Growth of Spring Canola (*Brassica napus*) under Deficit Irrigation in Western Nebraska

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Abstract

Drought is a periodic occurrence in the High Plains of the U.S.A.; thereby low-water using crops are desired. Canola, a biofuel and food oil, has been studied in the region under rain-fed conditions for several years. The study's objective was to measure plant growth, seed yield, and oil characteristic of canola at four levels of applied water in western Nebraska. The cultivar Hyola 357 Magnum was exposed to rain-fed only (RF), and irrigated with 10 (LI), 20 (MI), and 30 (HI) cm water. Adding irrigation increased plant growth, i.e., canopy height, stem length, and canopy weight. Highest canopy height (> 100 cm for MI and HI) was reached by 10 weeks after planting (WAP) with a total of 23 cm of applied water or 13 cm of irrigation. By 8 WAP, canopy fresh weight was increased by 37 to 58% by MI and HI irrigations. Pod fresh and dry weights at harvest (13 WAP) were increased > 50% and > 20%, respectively, by all irrigations. Seed yield were increased by each incremental increase in irrigation from 1220 kg/ha for RF to 2905 for HI, a 2.4-fold increase. Seed oil content was increased by MI and HI irrigations (4 to 8%). The fatty acid profile was not substantially altered by irrigation. There was a slight decrease of palmitic acid and increase in linolenic acid with HI. Canola showed that > 20 cm of applied water is needed for good vine and pod growth but > 40 cm was needed to achieve the highest yield.

Canola could be grown successfully in western Nebraska, supplying oil for fuel and cooking.

Keywords: oilseed; biodiesel; oleic acid; omega-9

1. Introduction

With a gradual changing climate, water levels in parts of the High Plains aquifer began to decline in the 1950s (Anderson and Woosley, 2005; Supalla et al., 1982). Furthermore, low rainfall and periodic, long and severe droughts in western Nebraska, where the average rainfall from mid April to mid July is 20.8 cm, result in less water available for agriculture (Basara et al., 2013) and decreasing irrigation allocations (Bleed and Babbitt, 2015). Water allocation have been restricted in some districts. Therefore, a low water supply for agriculture will be normal and no longer an exception during periods of drought (Fereses and Soriano, 2007). With less irrigation water available, there is a need to find low water-using crops. Studying several major crops, Schneekloth et al. (2001) suggested that applying limited water provides more profit potential and has less impact on the local economy than reverting some land to dryland. When deficit irrigation is used, full evapo-transpiration demand is not met and the crop is under continuous, but not severe, water stress. Proper deficit irrigation management may not reduce yield as much as might be expected with some crops (Hergert et al, 1993; Klocke et al., 2004). Deficit irrigation is a way of optimizing irrigation during drought-sensitive stages such as corn (maize) (*Zea mais*), cotton (*Gossypium hirusutum*), potato (*Solanum tuberosum*), soybean (*Glycine max*), and wheat (*Triticum aestivum*) (Geerts and Raes, 2009). English and Raja (1996) showed that deficit irrigation on corn, cotton and wheat, where water is scarce, is the optimal strategy by reducing irrigation by 25 to 60%. Pavlista (2015) demonstrated that for marketable yield of potato timing of deficit irrigation is crucial. However under some circumstances, deficit irrigation may not be economically advantageous (Trout et al., 2010). Canola-type rapeseed may be suitable for arid and semi-arid regions since it is reported to be water-stress tolerant

(Majnooni-Heris et al., 2014; Nielsen, 1997).

During World War II, rapeseed was grown in North America as a biofuel for marine vessels (Johnston et al., 2002). Due to rapeseed's high ercucic acid content, it was unacceptable as an edible oil. Following the war, breeding efforts in Canada resulted in a type of rapeseed that contained little of ercucic acid and was acceptable for consumption. The cultivars of this type were named canola to distinguish them from industrial oils (Johnston et al., 2002). Canola is a cool-season crop widely grown in the central and northern Great Plains of North America (Chen et al., 2005; Kutcher et al., 2010; McCartney et al., 2004; Nielsen, 1998; Pavlista et al., 2011b). Canola cultivars may be winter or spring types. Spring canola has been suggested as a suitable crop to grow before winter wheat in rotation (Nielsen, 1998) but under dryland conditions such as in Colorado, dryland spring canola may not be economical (Nielsen, 1997).

