Oilseed Crops for Semiarid Cropping Systems in the Northern Great Plains

Adrian M. Johnston,* Donald L. Tanaka, Perry R. Miller, Stewart A. Brandt, David C. Nielsen, Guy P. Lafond, and Neil R. Riveland

ABSTRACT

Oilseed crops are grown throughout the semiarid region of the northern Great Plains of North America for use as vegetable and industrial oils, spices, and birdfeed. In a region dominated by winter and spring wheat (*Triticum aestivum* L. emend. Thell.), the acceptance and production of another crop requires that it both has an agronomic benefit to the cropping system and improve the farmers' economic position. In this review, we compare the adaptation and rotational effects of oilseed crops in the northern Great Plains. Canola (*Brassica* sp.), mustard (*B. juncea* and *Sinapis alba* L.), and flax (*Linum usitatissimum* L.) are well adapted to cool, short-season conditions found on the Canadian prairies and northern Great Plains border states of the USA. Sunflower (*Helianthus annuus* L.) and safflower (*Carthamus tinctorius* L.) are better adapted to the longer growing season and warmer temperatures found in the northern and central Great Plains states. Examples are presented of how agronomic practices have been used to manipulate a crop's fit into a local environment, as demonstrated with the early spring and dormant seeding management of canola, and of the role of no-till seeding systems in allowing the establishment of small-seeded oilseed crops in semiarid regions. Continued evaluation of oilseed crops in rotation with cereals will further expand our understanding of how they can be used to strengthen the biological, economic, and environmental role of the region's cropping systems. Specific research needs for each oilseed crop have been recommended.

Oilseed crops are grown throughout the semiarid region of the northern Great Plains of North America for use as vegetable and industrial oils, spices, and birdfeed. In a region dominated by winter and spring wheat (*Triticum aestivum* L.), the acceptance and production of another crop requires that it both has an agronomic benefit to the cropping system and improves the farmers' economic position. Given that most oilseed crops have an indeterminate growth habit, adaptation is influenced by tolerance to high temperature and drought stress and by crop management to take advantage of optimum environmental conditions for flowering and seed fill. The increasing area of oilseed crop production is an indication of the success of plant breeders and agronomists in developing suitable cultivars and production methods in this semiarid region (Table 1).

While soybean [*Glycine max* (L.) Merr.] is the major oilseed crop produced in the USA, canola is the dominant oil crop in Canada. The cool climatic conditions characteristic of the Canadian prairies provide an ideal environment for *Brassica* spp. oilseeds and flax (Table 2) while the climate found in the USA is better suited to the warm season crops like soybean and sunflower. In the northern Great Plains, soybean is a relatively new crop finding a place in semiarid cropping systems with the development of early maturing, low heat-unit cultivars (Miller et al., 2002). As a result, the vast majority of soybean production in both the USA and Canada occurs in wetter regions east of the Great Plains. However, for the other oilseed crops listed in Table 1, the majority of production occurs within the northern Great Plains.

Diversification within cereal-based cropping systems can be critical to breaking pest infestations that are common with monoculture (Bailey et al., 1992, 2000; Elliot and Lynch, 1995; Holtzer et al., 1996; Krupinsky et al., 2002). Results of crop rotation studies in the Great Plains revealed that where oilseeds are adapted, their inclusion in rotation with cereals could increase net returns and reduce risk through improved production stability (Lafond et al., 1993; Dhuyvetter et al., 1996; Zentner et al., 2002). In addition, the yield of wheat was increased when following oilseeds in rotation, confirming that monoculture systems are the least effective means of optimizing wheat production (Lafond et al., 1992; Brandt and Zentner, 1995; Anderson et al., 1999).

The use of minimum and no-till seeding systems has been found to provide an effective means of controlling soil erosion in various regions of the Great Plains (Black and Power, 1965; Lindwall and Anderson, 1981). Improvements in seed yield with conservation tillage have been reported as a result of increased levels of plant-available water throughout the soil profile in the spring (Aase and Reitz, 1989; Brandt, 1992; Lafond et al., 1992) and increased water use efficiency due to favorable microclimate conditions created by standing stubble (Cutforth and McConkey, 1997). Some oilseed crops are small seeded, requiring good surface soil moisture for seed germination and crop establishment, as is effectively provided in direct-seeding systems in the northern Great Plains. As a result, adoption of conservation tillage management not only reduces soil loss by erosion, but also can facilitate extending the crop rotation and allowing for diversification of the crops grown. Economic success with a diversified crop rotation has been reported to be improved with the implementation of conservation tillage practices, such as minimum and zero-tillage (Lafond et al., 1993; Rossetti et al., 1999; Zentner et al., 2002).

