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Yield, irrigation response, and water productivity of deficit to fully irrigated spring canola

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ABSTRACT

Canola (*Brassica napus*) is an oil-seed crop that is adapted to the northern High Plains of the USA and is considered a viable rotational and biofuel crop. However, decreased ground water allocations have necessitated determining the impact of limited irrigation on canola productivity. The objectives of this research were to determine the effects of a range of irrigation from none to fully irrigated on yield, oil content, soil water changes and water productivity of spring canola. The study was conducted for four growing seasons at three locations in western Nebraska. Two sites had sandy soils whereas the other was a silt loam. Glyphosate tolerant canola was planted late March to early April. Cumulative irrigation treatments were 0, 100, 200, and 300 mm of water with the highest rate adjusted to be non-ET limiting. Canola extracted soil water from depths greater than 1.2 m in both fine textured and sandy soils making it a good alternative for deficit irrigation. Canola responded well to irrigation during dry years but showed little response in above average precipitation years. A water use efficiency of 7.6 kg mm^{-1} with a threshold of 123 mm was observed. Canola seed yield ranged from 440 to 3280 kg ha^{-1} with 165 and 582 mm of cumulative ET. During drier years, canola exhibited peak values in water use at 8–9 weeks after planting. Deficit irrigation reduced ET and yield and hastened maturity during drier years. Oil content was increased by irrigation during drier years with no effect shown when precipitation was above average. Oil content ranged from 30 to 50% depending on year and irrigation level. The water response provided benefits of not only higher yield, but also higher oil content which makes deficit irrigated canola an attractive alternative production and biofuel crop for this region.

1. Introduction

Irrigation was introduced to provide more stability and profit to Great Plains agriculture and the High Plains aquifer is a primary source of irrigation water. Irrigation pumping began in the 1920s and by the 1980s had transformed 6.5 million ha of dryland crop production and rangeland into highly productive farmland (Supalla et al., 1982). The High Plains aquifer underlies 445 million ha in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Water-level declines began in parts of the aquifer by 1950. Many areas of the High Plains region now face reduced irrigation amounts due to periodic drought (Basara et al., 2013), ground water pumping allocations (Bleed and Babbitt, 2015) and reservoir supplies that irrigate areas that recharge the aquifer but are affected by a changing climate (Anderson and Woosley, 2005).

The production of biofuel crops can compete for crop production area and irrigation water if there is an economic incentive to increase production. This incentive, and supporting research for biofuel crops, was realized with passage of the Energy Policy Act of 2005 (http://www.afdc.energy.gov/laws/epact_2005.html) which was extended and expanded by the Energy Independence and Security Act of 2007 (http://www.afdc.energy.gov/laws/eisa/). This legislation has been the driving force for the production of ethanol from maize (*Zea mays* L.) and in Nebraska, alone, accounts for 30% of the crop being used for biofuel, which does not include 25% of the crop that is exported for both feed and ethanol production (http://www.nebraskacorn.org/corn-production-uses/corn-usage/).

The western portion of the Central Great Plains of the US is defined as the northern High Plains region and has lower

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rainfall, sandier soils and higher elevation than the eastern portion. In recent years, alternative energy research has focused on oil-seed crops as a biomass source for biodiesel production. Oil seed crops considered as biodiesel alternatives include brown mustard (*Brassica juncea*), canola (*Brassica* 40 *napus*) (Pavlista et al., 2011b), camelina (*Camelina sativa*) (Obour et al., 2015), safflower (*Carthamustinctorius* L.), and sunflower (*Helianthus annuus*). These crops are well adapted to the northern High Plains region and, therefore, are potential biofuel crops under dryland or limited water conditions (Pavlista et al., 2011a).

Since canola can yield over 1030 l ha^{-1} of oil compared to 560 l ha^{-1} for soybean (CAST, 2008), it has become a crop of particular interest for biodiesel production in the northern Great Plains. Spring canola has traditionally been grown under rainfed conditions in the northern Great Plains, as well as in Canada, but has recently been shown to be a viable option in the central High Plains of western NE (Johnston et al., 2002; Pavlista et al., 2011b). Canola yields are affected by high temperatures during flowering (Gan et al., 2004) and this can be a greater constraint for areas south of traditional spring canola growing regions.

The effect of higher temperatures on reducing canola yield are often enhanced by reduced rainfall; however, the effect of reduced rainfall could be minimized by timely irrigation and adequate N (Kamkar et al., 2011). Because decreased ground water allocations were initiated in 2004 for the northern High plains area of western Nebraska (Bleed and Babbitt, 2015), determining water productivity response of potential biofuel crops was investigated.

Yield of canola in semi-arid climates under irrigation covers a wide range (Dogan et al., 2011; Faraji et al., 2008; Gan et al., 2004, 2009; Hamzei, 2011; Kamkar et al., 2011; Nielsen, 1997). The western NE latitude and elevation are similar to Iranian research but other environmental parameters are different. This was new research for the US when initiated in 2007 as preliminary work was just being completed on initial studies of investigating the feasibility of growing irrigated canola in the northern High Plains region (Pavlista et al., 2011b).

