Canola yield and quality under tile drainage in the Canadian Prairies

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ABSTRACT

For areas with seasonally shallow water tables and poorly drained soils, subsurface drainage systems are ideal for removing excess water from the root zone and improving soil workability, trafficability, and timeliness of field operations. With increased interest in tile drainage in southern Manitoba, the objective of this study was to evaluate the impacts of drainage on canola yield and canola oil qualities over three growing seasons (2019-2021) in Winkler, Manitoba. The study was carried out on replicated field plots with three different drainage treatments: controlled drainage (CD), free drainage (FD), and no drainage (ND). Subsurface drain tiles were installed at a depth of 0.9 m. The drains were spaced at 8 m for CD and 15 m for FD. Compared to FD plots (3.02 Mg/ha), the CD plots (3.51 Mg/ha) had significantly higher yields in 2019 with good rainfall. With low rainfall in 2020 and 2021, the impact of drainage, especially CD, diminished, with no significant differences between the treatments. In 2020, the average yields were 3.12, 2.52, and 2.97 Mg/ha for ND, CD, and FD, respectively. Similarly, in 2021, there was no significant difference between CD (1.14 Mg/ha), FD (1.52 Mg/ha), and ND (1.07 Mg/ha). The impact of CD under drought conditions was not significant. This could be related to the narrower drain spacing, which tends to remove water rapidly within the soil profile during short periods of high-intensity rainfall. The canola quality assessments (oil, protein, glucosinolate and fatty acid profile) showed no significant differences between ND, CD, and FD in each of the years. This suggests that environmental variables (mainly temperature and precipitation) may have masked drainage impacts on canola quality.

RÉSUMÉ

Pour les régions où selon les saisons les nappes phréatiques sont peu profondes et les sols mal drainés, les systèmes de drainage souterrain sont la solution idéale pour éliminer l'excès d'eau de la zone racinaire et rendre le sol plus facile à travailler ainsi que pour améliorer la circulation et la rapidité des opérations au champ. Considérant l'intérêt accru pour le drainage par tuyaux enterrés dans le sud du Manitoba, l'objectif de cette étude était d'évaluer les répercussions de ce type de drainage sur le rendement du canola et les qualités de l'huile de canola sur trois saisons de croissance (2019-2021) à Winkler, au Manitoba. L'étude a été réalisée sur des parcelles de terrain soumises à trois traitements de drainage différents : drainage contrôlé [CD], drainage libre [FD] et aucun drainage [ND]. Des tuyaux enterrés de drainage souterrain ont été installés à une profondeur de 0,9 m. Les dispositifs de drainage étaient espacés de 8 m pour le CD et de 15 m pour le FD. Comparées aux parcelles FD (3,02 Mg/ha), les parcelles CD (3,51 Mg/ha) ont eu des rendements significativement plus élevés en 2019 avec des conditions de bonnes précipitations. Avec des précipitations insuffisantes en 2020 et 2021, l'incidence du drainage, en particulier du CD, a diminué, et il n'y a pas eu de différence significative entre les traitements. En 2020, les rendements moyens étaient de 3,12, 2,52 et 2,97 Mg/ha pour les traitements ND, CD et FD, respectivement. De même, en 2021, aucune différence significative n'a été observée entre les trois traitements, CD (1,14 Mg/ha), FD (1,52 Mg/ha) et ND (1,07 Mg/ha). L'incidence du CD dans des conditions de sécheresse n'était pas significativement différente. Cela pourrait être lié à l'espacement plus étroit des drains, qui tend à éliminer rapidement l'eau dans le profil du sol pendant les courtes périodes de précipitations intenses. Les évaluations de la qualité du canola (huile, protéines, glucosinolates et profil des acides gras) n'ont montré aucune différence significative entre les trois traitements pour chacune des années. Ceci suggère que les variables environnementales (principalement la température et les précipitations) pourraient avoir masqué les répercussions du drainage sur la qualité du canola.

KEYWORDS

Subsurface drainage, water management, canola, Southern Manitoba.

MOTS CLÉS

Drainage souterrain, gestion de l'eau, canola, sud du Manitoba.

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INTRODUCTION

Canada, ranked fifth as a global exporter of many agricultural products, is a key player in global agricultural production (FCC, 2020). Agricultural production is concentrated in the Canadian Prairies (Saskatchewan, Alberta, and Manitoba). Canada is the largest producer and exporter of canola, accounting for 24 and 64% of the total global production and export trade, respectively (Cliff Jamieson 2021). The Canadian Prairies account for a significant amount of the total canola production in Canada. Canola was bred from rapeseed with significantly lower erucic acid and glucosinolates, making it fit for human and animal feed. Canola is the second most-produced oilseed after soybean, with 69.6 million metric tonnes in 2020 (United States Department of Agriculture, USDA, 2022). Canola production in Canada has increased steadily over the past two decades. The total production in 2018 (20.7 million tonnes) is more than 1.6 times the production in 2008 (12.6 million tonnes) (Canola Council of Canada, CCC 2022). This tremendous increase is due to an increase in cultivated area, improved hybrid cultivars, biofuel potentials, management methods, and high economic returns (Morrison et al. 2016). Canola generated the highest economic return in Manitoba, contributing $1.6 billion in 2021 (Manitoba Agriculture, 2022).

Hydrologic extremes, including waterlogging, drought, and high temperature, are the major threats to canola production in the Canadian Prairies. These extreme events account for a combined historical crop loss of 71% in Manitoba (MASC, 2020). Future climate scenarios for the region predict wetter springs and dryer summers (Sauchyn and Kulshreshtha, 2008). The accumulated snow in the winter and early rainfall in the spring could have severe consequences on soil workability, trafficability, timeliness of farm operations, and, consequently, total crop yield. According to Manitoba Agriculture, a delay of planting up to the first week of June could lead to a 20 - 30% reduction in yield depending on crop type. These challenges have necessitated Canadian producers, especially canola farmers, to introduce sustainable water management practices.

Agricultural drainage is an important water management practice that provides a conducive growing environment for root development and crop growth by lowering the water table and removing excess water within the root zone. Although drainage is mainly practiced in humid climates, it is also important in semi-arid climates such as the Canadian Prairies in controlling salinization (Dou et al. 2021). The benefits of agricultural drainage are well documented in several textbooks, including increased crop yield and decreased nutrients and drainage outflow (Natural Resources Conservation Service, NRCS 2001, Huffman et al. 2011). On the other hand, drainage has led to the loss of wetlands, mainly in North America, Europe, and Asia (Davidson 2014). Subsurface drainage has also led to increased nutrient loadings and eutrophication of most water bodies (King et al. 2015). Notable cases include the Gulf of Mexico, the China Sea, Lake Winnipeg, and the Great Lakes (Rabalais et al., 2007, Hawley et al., 2006, Schindler et al., 2012, Chen et al., 2013). Controlled drainage (CD) was developed to reduce nutrient loadings by placing control structures on subsurface drains at the outlet. Early studies on CD can be traced to the United States in the 1970s. Due to its enormous benefits, it has been recommended and adopted in various countries, including Canada, Italy, Sweden, Australia, China, and Iran (Wesström et al. 2014, Sunohara et al. 2016, Tolomio and Borin 2018, Jouni et al. 2018, Dou et al. 2021).

