Growth, Seed Yield, and Oil Production of Spring *Camelina sativa* in Response to Irrigation Rate, Seeding Date, and Nitrogen Rate, in the Klamath Basin, 2009

Richard J. Roseberg and Rachel A. Shuck[1]

Introduction

The recent increase in energy prices and political instability in the Middle East has sparked renewed interest in alternative energy sources and technologies both locally and nationally. Biodiesel is an appealing transportation fuel source for many reasons: it readily substitutes for petroleum diesel, it tends to burn cleaner with fewer pollutants, it can be made from many plant-based oil sources, and it can be produced on a large or small scale. Biodiesel can be made from many oilseed crops. However, the most prolific oil producers per acre tend to be tropical or subtropical crops such as palm oil, castor, and

[1] Associate Professor and Faculty Research Assistant, respectively, Klamath Basin Research & Extension Center, Klamath Falls, OR.

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soybean. Some temperate oilseed crops, such as sunflower, meadowfoam, and flax, have higher value end-uses than biodiesel. Therefore, much of the research on oilseeds for biodiesel in temperate regions has focused on rapeseed/canola, and more recently, another oilseed crop called camelina (*Camelina sativa)*. Please see the separate reports of past canola research we have conducted (2006-08).

Camelina is an ancient crop (grown as far back as 1000 BC) that was later used extensively as a source of edible oil as well as for oil lanterns for lighting in eastern Europe in the middle ages (Putnam et al., 1993). Its use decreased with the advent of improved trade for olive oil from southern Europe and, much later, the development of petroleum-based oils and then electric lighting in the 20th century. Camelina is of interest for dietary reasons due to its unusually high levels of Omega-3 fatty acids. It is of interest for biodiesel production because it seems to grow well in conditions of relatively poor soil, low fertility, and low moisture availability. Its seed contains 30-40% oil by weight, but seed yields are generally less than canola under ideal growing conditions, but may be similar under more stressful conditions. Both canola and camelina have been reported to exhibit some herbicidal properties in the following crop, which could potentially reduce weed control costs in crops seeded after these oilseed crops. Because camelina's fatty acid profile differs somewhat from canola's, it can be more easily converted into aviation fuel, another potential end-product.

Prior to about 2005, camelina was not a commercial crop in the US, but by 2007 about 15,000 acres of camelina was grown in the US, mostly in Montana, spurred by active private company contracting activity there. Acreage there has gradually increased, and interest has increased in other parts of the PNW and other regions of the country very recently, partially due to production incentives and research funding from Dept. of Defense and other sources due to camelina's potential use as a raw material to produce aviation fuel.

Research Justification and Objectives

We found minimal camelina research or commercialization efforts in Oregon prior to 2006. Fall-seeded camelina was tested at the Columbia Basin Ag. Research Center near Pendleton in the early 1960s, with mixed results (Don Wysocki 2008, pers. comm.). Two unrelated small trials were seeded at the Southern Oregon Research & Extension Center near Medford and at the Hyslop Farm near Corvallis in the mid-1990s. Those two trials did not produce much useful data due to poor crop emergence, growth and yield (Richard Roseberg 2006, pers. comm., Daryl Ehrensing 2008, pers. comm.). Nationally, most of the interest in camelina has been very recent, and commercial efforts have been centered in the western region, especially Montana, under conditions of limited moisture and soil fertility. This suggests that it may do well in parts of Oregon that are less than ideal for intensive cropping. The south-central region of Oregon has irrigation water available in certain areas, and reasonably good soils over larger areas. In the Klamath Basin, camelina may have a possible rotation fit with existing crops such as potatoes, grass and alfalfa hay, small grains, and pastures, especially in fields with less than optimal irrigation and fertility. Recent studies conducted at the Klamath Basin

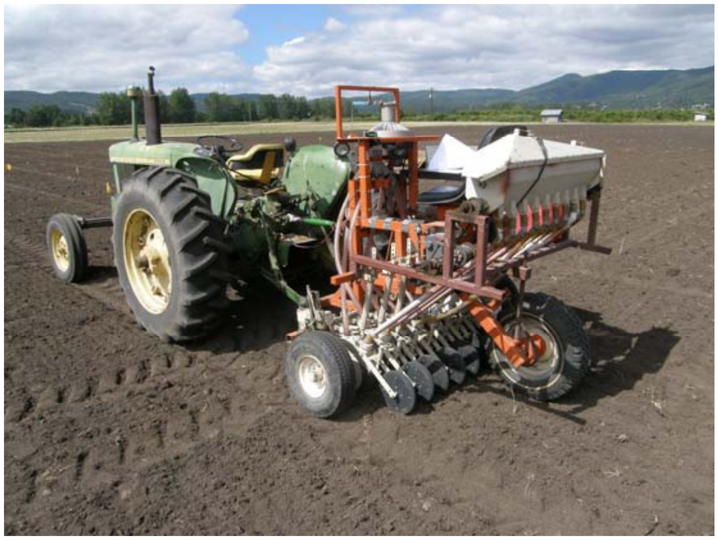
Research and Extension Center (KBREC) in 2007 and 2008 suggested that spring-seeded camelina would grow well here, but that it clearly benefited from some irrigation (Roseberg et al., 2007; Roseberg and Shuck, 2008).