Canola has experienced a resurgence of interest as a biodiesel in the U.S.A., an alternate to petro-diesel using renewable saddle crops (Bhardwaj, 2007). Two-thirds of canola oil is comprised of C18:1, most of which is C18:1 d9 (oleic acid, 'omega-9') (Ma and Hanna, 1999). Using cv. Hyola 357 Magnum, Haagenson and Wiesenborn (2011) reported acceptable properties of biodiesel from canola. Luo et al. (2010) reported that canola biodiesel properties were superior to those of soy-based biofuels. In comparison to three other canola cultivars, Hyola 357 Magnum was reported to be the highest yielding and well-adapted to the central Great Plains (Pavlista, 2011b).

Analyzing canola yield data across many years and locations in Saskatchewan, Canada, Kutcher et al. (2010) observed that "High-yield years were associated with greater-than-average precipitation ..." Most research on canola in North America has been under dryland (rain-fed) conditions. From these studies water-use functions were developed (Johnston et al., 2002; Brandt and McGregor, 1997; Nielsen, 1998). Recently, water-use functions of irrigated canola have been calculated for western Nebraska (Hergert et

al., 2011; 2015). Irrigation studies in North America focused on the stage of canola growth that is most sensitive to water stress (Nuttall et al., 1992; Stoker and Carter, 1984). Saseendran et al. (2010) developed a canola growth model from several studies in northeast Colorado. Most recent studies on deficit irrigation on canola have been reported from Iran (Majnooni-Heris et al., 2014; Motlagh et al., 2012; Naghavi et al., 2015). Recent studies on planting date, seeding amount and planting method for the northern Great Plains were reported (Aiken et al., 2015; Angadi et al., 2003; Chen et al., 2005; Pavlista et al., 2011a). Studies on canola under deficit irrigation are limited in the U.S.A. Pavlista et al. (2012) compared growth patterns of canola (*Brassica napus*) to brown mustard (*Brassica juncea*) and camelina (*Camelina sativa*) under low irrigation. However, the objective of this study was to identify the effects of various levels of irrigation on growth, yield and oil content of canola grown at two location over two years in western Nebraska.

2. Materials and Methods

2.1 Field trial Conditions

Four field trials were conducted on canola cv. Hyola 357 Magnum which requires less heat units for emergence than many canola cultivars (Chen et al., 2005). In each year, 2007 and 2008, one trial was at Scottsbluff and the other at Sidney, NE. At Scottsbluff, trials were at the Panhandle Research and Extension Center (41°89'N, 103°68'W with an elevation of 1189 m) on a Tripp fine sandy loam soil at pH 8.1 with an organic matter content of 1.2%. At Sidney, trials were at the High Plains Ag Lab (41°23'N, 103°02'W with an elevation of 1247 m) on a Keith silt loam soil at pH 6.8 and organic matter content of 2.4%. Plots consisted of 38 rows spaced 0.2 m apart and 9.1 m long or an area of 69 m² of which 6 rows 9 m long, an area of 10.8 m², was harvested. Previous crop was dry edible beans (*Phaseolus vulgaris*) at Scottsbluff in both years, and at Sidney, they were winter wheat (*Triticum aestivum*) in 2007 and foxtail millet (*Setaria italica*) in 2008. Fertilization was based on soil tests using guidelines adapted from recommendations on canola in the region (Boyles et al., 2006). Total residual N in the top 0.9 m were

>130 kg/ha at Scottsbluff in both years and >110 kg/ha at Sidney for both years. In Scottsbluff, a starter fertilizer was added pre-plant incorporated at 34 kg N/ha and 39 kg S/ha. In Sidney, the starter fertilizer added was 50 kg N/ha, 28 kg P₂O₅ and 22 kg S/ha. The starter was incorporated with 1.25 cm of water within 6 h of application. In Sidney, 30 kg N/ha supplemented the started fertilizer for the medium irrigation level and 56 kg N/ha was added to the high level, that was non-evapo-transpiration limiting.