Numerous studies have reported varying results on the agronomic and environmental impacts of different water management systems. Using CD, for example, which is regarded as one of the best management practices (BMPs), several studies have reported positive benefits, including increased yield and income, decrease in drainage flow, drop in nitrate and phosphorus export, disease control, salinity control, and improved soil structure (Tan et al. 1999, Fausey 2005, Cordeiro et al. 2014, Satchithanantham et al. 2014, Darzi et al. 2007, Drury et al. 2009, Skaggs et al. 2012, Awale et al. 2015, Gunn et al. 2015, Mehring et al. 2015, Sunohara et al. 2016, Smith et al. 2019, Wang et al. 2020, Mourtzinis et al. 2021, Dou et al. 2021, Helmers et al. 2022). On the contrary, negative results have also been reported for CD, including lower yield, increase in surface runoff, alternative routes to nutrients losses, increased potential for salinization and increased GHG emissions (Tan et al. 1998, Hornbuckle et al. 2005, Nangia et al. 2013, Kumar et al. 2014, Hanke 2018).

The above literature suggests that the performance of a water management system may be location-specific, which can be linked to a variety of factors that are not fully understood (Allerhand et al. 2013). Therefore, an understanding of the underlying factors affecting drainage systems is critical. It is also important to continuously evaluate different drainage systems, especially with global changes in climate variables, climate variability, and uncertainty, even as the Canadian Prairies are vulnerable to climate change impacts (Qian et al. 2012). The increasing number of agricultural drainage systems installed in this region also necessitated this study. Therefore, there is a need to develop local datasets of crops commonly grown for long-term modelling studies and develop alternative management scenarios through computer simulation. The main objective of the study was to evaluate the impacts of three water management practices, including free drainage (FD), controlled drainage (CD), and no drainage (ND-control), on canola yield and canola oil quality, including oil content, protein content, glucosinolate content and fatty acid composition, in Winkler, southern Manitoba. The prevalence of flat topography and seasonal shallow water tables in southern Manitoba provided the opportunity to implement the three different water table management treatments.

MATERIALS AND METHODS

Study Area

Field data were collected on research plots at Hespler Farms, located at 49.12 N, 97.96 W, elevation, 283 m, in southern Manitoba (Fig. 1). The region has a semi-arid climate, with average annual precipitation of 563.3 mm. Historical weather analysis obtained from the closest weather station (Schanzenfeld), located 10 km from the study site, revealed that rainfall and snowfall account for 80 and 20% of the precipitation. Also, the historical analysis showed that rain and snowfall have peak values in June (100.1 mm) and December (22.9 mm), respectively. The area has an average annual temperature of 4 ºC, with the lowest monthly temperature of -14.6 ºC in January and the highest temperature of 20 ºC in July (Environment Canada, 2019). The soil in the study area belongs to the Gleyed carbonated Rego black sub-group of the Reinland soil found in Morden-Winkler (Smith et al.1973). The soil is classified as imperfect to moderately well-drained (Smith et al.1973). The soil belongs to the sandy loam textural class with 69% sand, 20% silt, and 11% clay. The average bulk density, field capacity, porosity, and drainable porosity are 1.38 g/cm^3, 0.31 m^3/m^3, 47.8%, and 14.1%, respectively (Cordeiro, 2014). These average values were obtained over the 1.2 m profile (Cordeiro, 2014). The soil also has a distinct colour change from deep dark soil in the top 30 cm to light-coloured soil at depths > 60 cm.

Experimental Layout

The field is approximately 5.2 ha, with canola and soybean in a 3-year rotation (2019-2021). Canola was planted in the eastern section in 2019 and 2021 and in the western section in 2020. A buffer strip of about 4 m separated both crops. Each section measuring 84 m * 300 m is divided into three areas representing the replicates. Each replicate contained the three treatments: Controlled drainage (CD), Free drainage (FD), and No drainage (ND) as control. The ND had an area of 0.2 ha (40 m* 50 m), CD 0.2 ha (40 m* 50 m), and FD 0.23 ha (44 m* 50 m). For drained plots, (FD and CD) drain tiles were installed 0.9 m below the soil surface, parallel to the planting row in the North-South direction. The drain tiles are corrugated plastic pipes with 0.1 m diameter and 50 m long connected to the submain, about 0.4 m in diameter. On CD plots, drain tiles were spaced 8 m apart. Drainage control structures (Agridrain Corp, Adair Iowa), with adjustable stop logs, were placed at the outlet of the submain to conserve water and limit drainage flow. On FD plots, drain tiles were spaced at 15 m, connected to the submain, which discharged to the outlet separately. All the plots received equal water as canola is usually cultivated as a rainfed crop.

Agronomic practices - Tillage, planting, chemigation, and harvesting

Table 1 shows the agronomic practices, including tillage equipment, planting, harvest, fertilizer application, and

