Growth, Seed Yield, and Oil Production of *Camelina sativa* Grown Under Two Irrigation Rates from a Spring Seeding, and of Multiple Cultivars Seeded on Multiple Dates in the Fall, in the Klamath Basin, 2007-08

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

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

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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 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 canola research we conducted in 2008.

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 grown as 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 no evidence of commercialization efforts in Oregon prior to 2006. There were only a few small-scale tests of camelina at Oregon State University (OSU) prior to this time. Fall-seeded camelina was tested on a small scale at the OSU-Columbia Basin Ag. Research Center (CBARC) near Pendleton in the early 1960s, with mixed results (Don Wysocki 2008, pers. comm.). Two unrelated small trials were seeded at the OSU-Southern Oregon Research & Extension Center near Medford and at the OSU 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.

In the 2007-08 crop season, we conducted two separate camelina studies. First, we essentially repeated the 2007 study that evaluated spring-seeded camelina grown under two irrigation rates. The objective of this study was to measure the growth and seed yield of camelina as influenced by irrigation rate. This study was seeded in the same field and grown using similar management as a concurrent canola study, allowing us to observe how canola and camelina grew side-by-side under similar management. Second, we seeded a number of camelina cultivars on several dates during the fall of 2007 to measure the ability of various cultivars to germinate under various weather conditions in the fall, survive over winter, and produce a seed yield the following summer.

Procedures

Spring Seeded Irrigation Response Study

Blocks of 'Calena' camelina were seeded at KBREC in a Poe fine sandy loam soil following spring wheat grown in 2007. The camelina blocks were seeded next to the canola experiment blocks so that we could apply two rates of irrigation to separate areas during the season. Trifluralin (Treflan®) herbicide was applied May 8 at 2.0 pint/ac (1.0 lb a.i./ac) incorporated before seeding with a roto-tiller. No additional herbicides were applied during the season.

The plots were 20.0 by 4.5 ft, (9 rows at 6-inch spacing), with a harvested area of 13.0 by 4.5 ft. Seed was seeded one quarter inch deep at the rate of 8.0 lb/ac of raw seed with a tractor-mounted Kincaid (Kincaid Equipment Mfg.) plot drill on May 12 ('wet' irrigation block), and May 13 ('dry' irrigation block). Camelina was not fertilized at seeding, but 70 lb N/ac was applied as Solution 32 on July 2 through the irrigation water.

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. Due to proximity and required field layout, the camelina blocks received the same amount of irrigation as the adjacent canola plots. Thus, irrigation rate for the 'wet' irrigation block was based on crop water use estimates for canola calculated from the US Dept. of Reclamation Agricultural Meteorological (AgriMet) weather station at KBREC (US Bureau of Reclamation, 2008). The 'dry' irrigation block received about 70% the amount of irrigation applied to the 'wet' block after the initial germination period (Table 1). All plots were harvested on Aug. 27 using a Hege (Hans-Ulrich Hege) plot combine with a 4.5-ft-wide header. Data measured at KBREC included grain yield, test weight, and lodging percent. 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.

Fall Seeded Seeding Date x Cultivar Study

Fourteen cultivars of camelina were tested in this study. These were obtained from Dr. Don Wysocki of OSU-CBARC via Duane Johnson of the Great Plains Oil & Exploration Company. Cultivars included 12 numbered cultivars originating from Colorado State University (indicated as CS##, with ## indicating individual cultivars numbered 1-14), one cultivar originating at Montana State University (named MT102), and a true winter camelina type, indicated as 'Winter', of unknown origin. The CS and MT cultivars were technically not true winter types, but were nonetheless thought to possess excellent winter hardiness. This study was seeded at KBREC in a Poe fine sandy loam soil following summer fallow ('water bank') in 2007. Winter wheat was grown in this field in 2005-06. No herbicides were applied during the season. The area was not fertilized in 2007, but received 54 lb N/ac as ammonium sulfate on June 4, 2008.

The plots were 20.0 by 4.5 ft, (9 rows at 6-inch spacing), with a harvested area of 13.0 by 4.5 ft. Seed 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. The fourteen entries were seeded on four dates in the fall of 2007 (Aug. 28, Sept. 11, Sept. 25, and Oct. 9). Each entry was replicated twice and the study was laid out as a split plot design, with seeding date as the main plot and cultivar as the sub-plot.

Solid-set sprinklers arranged in a 40- by 40-ft pattern were used for irrigation. The area received a single irrigation after the Aug. 28 and Sept. 11 seeding dates, with no additional irrigation until the following May (Table 2). The entire study area received the same rate of irrigation in spring 2008 as the concurrent winter canola variety trial grown nearby. All plots were harvested on Aug. 1 using a Hege (Hans-Ulrich Hege) plot combine with a 4.5-ft-wide header.