The objective of this review is to summarize information on the adaptation and production potential of some

A.M. Johnston, Potash and Phosphate Inst. of Canada, 12-425 Pinehouse Dr., Saskatoon, SK, Canada S7K 5K2; D.L. Tanaka, USDA-ARS, Northern Great Plains Res. Lab., Box 459, Mandan, ND 58554; P.R. Miller, Montana State Univ., Dep. of Land Resour. and Environ. Sci., P.O. Box 173120, Bozeman, MT 59717-3120; S.A. Brandt, Agric. and Agri-Food Can., Box 10, Scott, SK, Canada S0K 4A0; D.C. Nielsen, USDA-ARS, Cent. Great Plains Res. Stn., 40335 Country Rd. GG, Akron, CO 80720; G.P. Lafond, Agric. and Agri-Food Can., Box 760, Indian Head, SK, Canada S0G 2K0; and N.R. Riveland, North Dakota State Univ., Williston Res. Ext. Cent., 14120 Hwy. 2, Williston, ND 58101-8629. Saskatoon Res. Cent. Publ. 1421. Received 1 Dec. 2000. *Corresponding author (ajohnston@ppi-ppic.org).

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Table 3. Estimated rooting depth for canola, flax, safflower, and sunflower grown at select locations across the northern Great Plains.

Crop	Estimated rooting depth	Comments method of determination	Source
	cm		
Canola			
B. napus (cv. Cyclone)	120	Neutron probe	Angadi and Entz, unpubl. data, 1998 (MB)
Rapeseed (cultivar unknown)	150	Unknown	Black et al., 1981 (ND)
B. napus (cv. Westar)	165	Neutron probe	Nielsen, 1997 (CO)
B. rapa (cv. Reward)	114	MRMV†	Merrill et al., 2000 (ND)
Flax (cv. Norlin)	61–76	Neutron probe	Lafond, unpubl. data, 1995 (SK)
Sunflower			
cv. Triumph 546	178	Neutron probe	Nielsen, 1998a (CO)
cultivar unknown	200	Unknown	Black et al., 1981 (ND)
cv. Pioneer 6339 and Cenex 803	145	MRMV	Merrill et al., 2000 (ND)
tall hybrid (cv. IS6111)	160	Neutron probe	Angadi and Entz, unpubl. data, 1998 (MB)
Safflower			
cultivar unknown	210–220	Unknown	Black et al., 1981 (ND)
cv. Montola 2000	164	MRMV	Merrill et al., 2000 (ND)

† Minirhizotron microvideo system (Merrill et al., 2000).

In the subhumid regions of the Canadian prairies, canola has been shown to have even higher water use efficiency, at 8.3 to 11.4 kg ha^{-1} mm^{-1}, reflecting the lower air temperatures and lower moisture deficits in this region (Johnston et al., 1996). Thus, water use efficiency is partially a function of crop adaptation.

Canola is a cool-season crop, with the duration of flowering having a strong influence on final seed yield (Nuttall et al., 1992; Brandt and McGregor, 1997; Angadi et al., 1999b). Heat stress during flowering of a canola crop can prematurely end flowering, resulting in limited seed set after the accumulation of large amounts of dry matter. Optimal daytime temperatures during flowering of 28°C for *B. rapa* and 20°C for *B. napus* indicate considerable difference in tolerance to air temperature between species (Angadi et al., 1999b). Nuttall et al. (1992) reported that a 3°C rise in maximum daily temperature (21–24°C) during flowering in July and August resulted in a 430 kg ha^{-1} decline in canola seed yield. Similar negative effects on seed yield have been observed with water stress during flowering and seed filling (Stoker and Carter, 1984; Nielsen, 1997). Water stress on the crop at flowering negatively influenced the formation of pods and seed size, resulting in lower final seed yield. Together, growing season precipitation and air temperature have been found to be good indicators of canola yield potential (Nuttall et al., 1992; Brandt and McGregor, 1997). Brandt and McGregor (1997) reported that the yield of canola on summer fallow at Scott, SK, was found to be closely related to temperature during flowering and early seed development while precipitation from early seed development through seed filling is essential to achieving full yield potential (see Eq. 1).

$$\text{Yield of } B.\ napus = 4323 + 5.90 \times \text{Precip} - 187.7 \times \text{Temp.} \quad R^2 = 0.76;\ \text{SE} = 221 \qquad [1]$$

$$\text{Yield of } B.\ rapa = 4836 + 3.33 \times \text{Precip} - 216.7 \times \text{Temp.} \quad R^2 = 0.72;\ \text{SE} = 200$$

where Precip (mm) = 21 June–20 Aug. (*B. napus* $R^2 = 0.83$; *B. rapa* $R^2 = 0.82$) and Temp (°C) = 15 June–15 Aug. mean daily temperature (*B. napus* $R^2 = -0.58$; *B. rapa* $R^2 = -0.52$).

