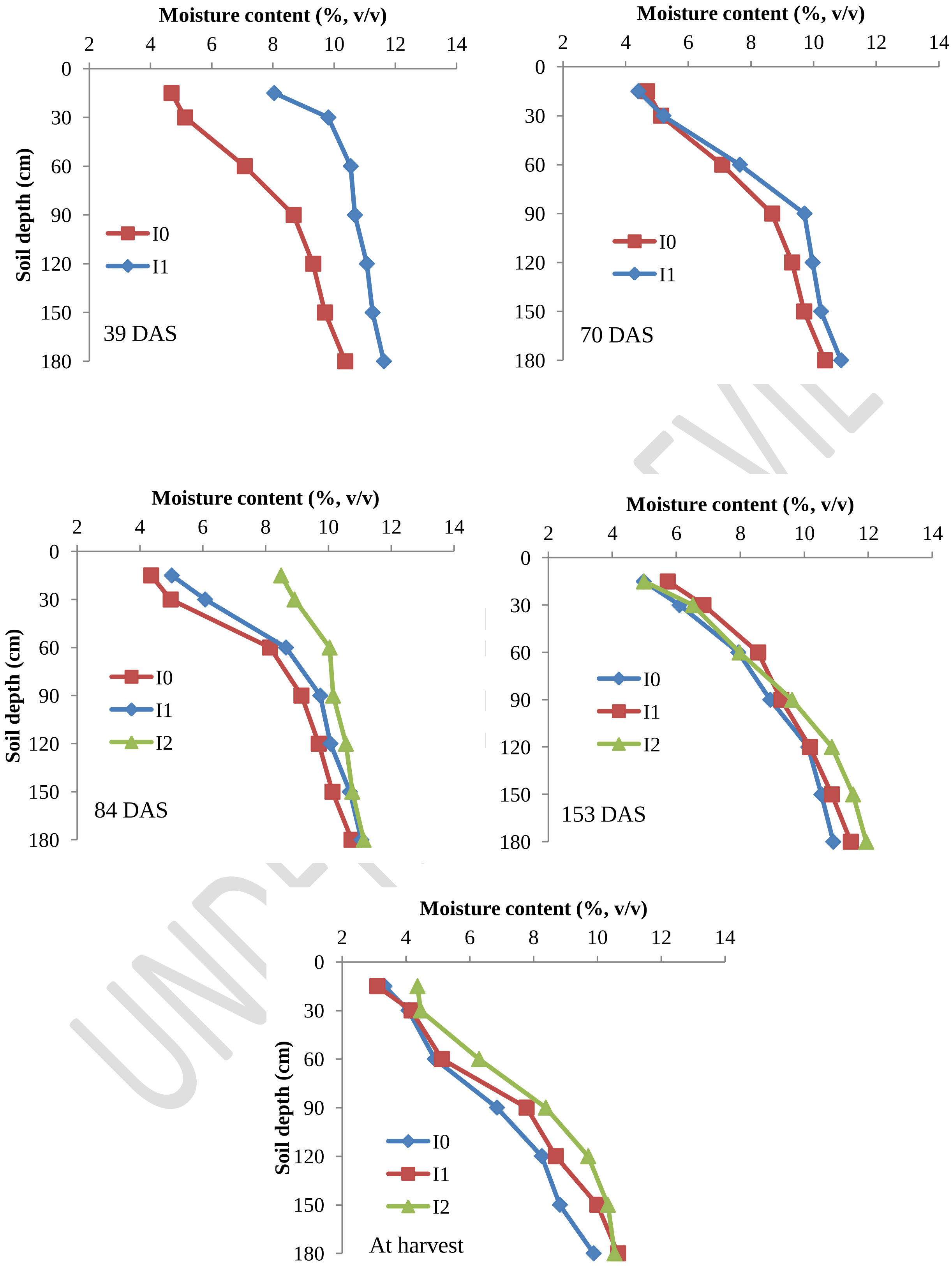

Figure 1. Effect of irrigation on depth-wise volumetric soil moisture content during growing season of canola.