Weather and soil temperature data was collected at the nearby AgriMet weather station at KBREC. Crop data measured at KBREC included grain yield, test weight, plant height, weediness, and lodging percent. 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.

Statistical Analysis

All measured parameters were analyzed statistically using SAS® for Windows, Release 9.1 (SAS Institute, Inc.) software. For the spring-seeded irrigation study, the student's *t* test at the 0.05 level was used to calculate whether differences observed for the measured parameters between irrigation treatment blocks were significant or not. If significant treatment effects were indicated, least significant difference (LSD) values were calculated at the 0.05 level. For the fall-seeded cultivar by seeding date study, data was analyzed as a split plot design, with seeding date as the main plot and cultivar as the sub-plot. 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% level.

Results and Discussion

Spring Seeded Irrigation Response Study

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 (only eight days with maximum temperatures above 90^{o}F, with none over 100^{o}F), suggest that heat and moisture stress was minimal where sufficient irrigation was applied. Lodging was not observed for either irrigation treatment. Weed pressure was light and did not seem to impact crop growth. Camelina height was quite uniform across the plots, approximately 30 inches tall in the 'wet' block and about 27 inches tall in the 'dry' block. The camelina flowered in early July, and seed pods were fully formed and filled with mostly green seeds by about Aug. 1. Seed seemed to mature slightly earlier in the 'dry' irrigation block, but this maturity difference became minimal by the time of harvest, and thus the two blocks could be harvested at the same time.

Seed yield, oil content, and oil yield were significantly different between the two irrigation regimes, but test weights were not different. Seed yield in the 'wet' block was nearly double that in the 'dry' block (Table 3). Because oil content was also significantly higher in the 'wet' block, the overall oil yield was almost twice as much in the 'wet' block as the 'dry' block. Although the overall seed yields were lower in 2008 compared to 2007, the pattern of response to the two irrigation rates was almost the same. It should be noted that the amount of precipitation plus irrigation applied to the 'dry' block in 2007 was similar to the amounts received by the 'wet' block in 2008, thus the similarity of yield in these two blocks suggests that camelina responded similarly to the degree of moisture stress it experienced in both years.

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 conditions, it responded dramatically to irrigation in the mineral soil. Seed yield and oil yield were both dramatically increased by a moderate increase in irrigation. Oil content was also increased somewhat by increased irrigation. Although to our knowledge camelina had not been evaluated in the Klamath Basin prior to 2007, this pattern of response to irrigation held true in both years where irrigation response was tested (2007 and 2008).

Fall Seeded Seeding Date x Cultivar Study

Despite irrigation after seeding, germination and stand density were very poor for the Aug. 28 seeding date. Almost no plants survived through the winter and weed competition was significant, resulting in no harvestable yield. The same was true for the

Sept. 11 seeding, except for cultivars CS3 and 'Winter'. CS3 had a very thin stand of mature plants that produced a very small amount of harvestable seed, whereas the winter type had a slightly better stand of mature plants and slightly higher seed yield (Table 4).

The Sept. 25 and Oct. 11 seeding dates resulted in harvestable stands of all cultivars. Differences between seeding dates were significant only for seed yield (Table 4). For almost every cultivar, the Oct. 11 seeding date resulted in a higher seed yield than Sept. 25. The only case where the earlier (Sept. 25) seeding date resulted in a higher seed yield was for the true winter type.

There were no significant differences between cultivar for any of the parameters measured, although height was nearly so (P=0.054). There were no significant interactions between seeding date and cultivar for any parameters.

In summary, fall-seeded camelina had better germination and higher eventual seed yield from the later seeding dates. Established seedlings of all the cultivars seemed to survive the winter fairly well. It was a bit surprising that the true winter type was the only cultivar that benefited from the earlier seeding date, but it was encouraging that even spring types seemed to have good winter hardiness in this region. It would be interesting to see how late into the fall camelina could successfully be seeded and still germinate in the fall and survive through the winter. It should be noted that the winter of 2007-08 was fairly cold (Fig. 1), but that unusually heavy snowfalls occurred, especially in January and February. Thus the area was covered with deep snow for most of the winter. Winter survival and performance under bare soil conditions in other years may differ.

Future Prospects

Although weed competition was not a big factor in 2008 (especially for the spring-seeded study), 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. Response to other crop inputs, such as fertilizer, also needs to be better understood. If required inputs 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 would 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. Growers have indicated that they plan to grow small test fields in the Rogue Valley and Klamath Basin in 2009. Further demonstration fields and research studies would help identify camelina's potential and limiting factors in this region.

References

Putnam, D.H., J.T. Budin, L.A. Field, and W.M. Breene. 1993. Camelina: A promising low-input oilseed. p. 314-322. *In:* J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

US Bureau of Reclamation, 2008. Agrimet: The Pacific Northwest cooperative agricultural weather network. http://www.usbr.gov/pn/agrimet/.