This relationship indicates that for each degree rise in mean daily temperature, the yield of *B. napus* declines by 188 kg ha^{-1} and *B. rapa* by 217 kg ha^{-1}. This indication of greater heat sensitivity for *B. rapa* contrasts with the observations in controlled environment conditions by Angadi et al. (1999a). Also, for each millimeter increase in precipitation, there is a corresponding 5.9 kg ha^{-1} yield increase with *B. napus* and 3.3 kg ha^{-1} yield increase with *B. rapa*, indicating a marked difference in water use sensitivity, contrasting with the equations presented in Table 4. Given that Brandt and McGregor (1997) used a common measurement period for their water use assessment and that *B. rapa* starts and finishes flowering 2 wk before *B. napus*, they may have introduced some bias into their evaluation of these crops.

Table 4. Estimated seed yield response to crop water use for canola, mustard, flax, safflower, and sunflower grown at select locations across the northern Great Plains.

Crop	Equation	Source
Canola		
B. rapa	kg/ha = 6.9 (WU† − 121 mm) $R^2 = 0.74$, SE = 1.29	Brandt et al., unpubl. data, 1998 (SK)
B. napus	kg/ha = 7.2 (WU − 132 mm) $R^2 = 0.62$, SE = 1.77	Brandt et al., unpubl. data, 1998 (SK)
B. napus	kg/ha = 7.7 (WU − 160 mm) $R^2 = 0.72$, SE = 0.88	Nielsen, 1998a (CO)
Mustard		
B. juncea	kg/ha = 7.6 (WU − 141 mm) $R^2 = 0.63$, SE = 1.84	Brandt et al., unpubl. data, 1998 (SK)
S. alba	kg/ha = 4.6 (WU − 67 mm) $R^2 = 0.53$, SE = 1.44	Brandt et al., unpubl. data, 1998 (SK)
Flax	kg/ha = 7.6 (WU − 127 mm) $R^2 = 0.71$, SE = 153	Brandt et al., unpubl. data, 1998 (SK)
Sunflower	kg/ha = 6.6 (WU − 175 mm) $R^2 = 0.80$, SE = 0.37	Nielsen, 1999 (CO)
Safflower	kg/ha = 8.2 (WU − 233 mm) R^2 = NA‡, SE = NA	Nielsen, 1995 (CO)

† WU, water use.
‡ Data not available.

development using a temperature of 35 to 15°C (day and night, respectively) reduced the seed yield of *B. juncea* by 34% and *B. rapa* by as much as 93%. *Brassica napus* and *S. alba* both flowered with fewer accumulated heat units when seeded early rather than late (Miller et al., 1998a). Delayed seeding of *S. alba* resulted in the largest proportional (30%) reduction in seed yield among 12 cereal, oilseed, and pulse crops grown in a seeding date study at Scott and Swift Current, SK. For both *B. juncea* and *S. alba*, the reduction in seed size was equal in proportion to the reduction in pod density.

Mustard Management in Rotation

Little research has been conducted into the management of mustard in rotation with cereals in the northern Great Plains. In one cropping sequence study at Swift Current, SK, *B. juncea* did not increase seed yield of spring wheat significantly over that of continuous spring wheat though a small increase (0.5 protein units) in wheat grain protein was observed (Miller et al., 1998a). During one of eight site-years of that study, volunteer mustard seedlings competed strongly with spring wheat at the seedling stage, reducing wheat yield by 49% compared with continuous spring wheat, despite complete control with herbicide application within the recommended window. Given that mustard has a water use, rooting depth, and growth and development pattern similar to canola, it is likely to provide cropping system effects similar to canola (Angadi et al., 1999b). As discussed for canola above, optimizing the yield of *Brassica* sp. oilseeds in semiarid environments will depend on the timing of water and high-temperature stress relative to crop flowering and seed formation.