Trifluralin (Treflan HFP @ 1.2 l/ha) was applied pre-plant incorporated for early weed control. As ‘Hyola 357 Magnum’ is glyphosate-resistant (‘Roundup Ready’), one post-emergence application of glyphosate (Roundup @ 1.1 l/ha) was applied at the 6-leaf stage for additional weed control. Canola seed was obtained pre-treated with a mixture of thiamethoxam, difenoconazole, metalaxyl, and fludioxonil (Helix-Xtra) for protection against flea beetle (*Phyllotreta* spp.) (Pavlista et al., 2011b) and several seed-borne pathogens. Downy mildew (*Hyaloperonospora camelinae*) did not appear on canola in these trials, therefore no foliar fungicide was applied. Therefore, neither insects or pathogens presented themselves as a problem in either location in 2007 and 2008.

Planting was in mid-April at both locations and in both years as recommended by Pavlista et al. (2011b). Soil moisture in the top 1 m, as measured by a neutron probe, was 27.7 and 28.0 cm at Scottsbluff in 2007 and 2008, respectively, and 36.3 and 25.1 cm at Sidney in 2007 and 2008, respectively. Available water was 16 cm in the soil at both locations. Seeding was 4 to 5 kg/ha in 20-cm row spacing using a double-disc drill at a depth of 1.2 cm (Aiken et al., 2015). All trials were harvested in mid-July, about 13 weeks after planting (WAP) with a small plot combine (Table 1). Canola seed was considered mature and ready for harvest when the pods desiccated and hardened, and the color changed from green to maroonish brown. Seed moisture was determined and yields adjusted to an 8% moisture basis. Physiological days (P-days) were calculated based on daily temperature fluctuations using the formula by Sands et al. (1979).

2.2 Irrigation Regimes

Weather stations were located near the trial fields, and rainfall and temperature were monitored by the High Plains Climate Center (Changnon et al., 1990). Irrigation was applied through an overhead, linear-move system. Four irrigation levels were applied to plots replicated three times in a randomized complete block design. A light irrigation of 0.5 cm was applied at planting to enhance and ensure uniform seed germination and plant emergence. The check was no irrigation during the growing season or rain-fed (RF). The three irrigated levels were targeted at a seasonal irrigation level of 10 cm (LI), 20 cm (MI) and 30 cm (HI) of applied water. Note that the actual amount of irrigation was decreased based on rainfall checked daily. In Scottsbluff, 2007 was a very dry year with the wettest month being May receiving 2.2 cm and less thereafter; 2008 was still dry but closer to normal, receiving 7.6 cm from 1 May to 30 June. In Sidney, 2007 was the wettest of the four trials receiving 17 cm during the growing season; 2008 was dry receiving 11.4 cm of rain from 1 May to 30 June. Since earlier research on canola indicated that flowering and early grain fill were the most sensitive stages to water stress (Gunasekera et al., 2006; Stoker and Carter, 1984; Tesfamariam et al., 2010), LI (10 cm), irrigations were timed to coincide with flowering and early grain fill. MI (20 cm) irrigations were applied through vegetative growth to flowering and early grain fill. Full irrigation (HI) was season long. Irrigation was not adjusted for rainfall, therefore, RF received 15.8 cm rain during the season while HI received 43.1 cm (rain plus irrigation) (Table 1). Distribution of irrigation was based on the weather station data and HI was not evapo-transpiration-limited. Actual evapo-transpiration obtained through weather stations operated by the High Plains Climate Center (Changnon et al., 1990) was used to calculate water use (Hergert et al., 2011). The water holding capacity of the soil was 6 cm in the top 30 cm.