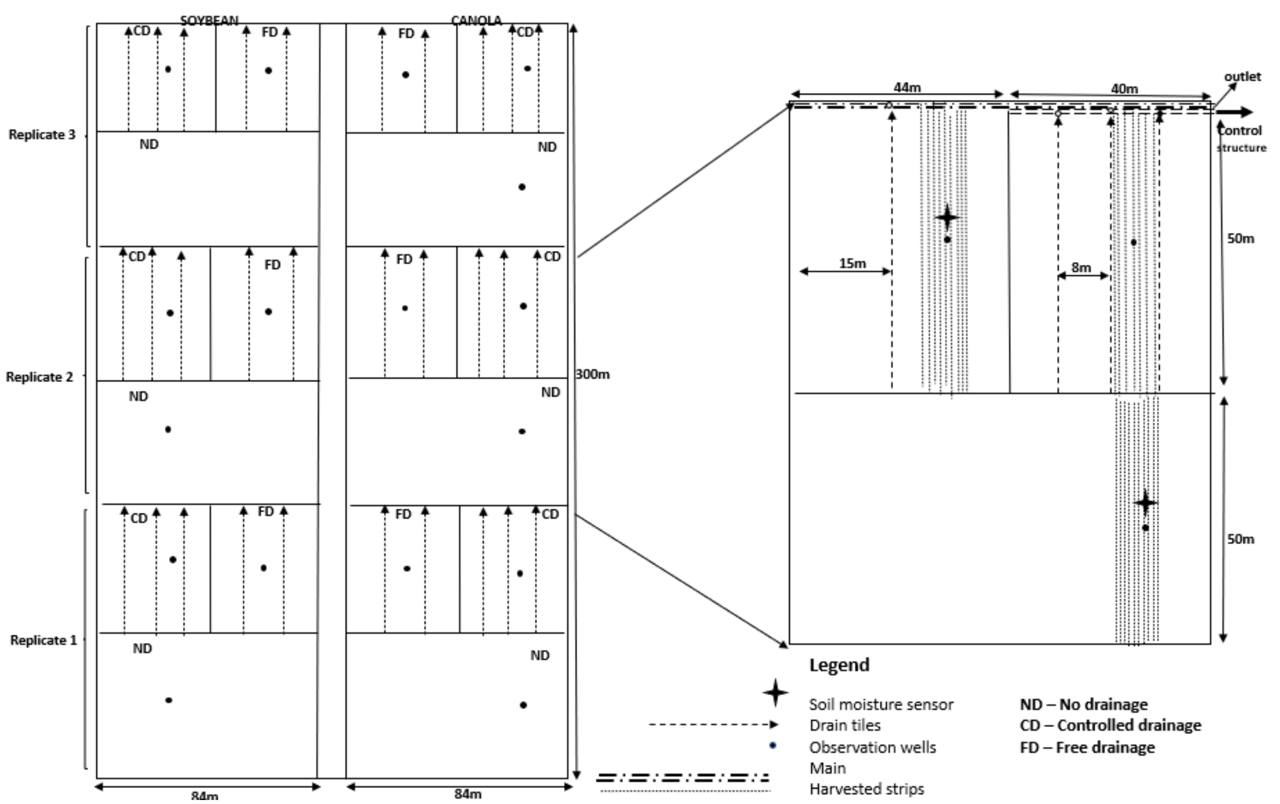


Fig. 1. Field layout and assignment of treatments.

Table 1. Agronomic practices during the study period.

Year	Tillage	Planting date	Harvest date	N lb/ac	P lb/ac	S lb/ac	K lb/ac	Chemical (product)	Application rate (L/ac)	Application date
2019	John Deere 730-disc drill	May 2	Sep 15	115	20	10	0	Herbicides (Liberty) Herbicides (Liberty) Fungicide (Proline) Desiccant (Glyphosate)	1.5 1.5 1.126 1.0	Jun 6 Jun 14 Jun 26 Aug 14
2020	Heavy Harrow	May 18	Sep 9	150	0	10	31	Herbicide (Liberty) Fungicide (Rovral Flo) Fungicide (Rovral Flo) Desiccant (Glyphosate)	1.5 0.84 0.42 0.8	Jun 11 Jul 2 Jul 9 Aug 20
2021	No-tillage. The seed was planted on stubble	May 4	Sep 2	127	31	15	29	Herbicides-Liberty No fungicide was applied because of the extreme dry weather	1.2 1.5	Jun 4 Jun 15

chemigation during the study period. Plant rows were arranged parallel to the drains (North-South direction). Canola (c.v. Invigor) was seeded at 5 cm depth, at a 5.0 lb/ac rate, on an inter-row spacing of 0.25 m and planting spacing of 0.10-0.12 m. Fertilizers were applied based on soil tests, usually done after harvest in the preceding year. The 2019 fertilizer application was done based on a soil test in September 2018. All treatment plots received the same fertilizer amount each year.

Harvesting was done on a 533.4 m^2 area (Fig. 2). In each plot, the width of the combine swath (10.7 m) and length (50 m) of the plot was harvested using the combine harvester (John Deer s680). The combine passed through centred on the location of the piezometers for measuring the water table elevation. The yield was calculated in Mg/ha as the quantity of seed weighed on the combine as it moved down the plots.

Instrumentation and Data Collection

Weather An on-site weather station about 150 m from the study area collected daily maximum and minimum temperature, precipitation, and evapotranspiration. Additional weather data, including relative humidity, wind speed and solar radiation, were collected hourly from the Winkler weather station, managed by Environment Canada, located about 12.53 km from the study area. The data from both sources provide complete weather information on the study area.

Water table depth Within each replicate, three wells were installed to measure groundwater depth. A total of nine wells were installed on the canola field. Water table depth was measured using water level sensors (Solinst Levelogger Junior 3001, Solinst, Canada, Ltd., Georgetown, Ontario, Canada) suspended inside a piezometer. A levelogger measures the absolute pressure. The levelogger measurements were converted to gauge pressure using the barometric pressure sensor reading (Solinst Barologger). A 0.1 m diameter hole was dug to about 2 m using a hand auger. The piezometers were made of schedule 40 steel pipe, with an internal diameter of 0.0413 m and pointed edges. A Kevlar rope was used to suspend the levelogger, tied to a ring (0.038 m diameter) hung on a bolt located 0.038 m from the top edge of the piezometer. The sides have slots covered with a geomembrane to allow easy movement of water and prevent soil and clay particles from entering the piezometer. The piezometers were inserted in the auger holes, and an offset of about 0.3 m was left above the soil surface. A bentonite-sand mixture was packed into the annular space after installation to prevent preferential flow along the length of the piezometer. The piezometers had caps on the top to prevent rainwater from the top. The sensors were installed and set on a 3-hr logging interval. On drained plots, the wells were located mid-spacing between two drain tiles.

Nutrient analysis

Soil samples were collected and analyzed on all the treatment plots for soil nitrate-N and soil test phosphorus-P (STP). A soil auger was used to collect soil samples at 30 cm, 60 cm, and 90 cm depths during different canola developmental stages. The samples were sent to the Agvise laboratory for analysis. The soil nitrate-N and phosphate-P were extracted using the cadmium reduction nitrate method and the Olsen phosphorus method, respectively (Gelderman and Beegle 2015).

Canola Quality Analysis

Oil, protein, and glucosinolate contents were analyzed using Near-Infrared Spectroscopy (NIRS), which works on the principle of reflectance. The NIR spectroscopic analysis was done using a NIR scanning monochromator (XDS Rapid content ™ Analyzer). About 5 – 7 g (n = 30) of canola seeds, free of debris, were collected in the standard ring cup (diameter = 0.014 m, height = 0.01 m). Spectral data were recorded as the logarithm of reciprocal reflectance in the 400 – 2500 nm wavelength range at 0.5 intervals. The scanning process per sample is about 1 min. The data was analyzed using the WinISI II software.

The fatty acid composition was determined by Gas chromatography (GC) of fatty acid methyl ester. Three subsamples from each plot were used for this analysis. The GC procedure is given below. First, about 300 mg of canola seeds were crushed in a test cylinder and placed in a 13 × 100 mm test tube. 3 ml of heptane was added and allowed to stand overnight to extract oil, after which supernatant was decanted into a 13×100 mm test tube the next day. This was followed by adding 500 µl of 0.5 N sodium methoxide reagent. The mixture was shaken for 30 minutes. This separates the fatty acid from the mixture. After this, 100 µl of acidified water (0.3% acetic acid) was added, mixed gently, and was allowed to clear by putting it in the fridge for 102 hours. About 500 µl of the mixture was put into a 2 ml autosampler vial for analysis. GC was performed on a 3900 Varian model fitted with a CP-8400 autosampler and flame ionization detector. Six major fatty acids (Palmitic (C16:0), Stearic (C18:0), Oleic (C18:1), Linoleic (C18:2), Linolenic(C18:3), and Erucic (C22:1)) were analyzed and expressed as percentages of the total fatty acids. Peak areas were measured using the Varian star workstation software system. Canola quality tests were done at the Oil Quality lab, Plant Science Department, University of Manitoba.

