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Camelina sativa as a fallow replacement crop in wheat-based crop production systems in the US Great Plains

Augustine K. Obour[a,*], Chengci Chen[b], Henry Y. Sintim[c], Kent McVay[d], Peggy Lamb[e], Eric Obeng[f], Yesuf A. Mohammed[b], Qasim Khan[d], Reza K. Afshar[b], Valtcho D. Zheljazkov[g]

[a] Agricultural Research Center- Hays, Kansas State Univ. 1232 240th Avenue, Hays, KS 67601, United States
[b] Eastern Agricultural Research Center, Montana State Univ., 1501 North Central Avenue, Sidney, MT 59270, United States
[c] Department of Crop and Soil Sciences, Washington State Univ., Puyallup Research and Extension Center, 2606 West Pioneer, Puyallup, WA 98371, United States
[d] Southern Agricultural Research Center, Montana State Univ., 748 Railroad Highway, Huntley, MT 59037, United States
[e] Northern Agricultural Research Center, Montana State Univ., 3710 Assinniboine Rd, Havre, MT 59501, United States
[f] Department of Agronomy, Kansas State Univ., 1712 Claflin Rd, Manhattan, KS 66506, United States
[g] Department of Crop and Soil Science, Oregon State Univ., 3050 SW Campus Way, Corvallis, OR 97331, United States

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A B S T R A C T

Oilseed camelina (*Camelina sativa* [L.] Crantz) has potential to diversify and intensify dryland wheat-based crop production in the US Great Plains. Field experiments were conducted to evaluate camelina as a fallow replacement crop in winter wheat (*Triticum aestivum* L) − fallow (W-F) crop rotation system across five locations in the Great Plains. Results showed both winter wheat and camelina grain yields varied across locations. Wheat yields after summer fallow averaged 3393 kg ha^{-1}, significantly greater than 2796 kg ha^{-1} wheat yields following spring camelina. This represents an average of 17.6% reduction in wheat yields following camelina compared to fallow. However, wheat protein concentration following camelina was not different from that after fallow. In general, camelina seed yield and oil concentration obtained in the northern Great Plains were approximately 28.7 and 18.5% more than that produced in the central Great Plains, possibly due to difference in mean growing season air temperature among the locations. Our findings showed camelina can be grown as a fallow replacement crop in dryland systems across the Great Plains but ready markets will be needed for grower adoption.

1. Introduction

Wheat (*Triticum aestivum* L.)-fallow (W-F) is a major crop production system in semi-arid regions of the US Great Plains adopted by producers to stabilize crop yields (Greb, 1979; Ryan et al., 2008). The fallow period in the production cycle allows enough time for soil water recharge before planting the subsequent wheat crop. Although fallow stabilized wheat yield, precipitation storage efficiency during fallow is usually less than 30% (Farahani et al., 1998), and economic profitability of W-F is generally low (DeVuyst and Halvorson, 2004; Nielsen et al., 2017). Research efforts have therefore focused on dryland cropping systems intensification to improve precipitation use efficiency (Peterson and Westfall, 2004; Aiken et al., 2013; Long et al., 2014; Sherrod et al., 2014; Nielsen and Vigil, 2017). Cropping systems intensification under no-till offers several benefits including increased annual crop yields, high crop residue, increased soil organic matter (SOM), improved soil water holding capacity associated with the increase in SOM, diversified markets and improved overall system profitability (Blanco-Canqui et al., 2010; Miller et al., 2015).

