Agricultural Water Management 177 (2016) 46–53

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Irrigation response and water productivity of deficit to fully irrigated spring camelina

G.W. Hergert[a,*], J.F. Margheim[a], A.D. Pavlista[a], D.L. Martin[b], T.A. Isbell[c], R.J. Supalla[b]

[a] University of Nebraska-Lincoln, PREC, Scottsbluff, NE 69361, USA
[b] University of Nebraska-Lincoln, Lincoln, NE, 68583, USA
[c] USDA-ARS, Peoria, IL 61604, USA

ARTICLE INFO

Article history:
Received 10 February 2016
Received in revised form 3 June 2016
Accepted 11 June 2016
Available online 4 July 2016

Keywords:
Biodiesel
Limited irrigation
High plains aquifer
Ground
Water decline

ABSTRACT

Camelina [Camelina sativa L. Crantz] is an oil seed crop that could be adapted to the northern High Plains of the USA as a biofuel crop. Decreased ground water allocations in Nebraska necessitated determining the impact of limited irrigation on camelina. The objective of this research was to determine the effects of a range of irrigation levels on camelina yield, oil content, soil water changes and water productivity. The study was conducted for four growing seasons at two locations in western Nebraska. One site had a sandy soil whereas the other was a silt loam. Camelina was planted in early to mid-April. Cumulative irrigation treatments were 0, 100, 200, and 300 mm with the highest rate adjusted to be non-ET limiting. Camelina extracted soil water from 0.9 to 1 m depths which was shallower than canola. It showed significant response to irrigation during dry years but no response in above-average precipitation years. A water use efficiency of 7.0 kg mm-1 with 125 mm ETc required to produce the first unit of seed yield was shown. Camelina seed yield ranged from 428 to 2867 kg ha-1 with 187 and 536 mm of cumulative ET. In 2007 and 2008 camelina exhibited peak values in water consumed at 9–10 weeks after planting. Deficit irrigation reduced ET and yield plus accelerated maturity in those years. Oil content was increased by irrigation during drier years with no effect with high growing season precipitation. Oil content ranged from 25 to 50% depending on year, irrigation level and disease. Downey mildew significantly reduced oil content during 2009. Deficit irrigated camelina could be an alternative biofuel crop for this region but further genetic improvement would enhance its competiveness with spring canola.

1. Introduction

Production of biofuel crops created major interest with the 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/). The bulk of energy research has focused on oil-seed crops as a biomass source for biodiesel production. Camelina [*Camelina sativa* L. Crantz] is an ancient crop that has been produced for many years in different parts of the world (Knorzer, 1978; Putnam et al., 1993). Recent interest in its potential as a biofuel (Bernardo et al., 2003; Frohlich and Rice, 2005; Moser and Vaughn, 2010; Zaleckas et al., 2012) and even as a jet fuel source (Shonnard et al., 2010) have been reviewed. Life cycle analysis of camelina as a biodiesel source shows its greenhouse gas emissions are 75–80% less than common petroleum fuels (Shonnard et al., 2010). Its high unsaturation levels of fatty acids result in poor oxidative stability which could limit camelina as a stand-alone biodiesel (Frohlich and Rice, 2005; Moser and Vaughn, 2010; Zaleckas et al., 2012). Blended camelina esters may be similar to soybean esters (Moser, 2010) and may be comparable to soybean biodiesel (Soriano and Narani, 2012). Part of the attraction of using camelina as a biofuel source is that it is considered a non-food crop, although camelina meal can be used as an animal feed (Pilgeram et al., 2007).

Camelina could be adapted for production in wheat-fallow rotations in the Great Plains of the USA (Aiken et al., 2015; Allen et al., 1998; Obour et al., 2015; Pavlista et al., 2011a; Schillinger et al., 2012). Research on camelina irrigation requirements are limited, with much of the research from Arizona using surface irrigation to achieve different levels of soil water depletion (French et al., 2009; Hunsaker et al., 2013). Pavlista et al. (2012) compared growth patterns of camelina to canola (*Brassica napus*) and brown mustard (*Brassica juncea*) under low irrigation. One of the limitations with

* Corresponding author.
E-mail address: ghergert1@unl.edu (G.W. Hergert).

http://dx.doi.org/10.1016/j.agwat.2016.06.009
0378-3774/

Table 1
Site characteristics for the two camelina locations for the top 20 cm.

Location	Elevation	Annual Precipitation	pH	Organic Matter	θv Field Capacity*	θ Wilting Point*
Scottsbluff	1189 m	394 mm	8.2	1.5%	0.23–0.28 m^3 m^{-3}	0.11 m^3 m^{-3}
Sidney	1247 m	404 mm	7.5	2.2%	0.25–0.31 m^3 m^{-3}	0.13 m^3 m^{-3}

*National Cooperative Soil Survey. National Cooperative Soil Survey Characterization Database. http://ncsslabdatamart.sc.egov.usda.gov/. Accessed Thursday, June 02, 2016.

shallow seeded *camelina* is germination under unpredictable spring precipitation in the Great Plains. If necessary, light irrigations at seeding facilitated improved germination and stand and make it a good candidate for limited irrigation (Aiken et al., 2015; Pavlista et al., 2016a).