Statistical analysis

Field data, including yield and nutrients (nitrates and phosphates), were analyzed separately for each year by conducting an ANOVA test using the JMP software (Version 16, SAS Institute, Inc, Cary, N.C). ANOVA was used to check the differences in treatment means for each measured field data. Soil nitrates and phosphates tests were analyzed for each sampling date. The mean values of the field data were separated using Tukey's test at a 5% ($p<0.05$) significance level.

RESULTS

Weather

The observed growing season monthly average rainfall (May to September) during the study period (2019-2021) is presented in Fig. 2. Apart from the 2019 growing season with a total rainfall of 374.2 mm, close to the long-term average (376.5 mm), the 2020 and 2021 growing seasons were 60.0 and 60.1% of the long-term average. The total monthly sums may have masked the monthly variation observed during the study period. Monthly analysis showed that the study periods deviated significantly from the monthly historical data. For example, in September 2019, the site received more than three times (151 mm) the long-term value (42.2 mm). Apart from July 2020, with rainfall 149% of the long-term average, all the other months were substantially lower than the long-term values. In 2021, May, June, July and September received 50.4, 44.4, 29.7, and 52.1% of the long-term values. The average temperature for the 2019 growing season (16.4 ºC) is almost the same as the long-term average (16.6 ºC), slightly higher (17.1 ºC) in the 2020 season and significantly warmer in 2021, with an average temperature of 18.0 ºC. The monthly temperatures during the study periods exceeded the long-term average, except in May. Figure 2 also showed an increasing temperature trend across all the months except September, where 2019 was slightly higher than 2020. Also, peak average temperature values were recorded in July, corresponding to periods of highest water use, and least values in May.

Canola Yield

Figure 3 shows the average annual yield per treatment. The result shows large differences in crop yield between the years, suggesting that yield may have been influenced by weather variables. The average yields during the study period were 3.2 Mg/ha in 2019, 2.9 Mg/ha in 2020, and 1.3 Mg/ha in 2021. Relative to the 2019 growing season, yield consistently decreased across the treatments and years. This could be linked to unfavourable weather conditions and drainage design (drain spacing).

In 2019, the yield per plot differed among treatments ($p = 0.0143$). The average yields per treatment were 3.27, 3.51, and 3.02 Mg/ha for ND, CD, and FD, respectively. For each replicate, CD plots were consistently higher than other treatments. Statistical analyses revealed that there was a significant difference between CD and FD. Although there was no significant difference between CD and ND, the CD was higher. The drain spacing may explain the significant difference in yield between CD and FD. Relative to other years, the 2019 growing season was wetter. Since the drains in CD plots are closely spaced, the excess water in the soil is removed faster, thereby providing a quicker return to good growing conditions for the crop. Another reason is the cumulative benefits of CD. Researchers have shown that CD has long-term benefits that may be hidden in short study periods (Thorp et al. 2008, Cooke and Verma, 2012).

In 2020, the average yields per treatment were 3.12, 2.52, and 2.97 Mg/ha for ND, CD, and FD, respectively. There was no significant difference among the treatments ($p>0.05$). The CD had the lowest average yield because of the high variability within the replicates. Another reason for low average CD yields could be the drain spacing. Since the 2020 and 2021 growing seasons were dry, the closely spaced drains in CD plots could have intercepted and removed the infiltrating rainwater, making it unavailable to the plant roots. Also, controlled drainage plots may have removed the excess rainfall received towards the late 2019 growing season resulting in lesser soil water for the 2020 growing season. This, together with significantly low rainfall in spring, could have adversely affected yield. Closely spaced drains tend to draw water rapidly from the profile. Unlike in the ND plots, the groundwater table is recharged by the rainwater, and through capillary action, plant roots can meet their water requirements. Moreover, since the soil has "imperfect" internal drainage (Smith et al. 1973) with heterogeneous texture and structure, a capillary barrier could easily form within the soil profile. This creates a dry layer in the soil profile despite the presence of groundwater. The dry layer is formed due to the mismatch between high ET demand and upward flux from groundwater. Kross et al. (2015) noted that the inherent and intrinsic soil properties are crucial to understanding how crop yields are affected by water management practices.

In 2021, the average yields were 1.14, 1.52, and 1.07 Mg/ha for CD, FD, and ND treatments, respectively, with

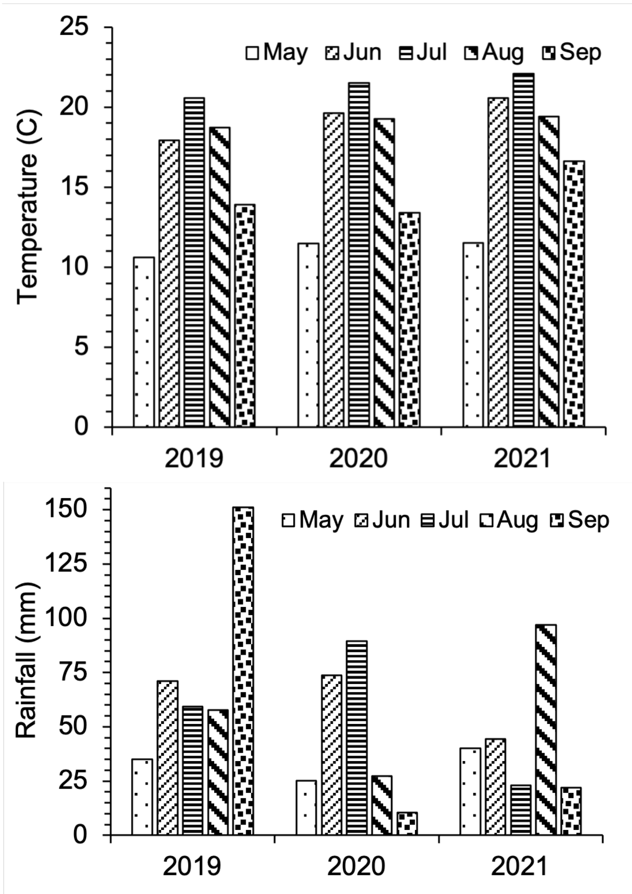


Fig. 2. Comparison of monthly average temperature and rainfall during the study period.