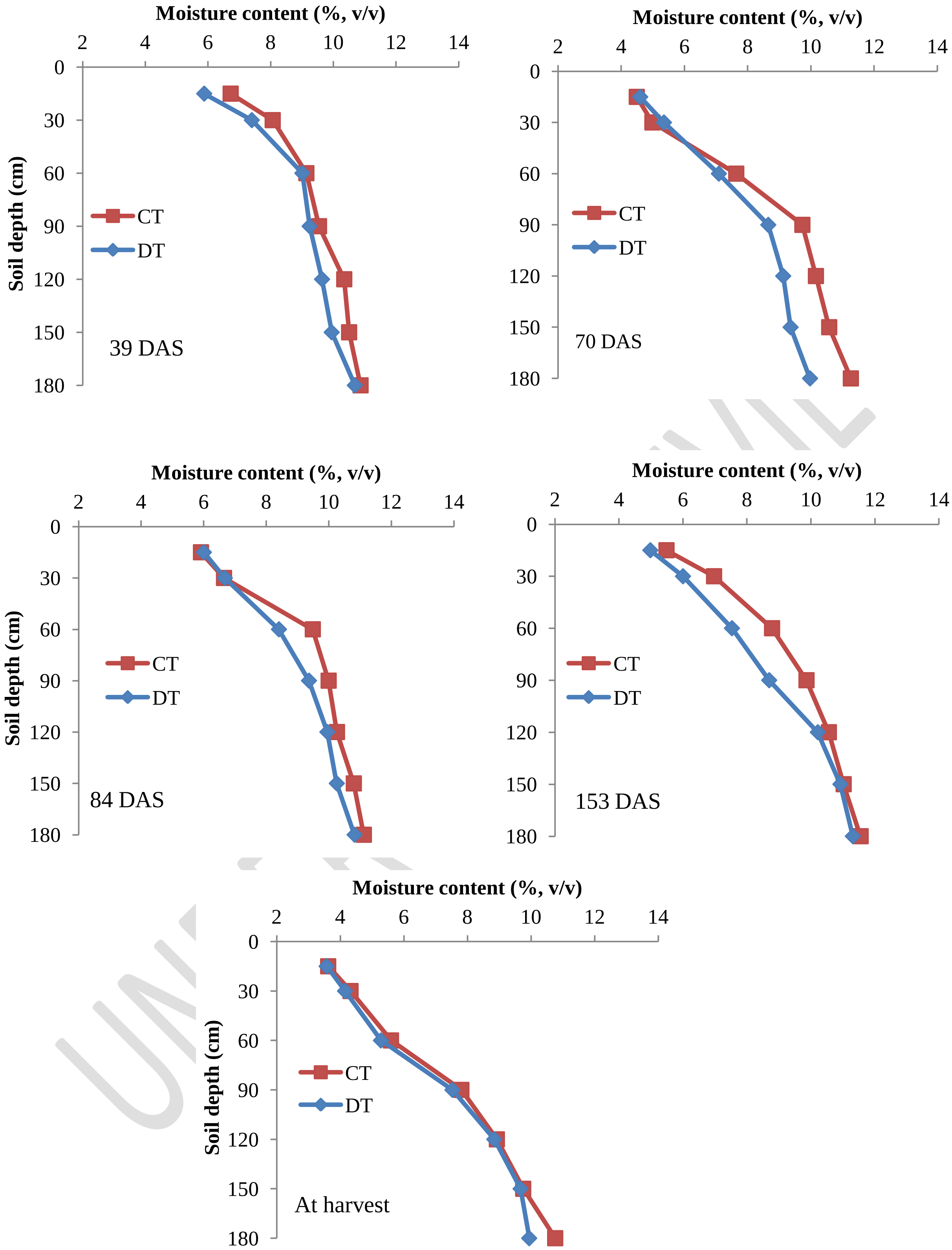

Figure 2. Effect of tillage on depth-wise volumetric soil moisture content during growing season of canola.