2.3 Data Collection and Analysis

To follow plant growth, canopy height and weight, stem nodes and length, were measured every 2 to 3

weeks starting at 4 WAP (Table 1) following the procedure of Pavlista et al. (2012a). Canopy height and width were measured with a meter-stick three times in the center rows of each plot at each reading and averaged. Stem length was measured with a meter stick, the number of nodes counted and canopy weighed on four plants cut at the base in each plot. Canopies were weighed with pods, if present, separated from the stem and branches. The plants were, then, dried in an oven set at 50°C for 7 to 10 days and re-weighed. Weights were averaged per plot at each reading. Seeds were harvested directly and yields were weighed. Plot yields were adjusted per area. Seed sub-samples were sent to the USDA-ARS laboratory in Peoria, IL, for oil extraction and fatty acid analysis following the procedure described in Pavlista et al. (2011b). Data were analyzed using Proc ANOVA in SAS with means separated using least significant differences and inferences based on a 5% significance level (SAS Inst 2003) when $p < 0.05$. There were no significant interactions between growth or harvest data with either year or location, therefore the data from the four trials were combined.

3. Results

3.1 Seasonal Growth

Differential irrigation and accumulation of physiological day (p-day) began at 50% emergence of canola which occurred 10 to 12 days after planting (Table 1). Growth was followed from about 4 WAP to harvest at about 13 WAP. Irrigation level did not affect the number of nodes on the main stem and 12 to 14 nodes was reached 6 WAP (data not shown). This corresponded to a p-day of 150 (Table 1). Canopy height was not affected by irrigation level until 8 WAP when RF plants were shorter than the irrigated plants (Table 2). Two weeks later, RF was the shortest at 76 cm, followed by LI at 89 cm while MI and HI were tallest over 100 cm. By harvest, all irrigation levels differed from each other with RF the shortest and HI the tallest. The time course of canopy height showed that the peak was reached by 10 WAP (Table 2) corresponding to a p-day between 295 and 331 (Table 1). Stem length and canopy width were also measured at 10 WAP showing similar differences between irrigation levels (data not shown). Canopy

fresh weight of RF was significantly less than any irrigation level by 6 WAP (Table 3). At later times, irrigation resulted in greater differences between levels. At 8 WAP, canopy fresh weight for HI and MI were significantly greater than RF and at 13 WAP, LI was also greater than RF (Table 3). Note that at 13 WAP, canola lost much of its stem plus branch fresh weight as plants were senescent. Pods were present at 8WAP but a difference in pod fresh weight between RF and irrigation levels did not appear until harvest when pods had matured (Table 3). The differences in total above-ground fresh weight corresponded to that of the vegetative vine at 6 and 8 WAP, and to the pods at 13 WAP (Table 3). Total above-ground dry weights followed a similar pattern at harvest except that LI did not significantly differ from RF (Table 4).

3.2 Yield

Seed was harvested at 13 WAP, when p-days were between 473 to 499. Yield showed a significant difference between all four irrigation levels with RF the lowest and HI the greatest (Table 4). The 10-cm increments in irrigation had a profound effect on canola seed yield (Table 4). Just irrigating with 10 cm of water increased yield by 519 kg/ha or 43%. Adding another 10 cm of irrigated water increased yield an additional 705 kg/ha (41% increase) and full irrigation, adding 27 cm of water to rainfall raised yield by still another 461 kg/ha over MI yields (19%). Comparing fully irrigated plants (HI) to rain-fed plants (RF), 27 cm of applied water resulted in a seed yield increase of canola of 1685 kg/ha or 238% of RF yield.

3.3 Oil and Fatty acids

Seed oil content was significantly higher with HI (full irrigation) compared to the other three moisture levels, and MI's oil content was higher than LI or RF (Table 4). Oil content was affected by both location and year but neither interacted with irrigation level. There were no interactions between either year or locale for any of the harvest data. The fatty acid profile showed that C18:1 was the major fatty acid group

in canola comprising two-thirds of the total fatty acid content. C18:1 consisted primarily (95%) of C18:1 d9 (oleic acid or ‘omega-9) (Table 5). Irrigation did not significantly affect the amount of oleic acid in the seed but a trend to decrease its presence was present (Table 5). C18:1 d11 (vaccenic acid), the other component of C18:1 was not affected by irrigation. The second major fatty acid component was C18:2 (linoleic acid) at 17% but showed no irrigation effect (Table 5). Two other noticeable fatty acid constituents were C16:0 (palmitic acid) and C18:3 (linolenic acid). Palmitic acid showed a significant decrease in seed when fully irrigated (HI) following the trend for oleic acid while linolenic acid showed the opposite with HI significantly having the highest content (Table 5).