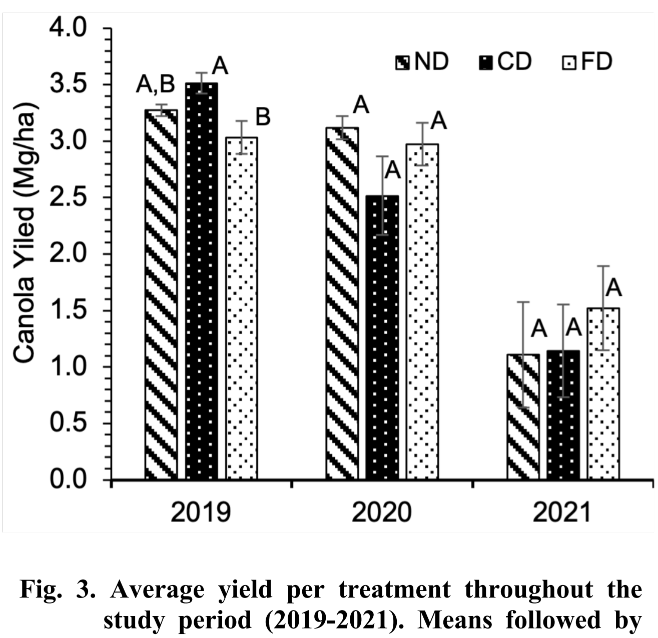


Fig. 3. Average yield per treatment throughout the study period (2019-2021). Means followed by different letters are significantly different based on Tukey's means separation p = 0.05.

no significant difference between the treatments due to high variability within the replicates. The inconsistency of the combine harvester under low yields could have led to the underestimation (personal communication with the farmer), even though canola production in Canada fell by 35.4 % (12.6 million tonnes), the lowest level since 2007 (Statistics Canada, 2022). This is due to the extreme drought and heat stress in the Canadian Prairies. The 2021 growing season started with deficit soil moisture due to low snow accumulation in the preceding winter, low spring runoff, and spring rainfall. The drought and heat continued into the developmental and reproductive growth stages (budding, flowering, and pod development) in 2021. In June and July, the rainfall was 55.5% and 70.4% of the long-term monthly average. Also, in 2021, there were 20 days with $T_{max}> 30$ ºC in June, seven days with $T_{max}> 30$ ºC in July, and one day with $T_{max}> 30$ ºC in August, respectively. Also, there were two days each with $T_{max} > 35$ ºC in June, July, and August. The heat stress index is defined as the summation of the difference between the maximum temperature and a threshold temperature of 29.5 ºC (Morrison and Stewart 2002). The total heat stress index calculated from June to September in 2021 (126.9) was almost thrice (45.3) and twice (63.8) that of the 2019 and 2020 growing seasons, respectively.

In the field, both high temperatures and drought coexist. They reduce crop yield by altering the biochemical, molecular, and physiological processes responsible for growth and development, such as photosynthesis, respiration, flowering, pollination, and seed filling (Prasad and Staggenborg 2008). While water stress could reduce the ability to obtain the nutrients needed for the development of reproductive organs, photosynthesis, and carbon assimilation, heat stress disrupts reproductive processes such as embryo sac differentiation, pollen gametogenesis, embryo development, ovule fertilization, endosperm development etc., resulting in the reduction of the number of flowers, the number of pods, seeds per pods, and the number of pods per plant which ultimately results in low yield. (Morrison et al. 2002, Gan et al. 2004, Hammac et al. 2017, Elferjani and Soolanayakanahally, 2018).

Generally, the prevailing weather condition could affect the impacts of drainage on the crop. In this study, the effects of drainage, especially CD, appeared to decrease with increasing drought conditions when the control structures were not set correctly to hold back the water. This agrees with other studies that state that the effects of CD are minimal, hidden, or insignificant under drought conditions due to the inability to store soil water within the profile (Kross et al. 2015). Skaggs et al. (2012) explained that CD benefits crop yield by retaining water that would have been lost via drainage and making that water available to the plant at later times. The yields in this study agree with previous studies in the same area (Cordeiro 2014, Satchithanantham 2013 and other related studies (Helmers et al. 2012, Schott et al. 2017, Acharya et al. 2019). In 2012 with low rainfall, Cordeiro et al. (2012) and

Satchithanantham et al. (2012) found no significant difference between the treatments. Acharya et al. (2019) studied the impacts of drainage and other management practices (tillage and crop rotation) on corn and soybean yield from 2014 to 2017 in North Dakota. Drainage treatments studied included ND, FD, and CD. They reported that rainfall throughout their study period was less than the 30–year average, varying between 17 to 46%. Their results showed no significant difference in soybean yield between the treatments implying that drainage had an insignificant impact on soybean yield.

Conversely, drainage did not affect corn yield for years with significantly low rainfall (2016 and 2017). In a 5-year (2011-2015) study in Iowa, Schott et al. (2017) reported no significant difference between the drainage treatments during 2011, 2012, and 2013 growing seasons. Also, Helmers et al. (2012) reported no significant difference in corn yields between the treatments during the 2007, 2008, and 2010 growing seasons and no significant difference in soybean yields during the 2007 and 2008 growing seasons. These studies have demonstrated that drainage impacts crop yield depending on the prevailing weather (rainfall). On the other hand, Poole et al. (2013) reported an average of 11 and 10% for corn and soybean yields, respectively, compared with the conventional drainage but no significant impact on wheat yield.

Overall, the results suggest that the impacts of drainage diminished with increasing drought conditions. In 2019 with good growing season rainfall, CD plots performed significantly better compared to FD and consistently had higher yields than FD and ND. As drought persisted in the following years, the benefits of CD were not apparent, showing no significant differences between the treatments. Given that the growing season has been predicted to be dry in the summer and that drought will persist in the future under rainfed conditions, the results in this study suggest that CD should be operated in a way to limit the outflows from drain tiles during periods of rainfall to improve soil storage. During the spring and heavy rainfall periods, the drain outflow could be pumped into water storage structures that could be reused during prolonged drought. This would provide both environmental and agronomic benefits. Careful management of the drainage control structures to conserve water is needed.

Nutrient analysis

Figure 4 show the soil nitrate-N content within the root zone for each treatment at different growth stages during the 2020 and 2021 growing seasons. The ND plots had higher nitrate concentrations than drained plots (CD and FD) for different growth stages. Even though ND was higher, the differences were not statistically significant ($p>0.05$). This may be due to the high variability of the data (see standard error e in Fig. 4).