Temperature effects during camelina flowering have not been researched extensively and this could be a constraint for spring c*amelina* as much of the initial research was in Montana (Pilgeram et al., 2007). Heat and moisture effects on oil seed crops, however, have been known for many years (Canvin, 1965). The effect of higher temperatures on reducing seed yield are often accentuated by reduced rainfall; however, the effect of reduced rainfall might be minimized by timely irrigation similar to canola (Kamkar et al., 2011).

Decreased ground water allocations (volumetric pumping restrictions) were initiated in 2004 for the northern High plains of western Nebraska (Bleed and Babbitt, 2015) and the need to determine water productivity response of potential biofuel crops was needed. Many areas of the High Plains have reduced irrigation amounts due to periodic drought (Basara et al., 2013), ground water pumping allocations (Bleed and Babbitt, 2015) and reservoir supplies used for irrigation and aquifer recharge that are affected by a changing climate (Anderson and Woosley, 2005).

The concept of deficit irrigation has been known for many years (English, 1990) and has been researched as a production strategy on many conventional crops in Nebraska (Garrity et al., 1982; Hergert et al., 1993; Klocke et al., Payero et al., 2006; 1989; Schneekloth et al., 1991) and more recently on canola (Hergert et al., 2016; Pavlista et al., 2016b), but not camelina. The goal of deficit irrigation is to manage irrigation timing so the resulting water stress has less of a negative impact on grain yield.

The objectives of this research were to determine the effects of deficit to full irrigation on the yield, oil content, soil water changes and water productivity of spring camelina.

2. Methods and materials

This experiment was conducted during the growing seasons of 2007 through 2010. Spring camelina (cv. Cheyenne) 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). The soil at the Scottsbluff site was a Tripp very fine sandy loam (coarse-silty, mixed, superactive, mesic Aridic Haplustolls) whereas the soil at the Sidney location was a Keith silt loam (fine-silty, mixed, superactive, mesic Aridic Argiustolls). The slope at both sites ranged from 0.5% to 1%. Other site characteristics are given in Table 1. Soil characteristics are for the top 30 cm. Previous crops before camelina at Scottsbluff were dry beans (*Phaseolus vulgaris*) in 2006, 2007 and 2008 and potatoes (*Solanum tuberosum* L.) in 2009. Previous crops before camelina at the High Plains Ag Lab were proso millet (*Panicum miliaceum* L.) in 2006, 2007 and 2008 and winter wheat (*Triticum aestivum* L.) in 2009.

The plots were 7.6 m wide by 9.1 m long, with treatments replicated three times in a randomized complete block design. The irrigation system used was a Lockwood electric linear move with 5 spans 53 m in length with a Lindsay™ variable speed control panel. The system was plumbed with drops at 1.5 m spacing and nozzles located 1.4–1.5 m above ground level, each equipped with a manual turn off. The height of adjacent drops was varied (e.g., one at 1.4 m then the next at 1.5 m, etc.) to reduce overlap interference with the spray pattern. The nozzles used on each drop were 3000 series 3 T #22 (Nelson Irrigation Corporation) that had maximum output of 10 l min^{-1}. The irrigation system was operated at 207 KPa. This arrangement provided a spray pattern diameter of 5.5–6 m which provided low instantaneous application rates that allowed maximum time for infiltration and no runoff. The combination of variable speed and the ability to turn off every other nozzle allowed water applications from 2.5 to 38 mm h^{-1}, however, regardless of water application amount, the system applied 10 mm h^{-1} which was below the soil's infiltration capacity.

Table 2
Camelina planting and harvest dates.

Site	Years	2007	2008	2009	2010
Scottsbluff	Sowing	15 Apr	8 Apr	10 Apr	9 Apr
	Harvest	24 Jul	24 Jul	20 Jul	8 Jul
Sidney	Sowing	18 Apr	16 Apr	8 Apr	12 Apr
	Harvest	18 Jul	25 Jul	13 Jul	14 Jul

Rain gauges were placed within plot areas to record irrigation and rainfall. Soil water content in 0–15 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 camelina emergence required 7–14 d depending on yearly weather conditions. This allowed tube placement into similar stand uniformities and helped reduce spatial variability.

Planting and harvest dates are shown in Table 2. Sowing was early to mid-April at rates of 3–3.5 kg ha^{-1} of pure live seed (PLS) in 20-cm row spacing with a double-disc drill. A planting depth of 10 mm was targeted. Fertilization was based on expected yield, soil organic matter and nitrate-N tests using canola fertilizer guidelines (Boyles et al., 2006) but N rates were reduced 30% based on the literature (Putnam et al., 1993; Zubr, 1997). The residual nitrate level in most of the plots was high enough in most years that a preplant blanket application of 200 kg ha^{-1} of ammonium sulfate (21-0-0 24S) provided sufficient N and S. P and K levels were also high (above critical level) and no fertilizer was required.

The herbicide trifluralin (Treflan® HFP) at 1.2 l ha^{-1} was soil incorporated preemergence for weed control. Plots were hand weeded as necessary and routinely scouted during the summer for insect damage; however, no significant insect problems were observed. Azoxystrobin (Quadris®) at 0.73 l ha^{-1} was used as a fungicide for downy mildew (*Peronosporaceae)* control during periods of cool/wet weather during 2009 and 2010. Disease was more severe at Sidney than Scottsbluff.

In many areas of the High Plains where ground water levels have declined or where pumping restrictions are enforced, producers who do not have enough water to meet full crop ET must use a different application and timing strategy than traditional full irrigation scheduling. Every rotation of a center pivot sprinkler increases cost, so if a producer can only apply 100 mm and they are not lim-