4. Discussion

4.1 Seasonal Growth

Canopy height and stem length increased with irrigation but stem node number was unaffected. This suggested that stem growth was due to internode elongation which may be related to gibberellic acid. The application of 23 cm of rain plus irrigation was sufficient to reach a tallest canopy height of 101 cm by 10 WAP. Comparing MI to RF irrigation levels (Tables 1 and 3), 17.8 cm of irrigation was needed to achieve the tallest height. Previous studies of canola in western Nebraska under low water availability (< 20 cm) reported a maximum canopy height of 90 cm reached after 9 WAP (Pavlista et al., 2012). Saseendran et al. (2010) a maximum plant height of 80 cm attained between 10 WAP under simulated average rain conditions for northeast Colorado. In their 2005 experiment, drought conditions, < 20.7 cm rain, did not affect plant height. But, in their 2006 experiment where the maximum water applied was 12.1 cm, plant height was 70 cm by 10 WAP and was reduced with less water applied. A recent study in Iran agreed with our findings that irrigation level reduced plant height. Majnooni-Heris (2014) reported a plant height of 98 cm with 50 cm of applied water reduced to 78, 62 and 58 cm with 41, 34 and 27 cm of applied water. Changes in height over time were not reported in their study.

Canopy fresh weight reached its greatest at 8 WAP with the two higher irrigation levels (MI and HI) being the greatest, between 85 and 98 g/plant, before maximum height was reached (Table 3). Pod fresh weight was near 90 g/plant at harvest, three weeks after maximum height at harvest (Table 3). To reach the greatest canopy fresh weight, 18 cm of applied water was needed and for the final pod fresh weight, 26 cm was needed. In an earlier study of canola under low water availability (< 20 cm), Pavlista et al. (2012) reported a high fresh weight of 30 g/plant attained at 6 WAP. Furthermore, they reported pod fresh weight reaching 25 g/plant by 9 WAP and remaining at this level to harvest. Their data are below that reported here. As with plant fresh weight, leaf area index is indicative of plant size. A decrease in leaf area index of canola plants associated with lower levels of applied irrigation have been reported, most recently by Majnooni-Heris et al. (2014).

4.2 Yield

Seed yield increased with every incremental increase of 9 cm of applied irrigation from 1220 kg/ha for RF (no irrigation) to 2905 kg/ha (full irrigation) with 43 cm of applied water (Table 4). With 20 cm water applied, Pavlista (2012) reported a yield of 1600 kg/ha which is near the amount reported here for LI treatment receiving 25-26 cm of water (Table 4). Hamzei (2011), and Hamzei and Soltani (2012) reported that 45 cm of applied water was needed to achieve a yield of 2565 kg/ha in Iran and a reduction of applied water to 30 cm reduced yield by greater than half. Majnooni-Heris (2014) recently reported a yield of 1790 kg/ha with 50 cm of applied water also in Iran. Faraji et al. (2009) using flood irrigation in Iran achieved a yield of 2567 kg/ha which was 500 kg/ha greater than rain-fed winter-grown canola cv. Hyola 401. In Australia, canola achieved a maximum 1800 kg/ha seed yield under rain-fed conditions with 21 cm of water (Gunasekera et al., 2006). The Canola Council of Canada reports on its website a yield of 2463 kg/ha under 37 cm of applied water. These yields and corresponding water needs correspond well with the data reported here. Water use equations have been reported for Colorado (U.S.A.) and Saskatchewan (Canada). Using their formulas, to achieve 2905 kg/ha of canola seed, the application of 40

to 49 cm of water would be needed in Saskatchewan (Brandt and McGregor, 1997; Johnston et al., 2002) and in northeast Colorado, this grain yield would need 37 cm of applied water in addition to 10 to 15 cm of estimated soil water (Nielsen, 1997; 1998). Our data would be in line with these predictions. Irrigating increased plant dry weigh, but the level did not have a significant effect (Table 4).