In 2009, we conducted two separate camelina studies at the Klamath Basin Research & Extension Center (KBREC). The objective of the first study was to measure the growth and seed yield of camelina as influenced by seeding date and irrigation rate. This study included camelina seeded on three different dates and grown under three irrigation rates. The objective of the second study was to measure the growth and seed yield of camelina in response to varying nitrogen rates. For this study, four different rates of nitrogen were applied to camelina that was seeded on one date, and grown under a single irrigation rate.

Procedures

Seeding Date x Irrigation Rate Trial

This study was laid out as a split plot design with irrigation rate as the main plot and seeding date as the subplot, and eight replications of each treatment combination. The soil was a Poe fine sandy loam and the previous crop in 2008 was teff. 'Calena' camelina was seeded on three different dates (April 16, May 8, and May 29) within each of the three irrigation treatments ('wet', 'medium', and 'dry') with eight replications. The plots were 20.0 by 4.5 ft, (9 rows at 6-inch spacing); with a slightly smaller harvested area after plot ends were trimmed near harvest time. Camelina was seeded one quarter inch deep at the rate of 8.0 lb/ac of raw seed with a Kincaid (Kincaid Equipment Mfg.) plot drill. This trial was not fertilized or treated with herbicides at seeding or during the growing season.



Kincaid Research Plot Drill

Solid-set sprinklers arranged in a 40- by 40-ft pattern were used for irrigation. The entire area was irrigated uniformly until plants were fully emerged. Irrigation rates were based on evapotranspiration (Et) estimates calculated from the US Dept. of Reclamation Agricultural Meteorological (AgriMet) weather station at KBREC (US Bureau of Reclamation, 2009). The goal was to apply (including natural rainfall) about half of calculated Et to the ‘wet’ irrigation treatment, about 1/3 of Et to the ‘medium’ irrigation treatment, and about ¼ of calculated Et to the ‘dry’ irrigation treatment. In actual practice the ‘wet’, ‘medium’, and ‘dry’ irrigation treatments received about 47%, 35%, and 28%, respectively, of calculated Et. Including the contribution of natural rainfall, the ‘medium’ treatments received about 75% of the total moisture received by the ‘wet’ treatment while the ‘dry’ treatment received about 59% of the total moisture received by the ‘wet’ treatment (Table 1).

The first seeding date was harvested on July 23 and July 28, the second seeding date was harvested on August 5, and the third seeding date was harvested on August 5 and August 19. Harvest dates for a given seeding date sometimes varied due to unequal maturation under the differing irrigation regimes. Plots were harvested using a Hege (Hans-Ulrich Hege) plot combine with a 4.5-ft-wide header. Data measured at KBREC included grain yield, test weight, plant height, and flowering date. Cleaned seed samples were sent to the Brassica Breeding & Research Lab (Dr. Jack Brown) at the University of Idaho to measure seed oil content, which also allowed calculation of oil yield.

Nitrogen Rate Response Trial

This study was laid out in a randomized complete block design with six replications. ‘Calena’ camelina was seeded at KBREC in a Poe fine sandy loam soil following teff grown in 2008. This trial was seeded in the ‘medium’ irrigation treatment only. The plots were 20.0 by 4.5 ft, (9 rows at 6-inch spacing), with a harvested area of

18.0 by 4.5 ft. Seed was drilled one quarter inch deep at the rate of 8.0 lb/ac of raw seed with a Kincaid (Kincaid Equipment Mfg) plot drill on May 8.

The nitrogen fertilizer treatments were applied on June 16, and consisted of 0, 40, 80, and 120 lbs N/ac as granular ammonium sulfate applied to the surface and watered into the soil with 0.50 inch of irrigation within 24 hours. No herbicides were applied during the season. The trial was harvested on August 5.