FLAX

Flax is an ancient crop belonging to the family Linaceae. Reports of its production go back to 3000 BC in Babylon (Flax Council of Canada, 1998). Cultivated flax consists of two main types, harvested for seed and harvested for fiber. In North America, primarily the oilseed type is grown, and flax production dates back 400 yr when Louis Hebert, the first farmer in Canada, brought it to New France. With time, flax production expanded westward and southward into the Great Plains. Flax oil is high in linolenic fatty acid (45–60%), making it a very effective drying agent. Although it is an edible oil, it is used primarily for industrial purposes, such as in the production of paints and oil-based coverings and in the manufacture of linoleum flooring (Flax Council of Canada, 1998). Linseed oil also offers important nutritional benefits because of the high levels of omega-3 fatty acids. Oil extraction in flax averages 44%, and the meal has an average protein content of 23% (DeClercq and Daun, 1999b). Recent plant-breeding achievements have led to the development of a new flax type called 'Solin', which is a name used for flax with low (<5%) linolenic acid in the oil (Dribnenki and Green, 1995). Solin, which responds agronomically as regular flax, is being developed exclusively for the edible oil market. In North America, all flaxseed is grown in the Great Plains region, with 35% of world production in Canada and 4% in the USA (Table 1).

Crop Water Use

Relative to the other oilseed crops, flax is a shallow-rooted crop (Table 3). Research on flax water use and extraction from the soil has shown that flax will extract 90% or more of plant-available water from the 0- to 60-cm soil layer (Lafond, unpublished data, 1998). In agreement, Campbell and Zentner (1996) showed that flax grown on fallow often conserved more water in the 60- to 120-cm soil layer than did spring wheat. Seed yield response to water use from trials conducted at Swift Current and Scott, SK, indicates little difference between flax and *B. napus* at the same location (Table 4). Once the minimum water use of approximately 127 mm was achieved, seed yield increased at a rate of 7.6 kg ha^{-1} mm^{-1}. However, at Indian Head, SK, 12 yr of water use (WU) data with flax gave a very poor relationship with seed yield [Yield (kg ha^{-1}) = 1.9 (WU + 532 mm); $r^2 = 0.06$]. This poor relationship at this higher-yielding location indicates that something other than water is influencing the seed yield response of flax (Lafond, unpublished data, 1998).

The shallow rooting behavior of the flax crop makes it well adapted to the improved moisture conditions of the surface soil found in no-till production systems (Lafond et al., 1992). The benefits of no-till production were demonstrated over a wide range of growing conditions, i.e., from hot and dry to cool and moist conditions (Lafond and Derksen, 1996). In fact, flax was shown to have greater water use efficiency under no-tillage (5.4 kg ha^{-1} mm^{-1}) relative to conventional tillage (4.9 kg ha^{-1} mm^{-1}).

Flax Management in Rotation

Although flax has been grown for a long time on the Canadian prairies and in the northern Great Plains of the USA, few rotational studies have included it (Lafond et al., 1992). Campbell and Zentner (1996) reported that flax conserved soil NO_3 and water below the 60-cm soil depth compared with spring wheat though it inexplicably failed to provide a rotational benefit to a subsequent wheat crop compared with continuous spring wheat. Soil under flax stubble dries and warms sooner than that under wheat stubble, and it is possible that timeliness of water use was compromised due to a common date for spring tillage operations, which had to be delayed until the wheat stubble was sufficiently dry. It has also been recommended that flax should not be grown after legumes or potato (*Solanum tuberosum* L.) because of the potential for infection from *Rhizoctonia* spp. bacteria (Flax Council of Canada, 1998). While the recommendations have never been substantiated, it is believed that flax grown after alfalfa does exceptionally well in subhumid regions of the Canadian prairies. Other studies that have examined flax from a crop rotation basis have revolved around seeding flax into canola stubble. These studies have shown that when young volunteer canola seedlings are tilled just before the seed-and sunflower-planting practices are employed to maintain previous crop residues on the soil surface during the sunflower growing season. In recent years, there has been increased interest in minimum- and no-till sunflower production practices (Blamey et al., 1997). Maintaining surface residue from the previous crop results in reduced soil erosion and evaporation and increased rainfall infiltration and soil water storage. Maintaining surface residue using no-till helped suppress evaporation and increased sunflower seed yield 16% compared with conventional tillage (Norwood, 1999).

The maintenance of surface crop residues in sunflower rotations helped to reduce or prevent the buildup of certain weed species. Weed populations often proliferate within the open canopy of sunflower, but combining cultural practices, such as delayed seeding, narrow rows, banded fertilizer, and increased plant population, has improved weed control (Tanaka and Anderson, 1999).