Some reports indicated that the stage most sensitive to water stress is flowering (Gunasekera et al., 2006; Tesfamariam et al., 2010). The irrigation levels applied in this study differed in the timing of water application. With LI, irrigation was applied at flowering and early grain fill; in MI, irrigation was applied throughout the vegetative stage and flowering but terminated at early grain fill. Under HI, irrigation continued throughout the season to a week before harvest. Since to achieve the highest seed yield, irrigation was required throughout the season, there was no special requirement for water at flowering. This observation agreed with the statements “Timing of water stress did not significantly affect yield.” (Nielsen, 1997). The different observations may be due to location differences between Colorado and Nebraska versus Australia and South Africa in the southern hemisphere. Besides seed yield, the timing of water application reported here did not seem to affect final canopy height and fresh weight, and seed oil content.

4.3 Oil and Fatty Acids

Seed oil content was highest with full irrigation (HI) receiving 43 cm of water, and oil content was higher with MI compared to LI and RF (Table 5). The oil content in HI seed was 35% compared to 32% for RF. The oil content in this study was on the low side of the range of 34 to 42% reported earlier in western Nebraska (Pavlista et al., 2011b; 2012), 36 to 44% reported in northeast Colorado (Nielsen, 1997). In Montana, Chen et al. (2005) reported a range of 38 to 44% for the cultivar Hyola 357 Magnum, the cultivar used in the Nebraska studies. Other reported ranges in oil content are 36 to 40% in South Africa (Tesfamariam et al., 2010) and 35 to 45% in Iran (Motlagh et al., 2012). Hamzei (2011) reported

that 45 cm of applied water was need to reach the highest seed oil content which agrees with our findings.

Adding irrigation slightly altered the fatty acid profile, however the major fatty acid, oleic acid (C18:1 d9, 'omega-9'), 64%, was not significantly affected (Table 5). Linoleic acid (C18:2), the second major component (17%), also was not affected. Two other components, however, were affected by HI. Palmitic acid (C16:0) showed a decrease and linolenic acid (C18:3) showed an increase (Table 5). These values were similar to those reported earlier for western Nebraska with 36 cm of applied water (Pavlista et al., 2011b) and with 20 cm of applied water (Pavlista et al., 2012). The only report on the effects of water stress on fatty acid composition is by Champolivier and Merrien (1996). They noted that only when water stress was applied at flowering and grain fill when they observed a decrease in oil and oleic acid content. Since irrigation was applied in all treatment levels at flowering and early grain fill, a comparison was not possible.

5. Conclusion

Canola needed about 18 cm of applied water (rain plus irrigation) for the highest canopy weight and 23 cm for the highest canopy height. The highest seed yield in this study was reached when at least 43 cm of water was applied of which 27.3 cm was irrigated. The National Marketing Year, three-year (2012, 2013, 2014) price average for canola is US\$ 470.25/Mg (USDA NASS). The value of the canola yield in this study would be \$418.50/ha for RF, \$721.36/ha for LI, \$979.53/ha for MI, and \$1,195.85/ha for HI. The difference in yield for applying 9.9 cm of water, from RF to LI, is 644 kg/ha or a gain of \$302.84/ha. Applying an additional 8.7 cm of water, from LI to MI, increased yield by 549 kg/ha and a sales gain of \$258.17/ha. Increasing irrigation by another 8.7 cm, from MI to HI, another yield increase of 460 kg/ha and an additional sales of \$216.32 are achieved.