Despite the benefits of intensified crop production systems, identifying alternative crops that are well adapted to drier areas of the Great Plains that can fit into existing crop rotations remains a challenge. Camelina is an alternative oilseed crop that is well adapted to the water-limited environments in the Great Plains (Putnam et al., 1993; Obour et al., 2015; Sintim et al., 2015). Camelina is a short-season, cold tolerant crop, compatible with existing farm equipment used for grain crops, and performs well on marginal lands (Budin et al., 1995; Gugel and Falk, 2006; Moser and Vaughn, 2010; Berti et al., 2016; Sintim et al., 2016b). Camelina oil can be used for biodiesel and renewable jet fuel production (Fröhlich and Rice, 2005; Moser, 2010; Soriano and Narani, 2012; Mupondwa et al., 2016). Biodiesel derived from camelina oil had fuel properties similar to that produced with soybean (*Glycine max* [L.] Merr.) oil (Moser and Vaughn, 2010). Camelina oil and meal have other industrial applications such as making adhesives, coatings,

* Corresponding author.
E-mail address: aobour@ksu.edu (A.K. Obour).

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Table 1
Selected physical and chemical characteristics in the top (0–15 cm) soil depth at the experimental sites (Hays, KS; Havre, MT; Huntley, MT, Moccasin, MT, and Sheridan, WY).

Sites	Soil type	Texture	pH	Organic[a] carbon	P	K[‡]	Ca	Mg	NO_3-N
				g kg^{-1}	mg kg^{-1}				
Hays, KS	Mollisol	Silty clay loam	6.7	15	20	528	3376	677	2
Havre, MT	Mollisol	Loam	6.9	16	16	282	2157	519	10
Huntley, MT	Entisol	Clay loam	8.1	11	9	414	–	–	6
Moccasin, MT	Mollisol	Clay loam	7.2	22	11	258	–	–	13
Sheridan, WY	Aridisol	Clay loam	7.2	22	15	277	2985	1203	4

[‡] Exchangeable Ca, Mg, and K concentration were determined on an ICP-OES after NH_4OAc extraction (Knudsen et al., 1982); and NO_3-N by 2 M KCl extraction procedure and N concentration determined colorimetrically by cadmium reduction (Keeney and Nelson, 1982).

[a] Organic carbon by dry combustion using Leco C/N analyzer; pH was determined potentiometrically by an electrode (Thomas, 1996); available P by Mehilich-3 extraction method (Mehlich, 1984) at Hays (KS) and Olsen-P extraction method (Olsen and Sommers, 1982) at Havre (MT), Huntley (MT), Moccasin (MT) and Sheridan (WY), P concentration following extraction was determined using inductively coupled plasma-optical emission spectrometry (ICP-OES).

gums, resins and varnishes (Kim et al., 2015; Nosal et al., 2015). Camelina meal and oil are used in animal feed (Mierlita and Vicas, 2015; Nain et al., 2015). Chicken (Jáskiewicz et al., 2014; Ciurescu et al., 2016) and sheep (Cieslak et al., 2013) fed camelina oil or meal had lower blood plasma cholesterol and higher contents of α-linolenic, eicosapentaenoic acid, and docosahexaenoic acid in muscles. Furthermore, camelina oil is edible and a good potential source of α-linolenic acid, a precursor for omega-3 fatty acids essential in human health (Zubr and Mathus, 2002; Belayneh et al., 2015). Therefore, additional potential markets exist for camelina oil besides biofuel production making it a highly valuable oilseed crop. Replacing fallow with camelina could generate additional revenue to improve profitability of dryland wheat-based production systems.

Previous cropping systems research at Moccasin, MT and at Lingle, WY reported growing camelina in place of fallow in a W-F rotation showed minimal reduction in winter wheat yield (6%) in wet years (Hess et al., 2011). However, in drier years, winter wheat yields following camelina were 13% (Moccasin, MT) and 30% (Lingle, WY) lower than yields after fallow (Chen et al., 2015; Hess et al., 2011). In Culbertson, MT, durum wheat (*Triticum durum* Desf.) yields after camelina were 31% less than that following fallow (Lenssen et al., 2012). Climatic variables such as rainfall amount, distribution, and temperature, and factors such as soil depth are highly variable in the Great Plains. Therefore, winter wheat yield response after camelina in the central Great Plains may vary from that reported in the northern Great Plains. Multi-state research is needed to evaluate camelina performance across the region and to evaluate potential effects on wheat production when incorporated into a wheat-based cropping system.