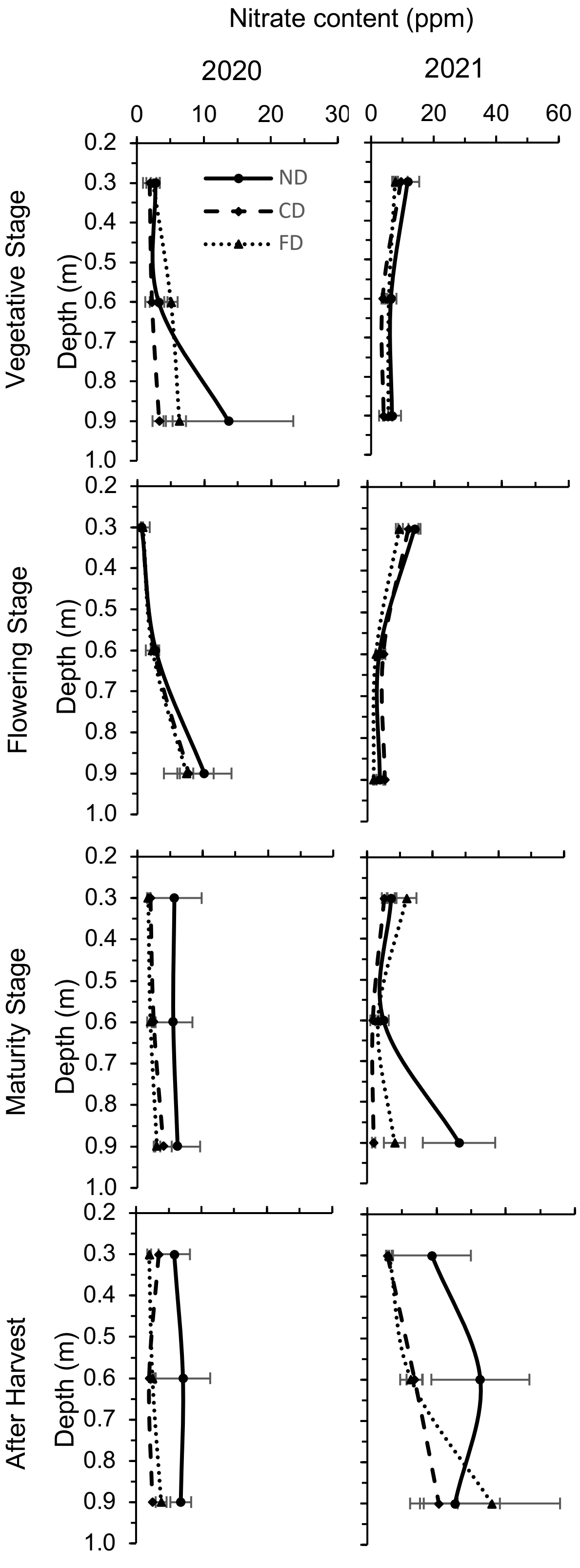
In this study, soil Nitrate-N content seems to vary with rainfall events. Samples collected after rainfall events had lower concentrations when compared with those collected after prolonged dry periods. Results also showed that the average nitrate content was higher than those reported in previous studies. This indicates low nitrate release and use due to low soil moisture, resulting in lower yields. Favourable temperature and sufficient soil moisture are needed for nutrient release (Abbas 2015). Given that nitrogen fertilizer has poor efficiency because less than half of applied N-fertilizer is absorbed by the plants (Wiesler 1998), under drought conditions, canola produces lower yield leaving more residual N in the soil, which accumulates via soil mineralization and nitrogen fertilizer application (Randall et al. 2005, Maaz et al. 2016).

Depth analysis showed increasing nitrate-N content as depth increases. The statistical analysis showed that at 90 cm, it was significantly higher than at other depths, especially during the vegetative and flowering growth stages. This may be attributed to the nutrient-rich groundwater. Haider (2015) measured the nitrate content of the groundwater in the study area and found it was 55 ppm for irrigated plots and 90 ppm for non-irrigated plots. Where no significant difference exists (maturity and after harvest), nitrate-N at the 90 cm depth was still higher.

The 2021 soil nitrate-N analysis was like the preceding year (Fig. 4). This may be because both years were dry. The result showed no significant difference between the treatments even though ND plots had higher nitrate content than the drained plots. However, depth analysis showed that soil nitrate was concentrated on the topmost layer and decreased with depth during vegetative and flowering growth stages. This corresponded to June and July, with significantly low rainfall. The third and fourth sampling periods saw a reversal of nitrate concentration between the 90 and 30 cm depths, with an increasing trend. This corresponded to August and September, which received significant rainfall amounts. This may be due to the following factors: rainfall washing down the nitrate-N content, capillary flux, or crop use at the later stages.

Soil Test Phosphate (STP)

Figure 5 shows the STP within the root zone for each treatment at different growth stages during the 2020 and 2021 growing seasons. In 2020, only the 30 cm depth was analyzed. Results show no consistent STP trends and no statistical difference between the treatments due to the high variability in the plots. However, STP was highly concentrated at the top layer throughout the study. Phosphate (P) is not as mobile as other nutrients as it is adsorbed to soil particles. This agrees with other studies (Vadas et al. 2005, King et al. 2015, Gramlich et al. 2018, Pease et al. 2018, Liu et al. 2021). Wilson et al. (2016) observed that STP at the top depth (0-15 cm) was significantly higher than at 15-60 cm depth under different fertilizer inputs, management, and history in eight fields in southwestern Manitoba. They reported a mean average of 10.8 and 2.8 mg/kg for 0-15 cm and 15-60 cm, respectively.