Table 1. 2008 Precipitation & irrigation for spring camelina irrigation rate trial. Klamath Basin Research & Extension Center, Klamath Falls, OR.

Month	Precipitation (inch)	"Wet" Block		"Dry" Block	
		Irrigation (inch)	Irrigation Applications	Irrigation (inch)	Irrigation Applications
May	1.69	3.43	1	3.43	1
June	0.66	1.93	2	1.93	2
July	0.03	7.01	6	4.00	4
August	0.20	1.43	1	1.43	1
Sept. 1-8	0.00	0.00	0	0.00	0
Total	**2.58**	**13.80**	**10**	**10.79**	**8**

Table 2. 2007-08 Precipitation & irrigation for the winter camelina variety trial. Klamath Basin Research & Extension Center, Klamath Falls, OR.

Month	Precipitation (inch)	Irrigation (inch)	Irrigation Applications
August	0.18	0.84	1
September	0.15	0.56	1
October	1.74	0.00	0
November	0.78	0.00	0
December	1.60	0.00	0
January	2.63	0.00	0
February	0.65	0.00	0
March	0.53	0.00	0
April	0.19	0.00	0
May	1.69	3.36	1
June	0.66	0.84	1
July	0.03	3.78	3
Total	**10.83**	**9.38**	**7**

Table 3. 2008 Spring camelina yield under two irrigation rates, seeded in mineral soil. Klamath Basin Research & Extension Center, Klamath Falls, OR.

Irrigation Block	Seed Yield (lb/ac)	Rank	Test Weight (lb/bu)	Rank	Oil %	Rank	Oil Yield (lb/ac)	Rank
Wet	1025	1	50.2	2	34.7	1	355	1
Dry	577	2	50.4	1	32.5	2	190	2
Mean	801		50.3		33.6		272	
***P* value**	**0.003**		**0.498**		**<0.001**		**0.002**	
LSD (0.05)	269		NSD		0.8		91	
CV (%)	44.5		1.4		3.1		44.3	

Table 4. 2008 Camelina fall seeding date & variety comparison, seeded in mineral soil. Klamath Basin Research & Extension Center, Klamath Falls, OR.

Seeding Date	Entry	Seed Yield (lb/ac)	Rank	Test Weight (lb/bu)	Rank	Height (inch)	Rank	Oil %	Rank	Oil Yield (lb/ac)	Rank
Sept. 11	CS3	7	30	nm	-	nm	-	34.0	19	5	30
Sept. 11	CS6	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS7	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS11	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS14	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS22	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS26	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS32	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS57	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS73	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS74	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	CS87	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	MT102	0	31	na	-	na	-	nm	-	nm	-
Sept. 11	WINTER	61	29	nm	-	22.0	2	34.4	10	42	29
Sept. 25	CS3	158	27	nm	-	17.5	26	33.5	25	54	27
Sept. 25	CS6	477	10	50.6	3	21.0	7	34.9	7	168	10
Sept. 25	CS7	281	18	nm	-	19.5	13	34.3	11	97	18
Sept. 25	CS11	310	17	nm	-	18.0	24	34.3	11	106	17
Sept. 25	CS14	252	20	nm	-	18.5	21	33.1	29	84	20
Sept. 25	CS22	218	23	nm	-	19.5	13	35.3	3	77	22
Sept. 25	CS26	280	19	nm	-	17.5	26	34.3	11	96	19
Sept. 25	CS32	349	15	nm	-	17.5	26	34.2	15	120	15
Sept. 25	CS57	329	16	nm	-	18.5	21	35.0	5	115	16
Sept. 25	CS73	420	12	49.4	7	19.0	18	34.5	9	146	11
Sept. 25	CS74	204	26	nm	-	18.0	24	33.6	24	70	26
Sept. 25	CS87	216	24	nm	-	18.5	21	33.5	25	73	24
Sept. 25	MT102	220	22	nm	-	19.0	18	34.2	15	75	23
Sept. 25	WINTER	407	13	49.0	10	20.5	10	34.3	11	139	13
Oct. 9	CS3	131	28	nm	-	17.0	29	33.2	28	44	28
Oct. 9	CS6	533	8	51.3	2	22.0	2	36.2	1	190	7
Oct. 9	CS7	399	14	nm	-	20.5	10	33.7	22	134	14
Oct. 9	CS11	788	5	50.1	4	19.5	13	34.2	15	270	5
Oct. 9	CS14	895	3	48.4	13	21.0	7	33.7	22	301	3
Oct. 9	CS22	948	1	48.5	12	21.5	6	35.0	5	333	1
Oct. 9	CS26	738	6	50.1	6	22.0	2	33.9	20	258	6
Oct. 9	CS32	522	9	51.7	1	19.0	18	35.3	3	186	9
Oct. 9	CS57	911	2	50.1	5	22.5	1	35.6	2	325	2
Oct. 9	CS73	849	4	49.1	9	22.0	2	34.8	8	294	4
Oct. 9	CS74	548	7	49.1	8	21.0	7	33.9	20	188	8
Oct. 9	CS87	430	11	48.7	11	19.5	13	32.7	30	143	12
Oct. 9	MT102	229	21	nm	-	20.0	12	34.2	15	79	21
Oct. 9	WINTER	211	25	nm	-	19.5	13	33.5	25	71	25
Mean		293		49.6		19.7		34.2		147	
***P* (Seeding Date)**		**0.004**		**0.882**		**0.097**		**0.405**		**0.137**	
LSD (0.05)- Seeding Date		115		NSD		NSD		NSD		NSD	
CV Seeding Date (%)		34.0		4.1		3.4		1.0		35.6	
***P* (Entry)**		**0.235**		**0.904**		**0.054**		**0.289**		**0.234**	
LSD (0.05)- Entry		NSD		NSD		NSD		NSD		NSD	
CV Entry (%)		73.0		4.1		7.5		3.9		63.2	
***P* (Seeding Date X Entry Interaction)**		**0.285**		**0.728**		**0.401**		**0.992**		**0.406**	