In western Nebraska according to the University of Nebraska-Lincoln Crop Budgets, the cost of applying irrigation is \$2.87/cm and includes labor, fuel, repairs, and ownership. This cost is based on applying water with an electric-powered pivot with a 38.1 m lift. The fixed electrical cost is \$74.13/ha. To

irrigate LI, the cost of applying 9.9 cm of water would be \$102.54/ha (operation at \$28.41/ha plus electricity at \$74.13/ha); with an increased value of \$302.84/ha, the increased profit is \$200.30/ha. To irrigate MI compared to dryland, the cost of applying 18.6 cm of water would be \$127.51/ha (operation at \$53.38/ha plus electricity of \$74.13); with an increased value of \$561.01/ha compared to dryland, the increased profit is \$433.50/ha. To irrigate HI compared to dryland, the cost of applying 27.3 cm of water would be \$152.48/ha (operation at \$78.35/ha plus electricity of \$74.13); with an increased value of \$777.33/ha compared to dryland, the increased profit is \$624.85/ha. These economic calculations show that growing spring canola under the semi-arid conditions of western Nebraska with low rainfall could be successful and profitable especially for the biofuel industry. Legal water restrictions limiting irrigation to 30 cm level would not be a drawback to spring canola production as it would be for other crops.

The results of this study are applicable throughout the High Plains and any semi-arid region that faces or may face water allocation restriction. In response to lower rainfall and reduced irrigation water availability, canola would be a good alternate crop due to its lower need for irrigation compared to some other crops grown region with a similar climate as western Nebraska. Furthermore, the US government is interested in developing biofuels from canola thereby increasing the market for this crop.

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Table 1.

Dates, physiological days and precipitation, means and standard errors of four canola trials, Scottsbluff and Sidney, NE, 2007 and 2008.

WAP ^b	DAP ^b	P-days ^c	RF ^a	LI	MI	HI
			precipitation ^d , cm			
4	31 ± 1	114 ± 8	2.9 ± 0.1	4.8 ± 0.8	5.6 ± 0.3	7.0 ± 0.9
6	43 ± 1	151 ± 24	6.6 ± 1.4	8.5 ± 1.0	11.0 ± 1.6	12.3 ± 2.2
8	57 ± 1	216 ± 16	9.4 ± 2.7	13.0 ± 0.6	17.7 ± 3.7	19.1 ± 3.2
10	71 ± 1	313 ± 18	10.8 ± 3.4	17.5 ± 2.2	23.4 ± 3.7	27.1 ± 2.9
12	88 ± 2	443 ± 8	14.2 ± 3.4	24.1 ± 3.5	32.3 ± 2.7	40.4 ± 1.5
13	94 ± 4	486 ± 13	15.8 ± 3.3	25.7 ± 3.3	34.4 ± 3.3	43.1 ± 2.7

^a Irrigation levels were rain-fed (RF) representing no irrigation, LI with a target irrigation of 10 cm, MI with a target irrigation of 20 cm, and HI with a target of 30 cm.

^b WAP = target week after planting; DAP = actual days after planting.

^c P-days were calculated as described in Sands et al., 1978.

^d Precipitation is the sum of rainfall plus irrigation. Irrigation level RF represents rainfall alone. Available water of the soil at both locations was 16 cm.

Table 2.

Canopy height as affected by irrigation level and time, mean of four canola trials.

WAP ^a	4	6	8	10	13	
P-days ^b	110	150	220	310	490	<i>p</i> -value
Irrigation ^c	canopy height, cm					
RF	15 c ^d	27 c	57 B ^e , b	76 C, a	86 D, a	<0.01
LI	14 d	29 c	65 AB, b	89 B, a	95 C, a	<0.01
MI	14 d	29 c	71 A, b	101 A, a	104 B, a	<0.01
HI	12 d	29 c	74 A, b	105 A, a	111 A, a	<0.01
<i>p</i> -value	NS	NS	0.02	<0.01	<0.01	

^a WAP = weeks after planting.^b P-days were calculated as described in Sands et al., 1978.^c Irrigation levels were rain-fed (RF) representing no irrigation, LI with a target irrigation of 10 cm, MI with a target irrigation of 20 cm, and HI with a target of 30 cm.^d Values in rows (across WAP) followed by the same ordinal letter were not significantly different at $p < 0.05$ based on least significant differences.^e Values in columns (across irrigation levels) followed by the same capital letter were not significantly different at $p < 0.05$ based on least significant differences; NS = not significant at $p < 0.05$.