Solid-set sprinklers arranged in a 40- by 40-ft pattern were used for irrigation. Irrigation rates were based on evapotranspiration (Et) estimates calculated from the US Dept. of Reclamation Agricultural Meteorological (AgriMet) weather station at KBREC (US Bureau of Reclamation, 2009). The goal was to apply about 1/3 of Et to this study (including natural rainfall). In actual practice the study area received precipitation plus irrigation of about 35% of calculated Et (Table 1).

The trial was harvested on August 5 using a Hege (Hans-Ulrich Hege) plot combine with a 4.5-ft-wide header. Data measured at KBREC included grain yield, test weight, height, and flowering date. Cleaned seed samples were sent to the Brassica Breeding and Research Lab (Dr. Jack Brown) at the University of Idaho to measure seed oil content, which also allowed calculation of oil yield.

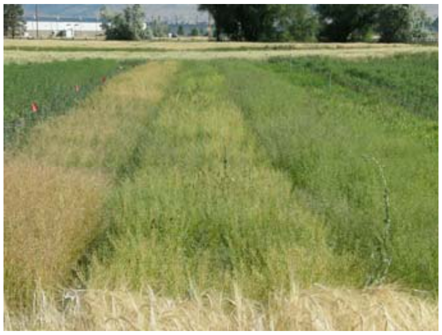
Statistical Analysis

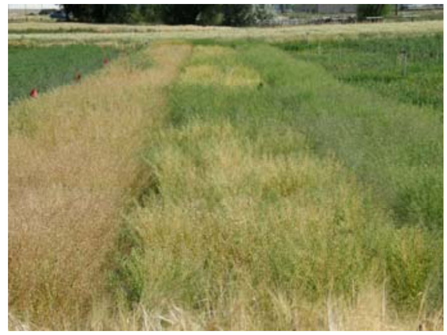
All measured parameters were analyzed statistically using SAS® for Windows, Release 9.1 (SAS Institute, Inc.) software. For the seeding date by irrigation rate trial, data was analyzed as a split plot design, with irrigation rate as the main plot and seeding date as the sub-plot, with eight replications. Treatment significance was based on the F test at the P=0.05 level. If this analysis indicated significant treatment effects, least significant difference (LSD) values were calculated based on the student's *t* test at the 5% t level.

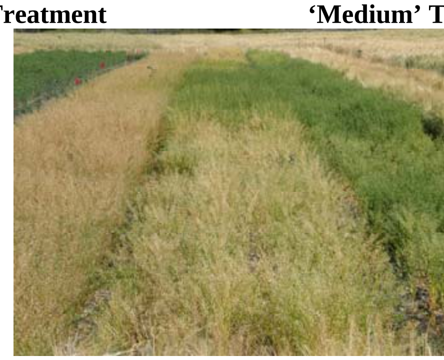
The nitrogen rate response trial was arranged in a randomized complete block design with six replications, the student's *t* test at the 0.05 level was used to calculate significance of nitrogen treatment on the measured parameters. If significant treatment effects were indicated, least significant difference (LSD) values were calculated at the 0.05 level.

Results and Discussion

Seeding Date x Irrigation Rate Trial


'Wet' Treatment


'Medium' Treatment


'Dry' Treatment

Soil moisture was good during seedbed preparation, and resulting germination and stand density were good. Good availability of irrigation water and relatively few hot days during the season (twelve days with maximum temperatures above 90^{o}F, with none over 100^{o}F, with most hot days occurring shortly before harvest), suggest that heat and moisture stress was minimal where sufficient irrigation was applied. Weed pressure was not heavy and did not seem to impact crop growth.

Irrigation treatment differences were not significant for all measured parameters (seed yield, test weight, oil percentage, and oil yield values), although the P value for seed yield was only slightly greater than 0.05. Conversely, seeding date treatment differences were significant for all measured parameters (Table 2).

Seed yield ranged from 310 to 761 lb/ac, with a mean of 548 lb/ac. Seed yield in the 'wet' irrigation treatment always tended to be less than in the 'medium' or 'dry' treatments for all seeding dates, suggesting that the highest irrigation rate was not beneficial to camelina. Seed yield for the April 16 seeding date was significantly higher than for the May 8 seeding date under the 'medium' and 'dry' irrigation rates, and was also higher than the May 29 seeding date under 'dry' irrigation rate. However, seed yields were not significantly different among seeding dates under the 'wet' irrigation rate, suggesting that early seeding favors camelina when moisture is more limiting.