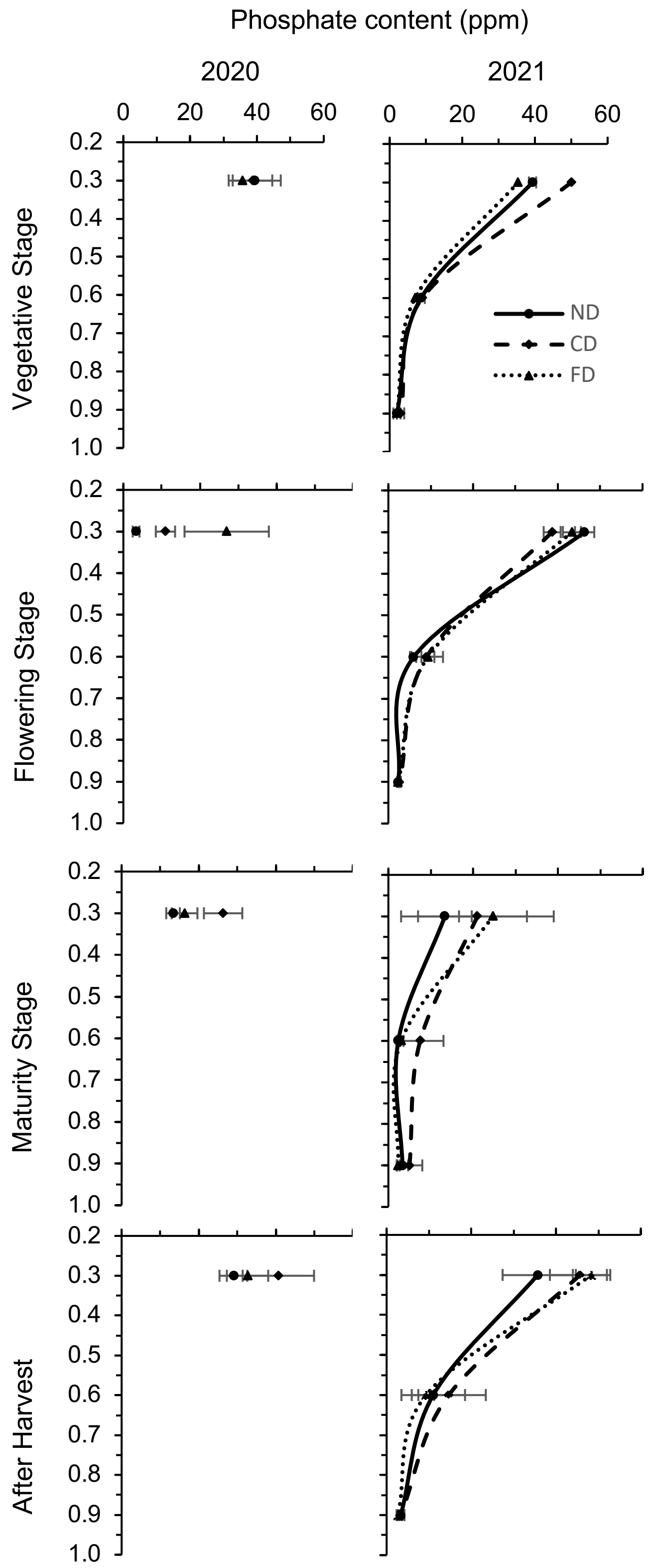


Fig. 4. Soil Nitrate-N content within the rootzone during 2020 and 2021 growing seasons.

Fig. 5. Soil Phosphate content within the rootzone during 2020 and 2021 growing seasons.

Too much fertilizer application can cause the transport of P down the soil profile and P export in drainage water. As shown in Fig. 5, STP decreased with increasing depth. Due to low rainfall and high temperature, low soil moisture might have limited dissolved P, limited P release, and reduced nutrient uptake, resulting in reduced yield. Pease et al. (2018) reported that weather conditions influence nutrient dynamics.

The STP is an indicator of dissolved P in snowmelt runoff and export from drain tiles (Vadas et al. 2005, King et al. 2015, Gramlich et al. 2018, Grenon et al. 2021). Several studies have reported a strong positive correlation between STP and dissolved P in drain tiles (Pease et al. 2018) and runoff (Wilson et al. 2019, Liu et al. 2021). According to the Manitoba soil fertility guide (2007), the level of STP in the study area is classified as very high STP (>15 ppm), medium STP (8-11 pm) and low STP (<3 ppm) for the top, mid-profile, and deep profile, respectively. The high concentration of STP at the study site poses an increased risk of P enrichment and water pollution, as research has shown that sites with STP higher than the recommended values would have high soluble P concentrations in drainage water and runoff (Pease et al. 2018).

Canola Quality Assessments

Canola quality assessments, including oil, protein, and glucosinolate contents, are presented in Fig. 6. Figure 6 shows the average annual values for the different treatments. Statistical analysis showed no significant differences between ND, CD, and FD. Also, there were no clear observable trends between the treatments during the study periods. However, some of the parameters had a statistical difference between the years. This suggests that environmental variables may have masked drainage impacts. This is in line with studies that reported that the environment significantly influences canola oil quality (Omidi et al. 2010, Hammac et al. 2017).

Oil content is positively correlated to yield (Khalatbari et al. 2021) since it constitutes about 40-45% of the dry weight (Barthet, 2020). Across the treatments, the average oil content was 45.9% in 2019, 46.0% in 2020, and 43.3% in 2021. The average protein content was 24.6, 24.2, and 27.8% in 2019, 2020 and 2021. Also, the average glucosinolate was 5.7, 19.6, and 13.9 μmol/g in 2019, 2020 and 2021, respectively. Despite the unusual weather observed in 2021, the glucosinolate content did not exceed the threshold set by the Canada Council of Canola. The values in this study were consistently higher than western Canada's 5-year average for oil, protein and glucosinolate content (Barthet, 2020).

There was a significant decrease in oil content and increased protein content in 2021 relative to 2019 and 2020. The 2021 growing season was characterized by heat and drought stress. This agrees with other reported research showing oil and protein content are inversely related (Rathke et al. 2005, Aksouh-Harradj et al. 2006, Hossain et al. 2019). Heat stress decreases oil content by downgrading the expression of genes associated with photosynthesis and lipid metabolism. In contrast, protein content is increased because of upgrading the expression of genes related to protein biosynthesis (Zhou et al. 2018). Also, the increase in protein content under heat stress could be related to the competition for carbon during the biosynthesis process (Rathke et al. 2005) and increased nitrogen bioavailability, resulting in more amino acid assimilation (Singer et al. 2016). However, the oil content recorded in this study was higher when compared with similar studies (Pavlista et al. 2016, Elferjani and Soolanayakanahally 2018, Khalatbari et al. 2021, Chaganti et al. 2021), despite the weather conditions. This may be due to cultivar differences and other local factors such as soil and nutrient.

Fatty Acid (FA)

Figure 7 shows the annual average of the FA components per treatment. As expected, of the total fatty acid profile, the oleic acid (C18:1) was the highest, comprising 63.8% of the total fatty acid, followed by Linoleic acid (C18:2), 19.1%, linolenic acid (C18:3), 8.8%, Palmitic (C16:0), 3.7%, Stearic acid (C18:0), 3.7%, and erucic acid (C22:1), 0.1%. Statistical results showed no clear observable trends for all the FA components and no significant differences between the treatments. However, there was a significant decreasing trend for Stearic and Oleic acid over the study period, while Linoleic and Erucic acid increased. Also, there was a higher proportion of Linoleic and Erucic acids in 2021, Linolenic and Palmitic acids and 2020, while Stearic and Oleic acids had higher contents in 2019. This could be related to the weather of the growing periods, which was classified as normal, dry, and dry-hot for 2019, 2020, and 2021 respectively. The results of this study agree with numerous studies that state that the FA composition is mainly affected by heat and drought stress. The trend observed in Oleic, Linoleic, and Linolenic acid agrees with Zhou et al. (2018), while the trend in Stearic acid agrees with Moghadam et al. (2011) and Palmitic agrees with Pokharel et al. (2020).

There are inconsistent trends of canola fatty acid profile in the literature due to environmental stresses. This is because of the strong interaction between the cultivar and the environment (Hammac et al. 2017, Pokharel et al. 2020). However, a lot of studies report that heat and drought stress increased relative proportions of saturated fatty acids (palmitic and stearic acid), oleic acid (monosaturated fatty acid) and decreased polyunsaturated fatty acids (linoleic and linolenic) (Pritchard et al. 2000, Pavlista et al. 2011, Aksouh et a. 2006, Pokharel et al. 2020). On the contrary, while some studies (Elferjani and Soolanayakanahally 2018, Zhou et al. 2018), reported decreased and increased proportions of oleic and linoleic acid, respectively, Pavlista et al. (2016) reported a slight impact on fatty acid composition, with no significant effect on Oleic and linoleic acid.