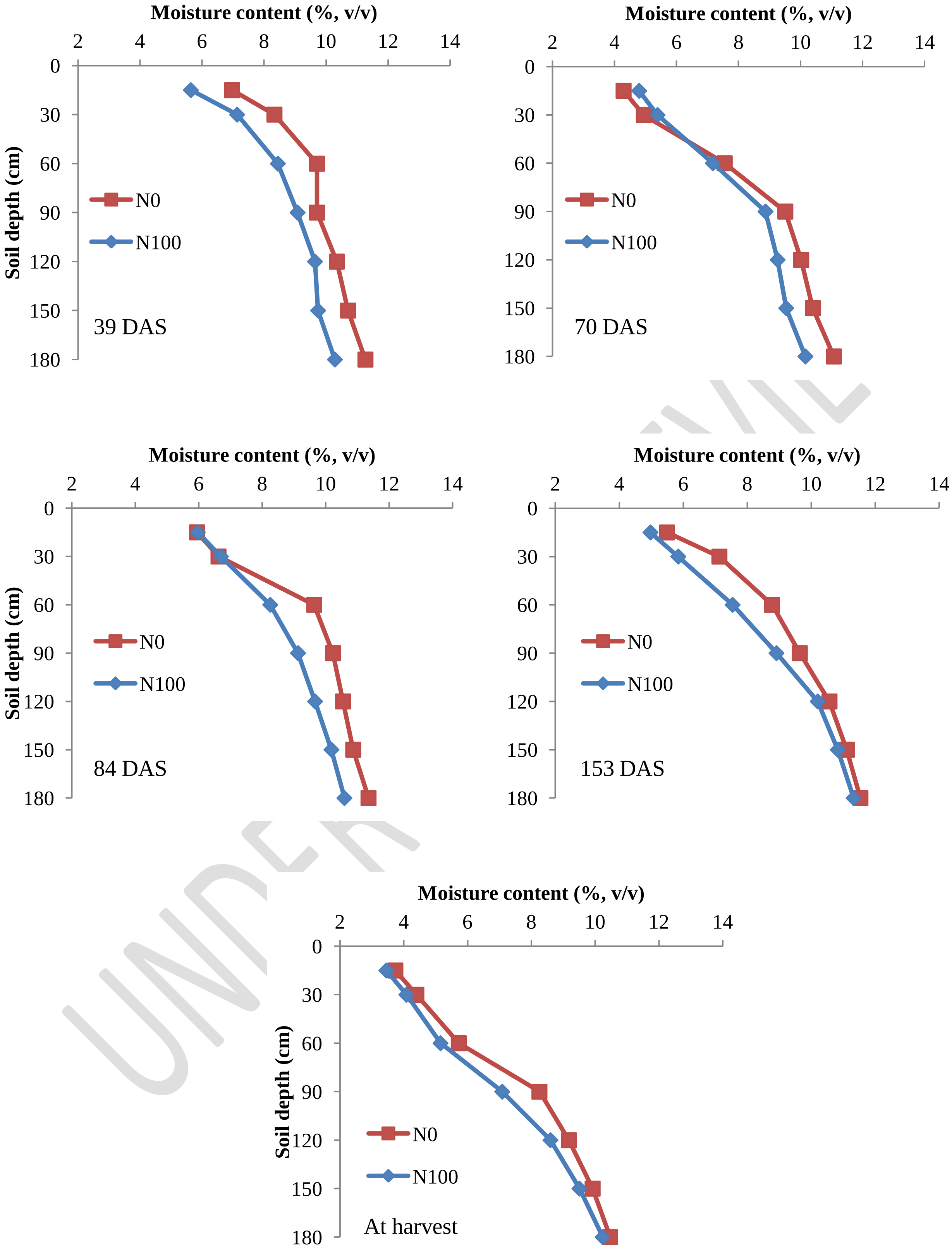

Figure 3. Effect of nitrogen application on depth-wise volumetric soil moisture content during growing season of canola.