Test weights ranged from 44.2 to 50.8 lb/bu, with a mean of 48.9 lb/bu. For all three irrigation rates, the middle seeding date resulted in significantly lower test weights than either the earlier or later seeding date. Reasons for this pattern are not obvious. The April 16 seeding date had a higher test weight only under the low irrigation rate, suggesting that earlier seeding improves seed quality when moisture is more limiting (similar to seed yield).

Oil content ranged from 31.2 to 35.0%, with a mean of 32.7%, and varied little due to irrigation. The April 16 seeding date had a higher oil content than the other two dates for all irrigation treatments, suggesting that a longer growing period resulted in fuller, higher quality seeds whether moisture was limiting or not.

Oil yield had a very large range from 100 to 268 lb/ac, with a mean of 182 lb/ac. Because both seed yield and oil content were highest for the April 16 seeding date for both the 'medium' and 'dry' irrigation rates, it is not surprising that oil yield followed the same pattern. Despite the differences observed for oil content in some cases, the overall pattern in oil yield essentially followed the pattern in seed yield, showing the benefits of earlier seeding where moisture was more limiting, and the non-benefit of the 'wet' irrigation rate.

Measurements of height and flowering date were not truly replicated, thus those data represent visually-averaged observations only. Heights ranged from 20.1 to 30.8 inches, with a mean of 26.1 inches. Although significant differences could not be calculated statistically due to non-replication of measurements, it appeared that later seeding dates resulted in shorter plants, especially where moisture was more limiting.

Date of 50% flowering ranged from 174 to 194 Julian days, with a mean of 184 Julian days. Although significant differences could not be calculated statistically, it appeared (not surprisingly) that later seeding dates resulted in later flowering dates, but the dates of 50% flowering were much closer together than the seeding dates were. Irrigation rate seemed to have minimal effect on flowering date.

In summary, spring-seeded camelina will produce a harvestable crop with limited irrigation under Klamath Basin mineral soil conditions. However, despite publicized claims about camelina's ability to grow and produce good seed yields under difficult growing conditions, in our studies it produced a greater seed yield and oil yield when a moderate level of irrigation was applied for the latter two seeding dates. Although to our knowledge camelina had not been evaluated in the Klamath Basin prior to 2007, this pattern of yield response to moderate irrigation held true in all three years where irrigation response was tested (2007, 2008, and 2009). However, seed yield, oil content, and test weight were greatly enhanced when seeding was early (April 16) if moisture from irrigation was more limited. Thus, it seems an early seeding date is best, but that later seeding dates can produce a good crop if some irrigation water is available.

Nitrogen Rate Response Trial

There was no significant difference between nitrogen rate treatments for any of the measured parameters (Table 3). However, some trends were observed. Average yields for each nitrogen rate treatment ranged from 351 to 571 lb/ac, with a mean of 454 lb/ac. Yield tended to increase as amount of nitrogen applied increased. Average treatment test weights ranged from 43.4 to 48.6 lb/bu, with a mean of 47.0 lb/bu.

Average heights ranged from 23.9 to 25.3 inches, with a mean of 24.4inches. Height tended to increase as amount of nitrogen applied increased. Average Julian date of 50% heading was the same for all entries, 184 days. Treatment oil percent varied only slightly, ranging from 30.8 to 31.5%, with a mean of 31.3%. Oil yield for each nitrogen treatment ranged from 109 to 180 lb/ac, with a mean of 143 lb/ac. The higher rates of nitrogen tended to have the highest oil yield, similar to the pattern seen for seed yield.

In summary, even though there was no significant difference between nitrogen rate treatments for any of the measured parameters, there were some observed trends that suggested that some nitrogen fertilizer may be beneficial to camelina production, but exact responses cannot be predicted from the results of this study. It would be interesting to see how different nitrogen rate treatments would respond to different irrigation rates and seeding dates.

Future Prospects

Although weed competition was not a big factor in 2009, the ability of camelina to compete with weeds is a question that needs to be answered, as well as the related need to develop acceptable herbicide practices. Although this study suggests that camelina may respond to added nitrogen fertilizer when grown under a moderate level of irrigation, these results would need to be confirmed before particular amounts of fertilizer N are routinely recommended. If required inputs for camelina are in fact lower compared to other crops, camelina may find a profitable place in Klamath Basin crop rotations, especially on non-prime farmlands. If it can be demonstrated that it also provides rotation benefits to subsequent crops, it could also be more viable on higher value, more intensively managed crop land.