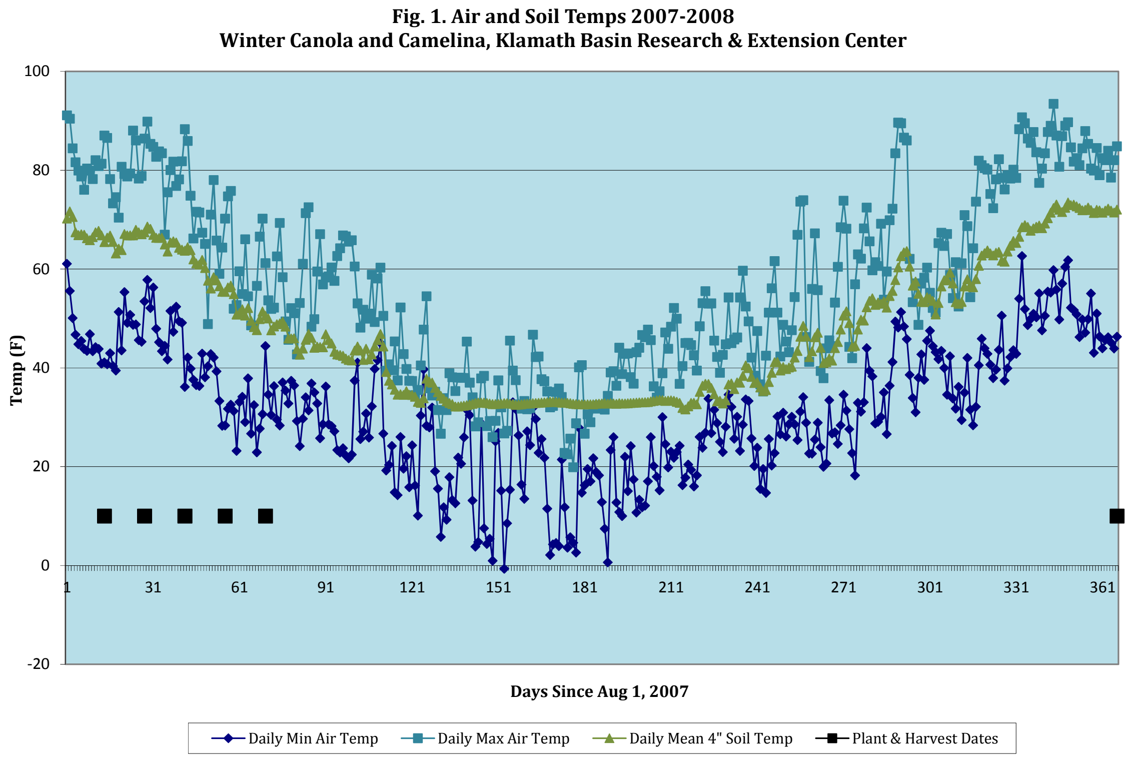
Fig. 1. Air and Soil Temps 2007-2008
Winter Canola and Camelina, Klamath Basin Research & Extension Center
100
80
60
40
20
0
-20
Temp (F)
1
31
61
91
121
151
181
211
241
271
301
331
361
Days Since Aug 1, 2007
Daily Min Air Temp
Daily Max Air Temp
Daily Mean 4" Soil Temp
Plant & Harvest Dates