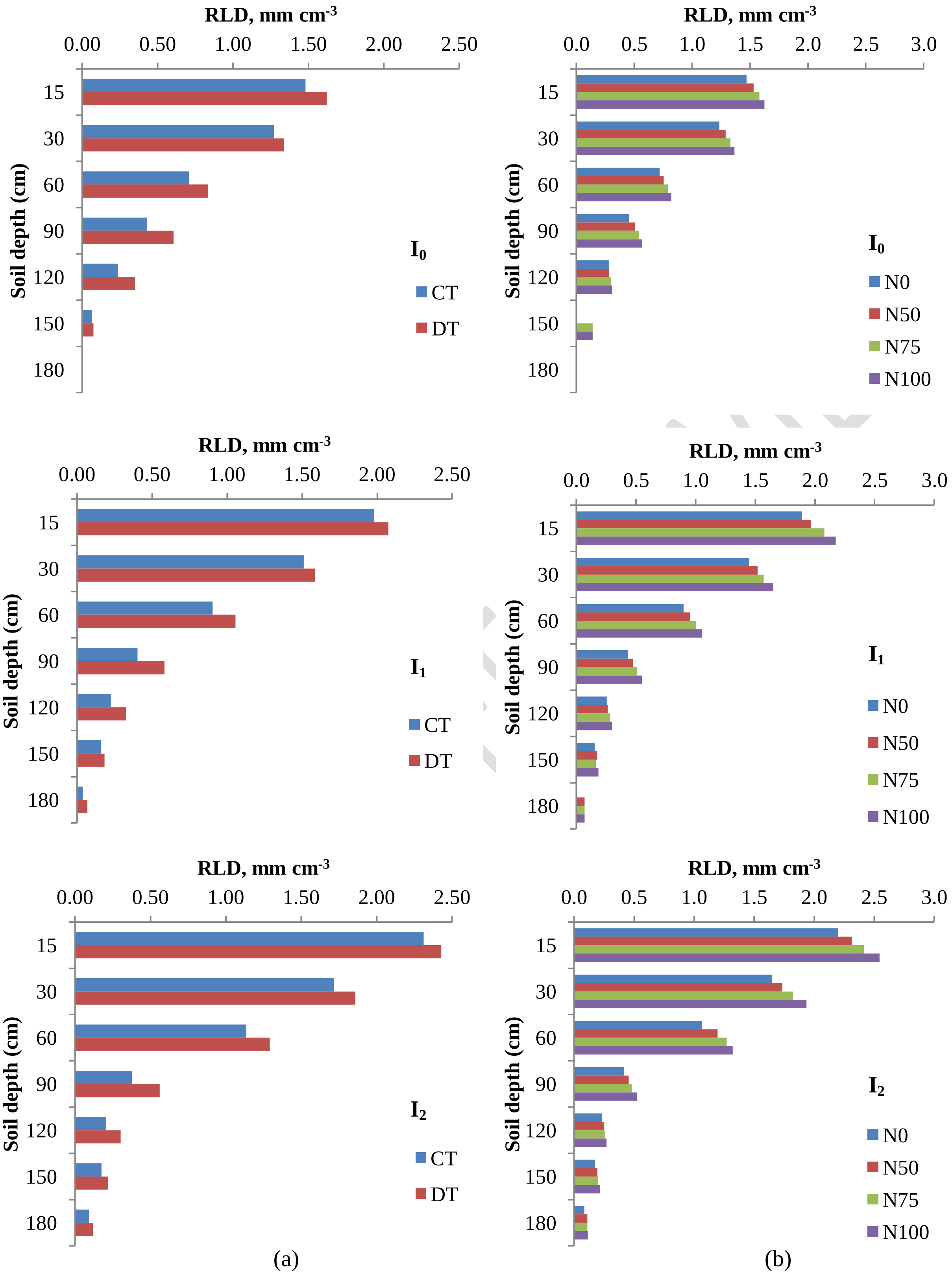

Figure 4. Effect of (a) tillage and (b) nitrogen rates on depth-wise root length density (RLD, mm cm^{-3}) of canola under different irrigation regimes.