SAFFLOWER

Safflower is a member of the Compositae or Asteraceae family and provides three products: an edible oil, meal, and birdseed. Historically, safflower was grown for its flowers, with the florets being used for coloring and flavoring foods, for making dyes, and as medicines (Mundel et al., 1992). It is one of humanity's oldest crops and was usually grown in small plots for a grower's personal use. Safflower is a thistle-like annual herbaceous plant with long, sharp thorns that is grown mainly in arid and semiarid areas of the world. Currently, it remains a minor crop, with world seed production around 800 000 t annually (Gyulai, 1996).

The crop was introduced into North America as early as 1899 from its origin in the Middle East and South Asia. Safflower was initially tested in the USA in 1925 as a new oilseed crop and was commercially grown in the Great Plains beginning in the late 1950s (Knowles, 1958). Oil content of safflower seed ranges from 35 to 40%. There are two types of safflower cultivars: those producing oil high in oleic or monounsaturated fatty acid and those high in linoleic polyunsaturated fatty acid (Berglund et al., 1998). After oil extraction, the seed meal has a protein content of about 24% (Hoag et al., 1969). Safflower seed that is uniformly bright white in color or lightly striped can be marketed as birdseed.

Crop Water Use

Safflower generally is considered a daylength-neutral, long-day plant that needs at least 1400 degree days (5°C basis) to reach maturity. Miller et al. (2001) used a very early maturing cultivar of safflower (Saffire) to calculate degree-day requirements of 1430 to 1480 at Swift Current, SK, concluding that maturity requirements for safflower generally were too great for that location. Plants have a deep taproot that can extend to a depth of 220 cm (Table 3) and xerophytic spine attributes that contribute to good drought and heat tolerance (Dajue and Mundel, 1996). Safflower will not survive in standing water for even a few hours during warm weather (Mundel et al., 1997). Therefore, good estimates of yield per unit of water are difficult to determine. Research at Mandan, ND, found that the water use efficiency of safflower ranged from 1.2 to 5.1 kg ha^{-1} mm^{-1} for crops seeded mid-May or early June (Alessi et al., 1981). Studies conducted by Hang and Evans (1985) using a line-source irrigation method determined that safflower's water use efficiency was 8.45 kg ha^{-1} mm^{-1} at 50 cm of irrigation. In north-central Montana, Brown and Carlson (1990) collected water use data in safflower cultivar trials over 10 yr, generating a rainfed yield–water use equation of:

$$\text{Seed yield (kg ha}^{-1}\text{)} = 7.2(\text{evapotranspiration} - 185 \text{ mm}) \quad [2]$$

Water use was estimated based on soil water extraction to an assumed 213-cm soil depth, with an estimated 254 mm of plant-available water. The Brown and Carlson (1990) equation appears similar to the high end of the range reported by Alessi et al. (1981). In general, safflower grown in the northern Great Plains of the USA yields best in areas where along with good soil moisture at seeding, growing season precipitation (May through August) is in the 15- to 25-cm range, with at least 75% of the precipitation occurring before the end of July. The flowering and pollination of safflower can be severely reduced by rainy days or days with excessive dew and high humidity. Plant diseases such as alternaria (*Alternaria carthami*) and bacterial blight also flourish under these conditions and can cause major yield reductions.

Safflower in Rotations

Including safflower in wheat-based rotations can improve use of deep soil water and N (Black, 1993). The long growing season required by the crop permits deep root growth, enabling safflower to use water and nutrients from a greater soil depth than crops with a shorter growing season. Because safflower uses more soil water and requires a longer growing season than small grain crops, it and other crops of similar rooting depth should be grown in 3-yr or longer rotations to reduce potential failure of other crops in a rotation. In areas that have dryland saline-seep problems, safflower can be used in rotation to use surplus water from recharge areas to prevent the expansion of saline seeps (Mundel et al., 1992). Control of grassy weeds in safflower can benefit subsequent small grain crops in a rotation. Conversely, broadleaf weed control in small grains can also benefit safflower production because few herbicides are registered for use in this minor crop.

OILSEED CROP RESEARCH NEEDS IN THE NORTHERN GREAT PLAINS

The successful use of oilseed crops to diversify cropping systems in the northern Great Plains has been demonstrated in this review. The oilseeds canola, mustard, and flax are well adapted to cool, short-season conditions found on the Canadian prairies and northern

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