Furthermore, winter and spring camelina genotypes exist, but most studies on camelina have generally focused on spring types (McVay and Khan, 2011; Sintim et al., 2015; Sintim et al., 2016a). Fall seeded camelina can improve plant establishment and early spring growth which can suppress weed competition. Early weed suppression is important because of limited herbicides labeled for use in camelina production. Sethoxydim (2-[1-(ethoxyimino) butyl]-5-[2-(ethylthio) propyl]-3-hydroxy-2- cyclohexen-1-one) for grass weed control is the only registered herbicide for camelina (Obour et al., 2015). In addition, fall seeded camelina is harvested earlier than spring types (Sintim et al., 2016b), which will potentially allow more time for soil water recharge before planting of the subsequent wheat crop. Besides, winter camelina will particularly fit well in dryland winter wheat-based cropping systems in regions where warmer summer temperatures may limit camelina production. Most of the research on camelina had been conducted in the northern Great Plains and Pacific Northwest regions (Budin et al., 1995; Gugel and Falk, 2006; Gesch and Cermak, 2011; McVay and Khan, 2011; Wysocki et al., 2013; Gesch and Johnson, 2015; Berti et al., 2016; Sharratt and Schillinger, 2016). The current study was undertaken to explore the performance of camelina beyond the aforementioned locations. This multi-state research effort was aimed at evaluating camelina as fallow replacement for dryland crop production in the US Great Plains. Specific research objectives were to i) evaluate productivity of winter wheat in a W-F and wheat-camelina production systems, and ii) determine spring and winter camelina performance and oil concentration when grown after wheat in the Great Plains.

2. Materials and methods

2.1. Study site description

The research was conducted in 2012 through 2015 growing seasons across five sites in the US Great Plains. Field experiments were conducted at Kansas State University Agricultural Research Center near Hays, KS (38°86′ N, −99°27′ W, and 609 m above sea level), Montana State University Agricultural Research Centers near Havre (48.52N −109.76W 804.7 m above sea level), Huntley (45.92 N, 108.24 W, 917 m above sea level), and Moccasin, MT (47° 03′ N, −109° 57′ W, 1400 m above sea level). A fifth site was University of Wyoming Sheridan Research and Extension Center, 9.5 km east of Sheridan, WY (44°48′ N, −106°46′ W, 1154 m above sea level). Detail information on soil type at each site is provided in Table 1. Before initiating experiments, composite soil samples were taken at 0–15 cm depth from all sites. The soil samples were air-dried and ground to pass through a 2-mm mesh sieve and analyzed for soil chemical properties (Table 1). In addition, seasonal temperature and precipitation information were recorded for all sites (Table 2).

2.2. Study design and plot management

The experimental design at each environment (site-year) was a randomized complete block (RCBD) with four replications except in Havre and Sheridan that had three and five replications, respectively. Treatments were two crop rotations, W-F and winter wheat-spring camelina (WW-CAM). These two rotations were common to all site-years. At Hays and Sheridan sites, a winter wheat-winter camelina (WW-WCAM) rotation treatment was added to compare wheat yields as affected by camelina genotype in the rotation. All crop rotations were fixed in space and both phases of the crop rotations were present in each year of the study. Winter wheat and winter camelina were planted in the fall (September through mid-October) while spring camelina was planted the second or third week in April. Seeding rates at each site were 65 and 5.6 kg ha^{-1} for winter wheat and camelina, respectively. Weeds were controlled in the crop growing season and fallow period with herbicides as needed. Grain yields at each site were determined by harvesting an area of approximately 1.5 m × 15 m from each plot with a plot combine harvester except at Sheridan where the harvested area was 1.5 m × 52 m. Winter camelina was usually harvested in late June while winter wheat and spring camelina were harvested in late July or early August. Grain yields for camelina and wheat were adjusted to 80