A commercial biodiesel production facility is currently in operation near Klamath Falls, and a Willamette Valley-based company has been scouting for grower contracts in this area, but high grain prices have led growers to seed wheat and barley instead of the more speculative canola and camelina. Based on our research information, a commercial 25-acre field of camelina was grown in the Rogue Valley in 2008 without irrigation, resulting in a fairly good stand and apparent harvestable seed yield. It has been reported that a couple of small test fields were grown in the Rogue Valley and Klamath Basin in 2009, with mixed, but somewhat encouraging results. Further demonstration fields and research studies would help identify camelina's potential and limiting factors in this region.

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Table 1. 2009 Precipitation & irrigation for camelina seeding date x irrigation rate comparison. Klamath Basin Research & Extension Center, Klamath Falls, OR.

		"Wet" Block		"Medium" Block		"Dry" Block	
Month	Precipitation (inch)	Irrigation (inch)	Irrigation Applications	Irrigation (inch)	Irrigation Applications	Irrigation (inch)	Irrigation Applications
April	0.70	0.56	1	0.56	1	0.56	1
May	1.74	3.22	3	2.10	2	2.10	2
June	1.84	0.49	1	0.49	1	0.00	0
July	0.17	3.43	3	1.47	1	0.00	0
August	0.20	0.00	0	0.00	0	0.00	0
Total	**4.65**	**7.70**	**8**	**4.62**	**5**	**2.66**	**3**

Table 2. 2009 Camelina seeding date x irrigation rate comparison, seeded in mineral soil. Klamath Basin Research & Extension Center, Klamath Falls, OR.

Irrigation Rate	Seeding Date	Seed Yield (lb/ac)	Rank	Test Weight (bu/ac)	Rank	Height (inch)	Rank	50% Flowering Date (day of year)	Rank	Oil %	Rank	Oil Yield (lb/ac)	Rank
Wet	April 16	491	7	48.6	5	28.4	3	174	8	34.3	2	170	6
	May 8	517	6	46.3	8	23.6	7	182	6	32.0	5	170	6
	May 29	535	5	49.0	4	24.3	6	193	3	32.5	4	175	5
Medium	April 16	761	1	50.3	2	30.4	2	175	7	35.0	1	268	1
	May 8	568	4	47.9	6	27.5	5	183	5	31.2	9	180	4
	May 29	699	3	50.0	3	22.1	8	194	1	32.0	5	224	3
Dry	April 16	706	2	50.8	1	30.8	1	174	8	34.1	3	242	2
	May 8	348	8	44.2	9	27.7	4	188	4	31.4	8	109	8
	May 29	310	9	47.0	7	20.1	9	194	1	31.9	7	100	9
Mean		548		48.9		26.1		184		32.7		182	
***P* (Irrigation Rate)**		**0.071**		**0.279**		NA		NA		**0.642**		**0.094**	
LSD (0.05)- Irrigation Rate		194		NSD		NA		NA		NSD		NSD	
CV Irrigation (%)		57.1		6.8		NA		NA		5.6		60.7	
***P* (Seeding Date)**		**<0.001**		**<0.001**		NA		NA		**<0.001**		**<0.001**	
LSD (0.05)- Seeding Date		79		1.6		NA		NA		0.8		29	
CV Seeding Date (%)		24.8		3.8		NA		NA		4.3		27.2	
***P* (Irrig. Rate X Seeding Date Interaction)**		**<0.001**		**0.324**		NA		NA		**0.623**		**<0.001**	

NA- Measurements of height and flowering date were not truly replicated, thus those data represent visually-averaged observations only.

Table 3. 2009 Camelina nitrogen fertilizer rate comparison, seeded in mineral soil.
Klamath Basin Research & Extension Center, Klamath Falls, OR.

Nitrogen Rate	Seed Yield (lb/ac)	Rank	Test Weight (lb/bu)	Rank	Height (inch)	Rank	50% Flowering Date (day of year)	Rank	Oil %	Rank	Oil Yield (lb/ac)	Rank
High	571	1	47.3	2	25.3	1	184	3	31.4	3	180	1
Medium	516	2	46.4	3	24.2	2	184	4	31.5	1	163	2
Low	378	3	43.4	4	24.0	3	184	1	30.8	4	109	4
None	351	4	48.6	1	23.9	4	184	1	31.5	1	120	3
Mean	454		47.0		24.4		184		31.3		143	
***P* value**	**0.138**		**0.641**		**0.775**		**0.933**		**0.566**		**0.150**	
LSD(0.05)	NSD		NSD		NSD		NSD		NSD		NSD	
CV (%)	39.3		9.2		10.9		0.8		3.2		40.6	