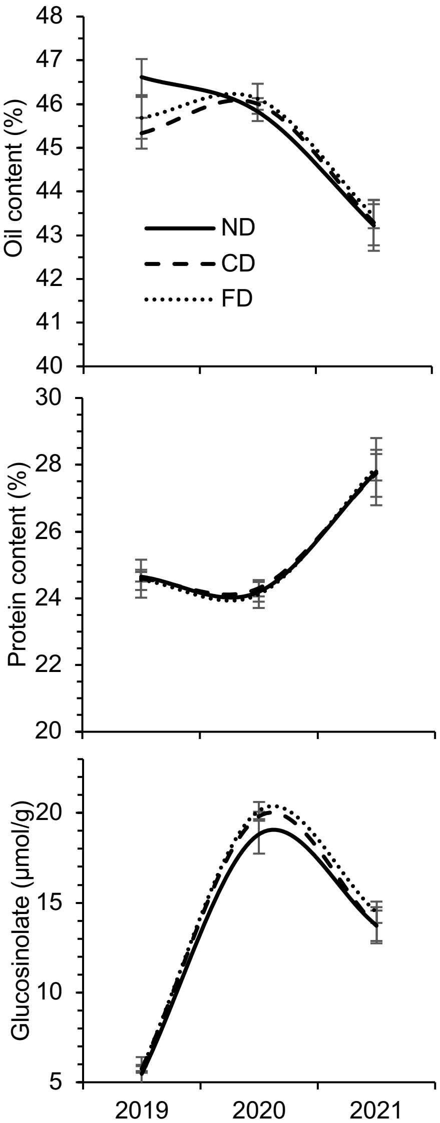


Fig. 6. Average annual oil, protein, and glucosinolate contents.

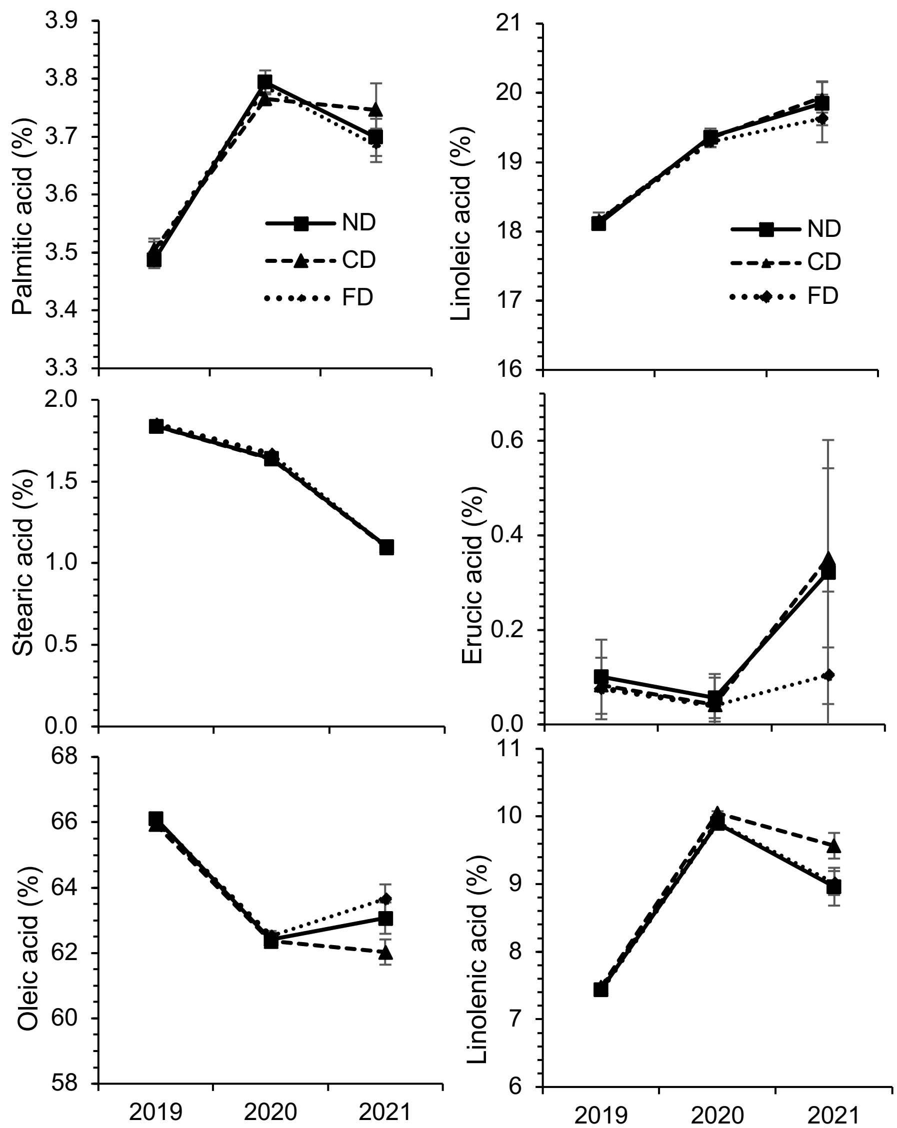


Fig. 7. Average annual proportions of fatty acids (Palmitic acid (C16:0), Linolenic acid (C18:3), Stearic acid (C18:0), Erucic acid (C22:1), Oleic acid (C18:1), Linoleic acid (C18:2).

CONCLUSIONS

The impacts of water management on canola yield and quality were evaluated under three different treatments: controlled drainage (CD), free drainage (FD), and no drainage (ND) for three growing seasons (2019-2021). Canola yield, oil quality tests (oil, protein, and glucosinolate contents), fatty acid profile tests, and nitrate and phosphate contents were also measured for each treatment. The result showed that weather might have influenced drainage impacts on yield. In 2019 with relatively reasonable rainfall amount and average normal temperature, results showed that CD plots consistently had the highest yield across all replicates, with a significant statistical difference between CD (3.51 Mg/ha) and FD (3.02 Mg/ha). However, as the growing season rainfall decreased in the following years, the impact of drainage, especially CD, diminished, resulting in no significant differences between the treatments. In 2020, the average yields were 3.12, 2.52, and 2.97 Mg/ha for ND, CD, and FD, respectively. Similarly, in 2021, there was no significant difference between CD (1.14 Mg/ha), FD (1.52 Mg/ha), and ND (1.07 Mg/ha). Soil nutrient analysis showed that ND had higher soil nitrate content across the treatments, although it was not significantly different from CD and FD.

Canola oil quality results, including oil, protein, glucosinolate, and fatty acid profile, showed no significant differences between the treatments but varied significantly over the years. This suggests that environmental variables might have masked drainage impacts. With the predicted rise in temperature and prolonged water deficits in the Canadian Prairies in the future, the results in this study suggest the examination of drainage design and precise water management strategies. A significant amount of water from snowmelt is lost during the spring, which could otherwise be captured, stored and re-used during the dry periods.

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