Table 3.

Canopy, pod and above-ground fresh weight as affected by irrigation level, mean of four canola trials.

	Stem and branch fresh weight, g/plant			Pod fresh weight, g/plant			Plant top fresh weight, g/plant		
WAP ^a	6	8	13	6	8	13	6	8	13
Irrigation ^b									
RF	21 B	62 C	20 C	1	19	54 B	22 B	81 C	74 B
LI	29 A	71 BC	29 B	1	19	81 A	30 A	91 BC	110 A
MI	30 A	85 AB	35 B	1	20	88 A	31 A	105 AB	122 A
HI	28 A	98 A	44 A	1	22	88 A	29 A	120 A	132 A
<i>p</i> -value ^c	<0.01	<0.01	<0.01	NS	NS	<0.01	<0.01	<0.01	<0.01

^a WAP = weeks after planting.^b Irrigation levels were rain-fed (RF) representing no irrigation, LI with a target irrigation of 10 cm, MI with a target irrigation of 20 cm, and HI with a target of 30 cm.^c Values in columns followed by the same capital letter were not significantly different at $p < 0.05$ based on least significant differences; NS = not significant at $p < 0.05$.

Table 4.

Harvest^a data as the means of four canola trials, Scottsbluff and Sidney, NE, 2007 and 2008.

Irrigation level ^b	Yield, kg/ha	Plant dry weight ^c , g/plant	Seed oil, % dry weight
RF	1220 D ^d	27 b	32.3 C
LI	1739 C	33 ab	32.2 C
MI	2444 B	35 a	33.6 B
HI	2905 A	36 a	34.8 A
<i>p</i> -values:			
Irrigation (I)	<0.01	<0.10	<0.01
Year (Y)	<0.01	<0.01	<0.01
Locale (L)	NS	<0.01	<0.01
I*Y	NS	NS	<0.01
I*L	<0.01	NS	<0.10
I*L*Y	<0.01	<0.01	NS

^a Harvests of the four trials were around 17 Jul (calendar day 198) or about 13 weeks after planting. The mean P-days $\pm$ standard error at harvest was 486 ± 13 calculated as described in Sands et al., 1978.

^b Irrigation levels were rain-fed (RF) representing no irrigation, LI with a target irrigation of 10 cm, MI with a target irrigation of 20 cm, and HI with a target of 30 cm.

^c Plant weights were of the total above ground weights; roots were not included.

^d Values in columns followed by the same capital letter were not significantly different at $p < 0.05$ based on least significant differences; values in columns followed by the same ordinal letter were not significantly different at $p < 0.10$ based on least significant differences; NS = not significant at $p < 0.10$.

Table 5.

Profile of major fatty acids in canola seed, mean of four trials.

	C16:0 ^b	C18:1 d9	C18:1 d11	C18:2	C18:3
Irrigation level ^a	% seed oil				
RF	4.81 AB ^c	64.5 a ^c	3.3	17.1	6.5 BC
LI	4.88 A	64.2 ab	3.5	17.4	6.4 C
MI	4.74 BC	63.8 ab	3.3	16.9	6.8 B
HI	4.68 C	63.5 b	3.3	17.0	7.4 A
<i>p</i> -values:					
Irrigation (I)	0.02	NS	NS	NS	<0.01
Year (Y)	<0.01	-	-	NS	NS
Locale (L)	<0.01	NS	NS	NS	NS
I*Y	NS	-	-	NS	NS
I*L	NS	NS	NS	NS	NS

^a Irrigation levels were rain-fed (RF) representing no irrigation, LI with a target irrigation of 10 cm, MI with a target irrigation of 20 cm, and HI with a target of 30 cm.

^b Fatty acid profile was determined by the method described in Pavlista et al., 2011b.

^c Values in columns followed by the same capital letter were not significantly different at $p<0.05$ based on least significant differences. Values in columns followed by the same ordinal letter were not significantly different at $p<0.10$ based on least significant differences. NS = not significant at $p<0.05$.