Deficit irrigation is defined as “the deliberate under-irrigation of the crop” by English (1990) and applies less water than is required to meet full evapotranspiration (ET). The goal is to manage irrigation timing such that the resulting water stress has less of a negative impact on grain yield. The strategy has been researched for many years. Previous NE research on limited irrigation (Garrity et al., 1982; Hergert et al., 1993; Klocke et al., 1989; Schneekloth et al., 1991) has looked at a range of crops, but not canola. Analytical tools (Water Optimizer) have been developed recently that can assist producers and water managers to assess reduced irrigation impacts on water balance and economic consequences for major crops of the Central Great Plains (Martin et al., 2010).

The objective of this research was to determine the effects of a range of water from no irrigation to full irrigation on the yield, oil content, soil water changes and water productivity of spring canola.

2. Methods and materials

The experiment was conducted in growing seasons 2007 through 2010. Spring canola (cv. Hyola 357 Magnum) was planted under linear irrigation systems at the Panhandle Research and Extension Center, Scottsbluff, NE (41.89° N, 103.68° W) and the High Plains Ag Lab, Sidney, NE (41.23° N, 103.02° W). West of Alliance, NE (42.13° N, 103.20° W) canola was planted under a small center pivot irrigation system. The soil at Scottsbluff was a Tripp very fine sandy loam (coarse-silty, mixed, superactive, mesic Aridic Haplustolls); the soil at the Alliance location was a Creighton fine sandy loam (coarse-loamy, mixed, superactive, mesic Aridic Haplustolls); the soil at the Sidney location was a Keith silt loam (fine-silty, mixed, superactive, mesic Aridic Argiustolls). Other site characteristics are given in Table 1.

Plots were 7.6 m wide by 9.1 m long, with treatments replicated three times in a randomized complete block design. Rain gauges were placed within plot areas to record irrigation and rainfall. Soil water content from 0 to 15 cm was determined gravimetrically every week, while water content at soil depths of 30, 60, 90, 120 and 150 cm was determined from weekly neutron probe measurements in each plot (503 DR Hydroprobe®, CPN International, Inc.). Neutron access tubes were installed two weeks after planting to allow evaluation of stand uniformity as canola emergence required 7–14 days depending on yearly climatic conditions. This allowed tube placement into similar stand uniformities and helped reduce spatial variability.

Throughout the study years, glyphosate tolerant canola was planted late March to early April at rates of 4–5 kg ha^{-1} of pure live seed (PLS) in 20 cm row spacing with a no-till double-disc drill. A planting depth of 12 mm was targeted. Planting and harvest dates are shown in Table 2. Fertilizer was based on expected yield, soil organic matter and nitrate-N tests using fertilizer guidelines from Boyles et al. (2006). The herbicide trifluralin (Treflan® HFP) at 1.2 l ha^{-1} was soil incorporated for preemergence weed control. Canola seed was treated with thiamethoxam (Helix®-Xtra) for protection against flea beetle (*Phyllotreta* spp.). Canola plots were sprayed once with 1.1 l ha^{-1} glyphosate (Roundup) before the 6-leaf stage. Plots were hand weeded as necessary and routinely scouted during the summer for insect damage; however, no significant insect problems were observed. Azoxystrobin (Quadris®) was used as a fungicide for downy mildew (*Peronosporaceae*) control during periods of cool/wet weather during 2009 and 2010.

When producers have less water than is required to meet full crop ET, they must use a different application and timing strategy than traditional full irrigation scheduling. Each turn of the pivot increases cost so if a producer can only apply 100 mm and they are not limited by well capacity, they will apply 5 irrigations of 20 mm rather than applying 10 irrigations of 10 mm. Irrigation application rates of 12.7 or 19.1 mm were used in this research to simulate producer practices. The highest rate of 19 mm was applied over 2 h and did not exceed the infiltration capacity of the soils. With higher irrigation levels (e.g., 40 mm) biweekly irrigations were applied. Previous research has shown that for most grain crops, applying limited water around flowering through early grain fill provides the greatest response to water (Anapalli et al., 2014; Hergert et al., 1993; Garrity et al., 1982; Klocke et al., 1989). For the 100 mm treatment, irrigations were timed around flowering and early grain fill. The 200 mm treatment usually allowed irrigation from vegetative through mid-grain fill.

Cumulative irrigation treatments had targeted amounts of 0, 100, 200, and 300 mm of water. The highest rate was set to be non-ET limiting and actual ET was used to calculate water use based on weather data from the High Plains Climate center (Changnon et al., 1990). Growing season water application for the highest irrigation level exceeded 300 mm in several instances due to high water demand. All treatments received light irrigations (5 mm) to enhance and ensure uniform seed germination and plant emergence.

Growing season rainfall at the three sites (Table 3) was dramatically different over the four years (NOAA, 2015). This provided an excellent range of conditions from drought to above average precipitation to determine plant growth and rooting depth from soil moisture extraction. Precipitation at Alliance and Scottsbluff during 2007 and 2008 was well below the long term average. At Sidney, 2007 precipitation was near average and 2008 was below average. Precipitation was well above average at all locations in 2009 and near average in 2010.