



# Simulating the Production Potential of Dryland Spring Canola in the Central Great Plains

D. C. Nielsen,\* S. A. Saseendran, L. Ma, and L. R. Ahuja

## ABSTRACT

Canola (*Brassica napus* L.) has potential to be grown as a dryland crop to diversify the winter wheat (*Triticum aestivum* L.)–fallow production system of the semiarid central Great Plains. Extensive regional field studies have not been conducted under rainfed conditions to provide farmers, agricultural lenders, and crop insurance providers with information about the production potential and expected yield variability of canola in this region. The purpose of this study was to use an agricultural system model to simulate canola production under rainfed conditions in the central Great Plains and to determine the economic viability of canola production. The CROPGRO-canola model was used within the Root Zone Water Quality Model (RZWQM2) with weather data (1993–2008) to simulate canola yield for nine central Great Plains locations under four plant-available water (PAW) contents at planting. Average yield with 75% PAW was highest (1725 kg ha<sup>-1</sup>) at Champion, NE, in the north-central area and lowest (975 kg ha<sup>-1</sup>) at Walsh, CO, in the south-central area. Simulated yields increased with increasing PAW at planting at an average rate of 5.31 kg ha<sup>-1</sup> mm<sup>-1</sup>. Yield variability was simulated to be lowest at Sidney, NE, Stratton, CO, and Walsh, CO, and highest at Akron, CO, Tribune, KS, and Garden City, KS. Yield variability did not consistently change with amount of PAW across the region. Calculated average net returns indicate that profitable canola production is possible across a large portion of the central Great Plains when PAW at planting is at least 50%.

INTEREST IN THE production of canola continues to grow as its use as a feedstock for biodiesel production (Blackshaw et al., 2011; Patil and Deng, 2009; Pavlista and Baltensperger, 2007) is evaluated in addition to its current use as a source of edible oil for human consumption (Starter et al., 1999). The central Great Plains of the United States is a region where canola has been considered as an alternative crop to be grown in dryland rotations with winter wheat (Nielsen, 1997, 1998), but most of the reported yields from studies done in this region have come from irrigated studies (Hergert et al., 2011; Pavlista et al., 2011). Yield results from dryland field studies have not been reported across this region.

Previous work at Akron, CO, (Nielsen, 1997) indicated that canola seed yield response to water use was

$$Y = 7.72(W - 158.0)$$

where  $Y$  is grain yield (kg ha<sup>-1</sup>) and  $W$  is water use or evapotranspiration (mm). The slope of 7.72 kg ha<sup>-1</sup> mm<sup>-1</sup> is lower than found for the C<sub>3</sub> grain crop winter wheat

(12.49 kg ha<sup>-1</sup> mm<sup>-1</sup>) and the C<sub>4</sub> grain crop corn (*Zea mays* L.) (25.67 kg ha<sup>-1</sup> mm<sup>-1</sup>) but similar to two other C<sub>3</sub> oilseeds (6.64 kg ha<sup>-1</sup> mm<sup>-1</sup> for sunflower [*Helianthus annuus* L.] and 6.53 kg ha<sup>-1</sup> mm<sup>-1</sup> for soybean [*Glycine max* (L.) Merr.]) grown at Akron (Nielsen et al., 2011). These differences in the response of yield to water use are primarily a function of the photosynthetic pathway (C<sub>3</sub> or C<sub>4</sub>) and the fraction of oil, protein, and starch in the seed. Consequently, it is likely that the slope for winter canola would not be greatly different from spring canola. The water use offset of 158.0 mm could be higher for winter canola because there would now be water use occurring from planting in late summer until winter dormancy, but we are unaware of published water use–yield relationships for winter canola.

Using this simple linear production function with 30-yr rainfall records (1965–1994) and average soil water extraction of 102 mm, Nielsen (1997) estimated an average dryland canola yield at Akron, CO, of 1142 kg ha<sup>-1</sup>, with a yield range of 314 to 2643 kg ha<sup>-1</sup>. Other important environmental factors, however, in addition to water use, such as ambient temperature, solar irradiance, and timing of water stress, probably affect canola yield formation in addition to seasonal water use. Kutcher et al. (2010) found that canola yields were significantly decreased as the number of days with maximum ambient temperatures >30°C during the growing season increased. Gan et al. (2004) reported that canola yields were reduced 15% when subjected to high ambient temperature (35°C) during bud formation, 58% when temperature stress occurred during flowering, and 77% when stressed during pod development stages. Nielsen (1997) found no significant effects of water stress timing on canola yield but noted a trend for the lowest yields when water stress occurred during the grain-filling stage.

D.C. Nielsen, USDA-ARS, Central Great Plains Research Station, 40335 County Road GG, Akron, CO 80720; S.A. Saseendran, L. Ma, and L.R. Ahuja, USDA-ARS, Agricultural Systems Research Unit, 2150 Centre Ave., Bldg. D, Fort Collins, CO 80526. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA. The USDA is an equal opportunity provider and employer. Received 7 Feb. 2012. \*Corresponding author (david.nielsen@ars.usda.gov).

Published in Agron. J. 104:1182–1188 (2012)

Posted online 7 June 2012

doi:10.2134/agronj2012.0048

Copyright © 2012 by the American Society of Agronomy, 5585 Guilford Road, Madison, WI 53711. All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

**Abbreviations:** PAW, plant-available water; RZWQM2, Root Zone Water Quality Model.

Because of the yield-reducing effects of high temperatures, there has been increased effort in recent years to use winter canola cultivars that are planted in the fall and harvested earlier in the year (before the warmest conditions) rather than spring cultivars. Unfortunately, the central Great Plains region has shown sporadic success with the use of winter cultivars because of the frequent occurrence of warm temperatures in January and February that cause the winter canola cultivars to break dormancy, followed by very cold periods without snow cover resulting in significant winter kill and stand reductions. For example, data from the National Winter Canola Variety Trial averaged across many winter canola cultivars at a few central Great Plains sites indicated 88% winter survival at Garden City, KS (5-yr average), 69% winter survival at Colby, KS (3-yr average), 60% winter survival at Sidney, NE (3-yr average), and 30% winter survival at Akron, CO (1 yr) (data available at [www.agronomy.ksu.edu/extension/p.aspx?tabid=98](http://www.agronomy.ksu.edu/extension/p.aspx?tabid=98)). Consequently, spring canola is, in our opinion, currently a better choice than winter canola to result in consistent plant stands in this region.

Properly calibrated and validated crop models provide a viable tool to assess these combined water and temperature effects on crop production without having to conduct extensive field trials at numerous locations for several years. While the EPIC model was calibrated and validated in the Prairie Provinces of Canada (Kiniry et al., 1995), there has yet to be a model validated for spring canola under the conditions found in the central Great Plains of the United States.

Recently, a canola model (Saseendran et al., 2010a) was developed from CROPGRO-faba bean (Boote et al., 2002) to be used with RZWQM2 (Ahuja et al., 2000) and the Decision Support System for Agrotechnology Transfer (DSSAT 4.0) (Jones et al., 2003). This model considered the effects of more than just water use factors on canola growth, development, and seed yield. The model also simulated the effects of water stress, temperature, and soil and management factors. The CROPGRO-canola model was calibrated, and validation results indicated that the model performed well in simulating canola yields across the range of 0 to 3000 kg ha<sup>-1</sup> (Fig. 1). Consequently, this model could be used to simulate regional dryland canola yield throughout the central Great Plains, thereby obviating the need for dryland field studies over many years and many locations.

In order for dryland Great Plains farmers to be willing to incorporate canola into their production systems and to assist in the implementation of federal crop insurance programs, the risk involved in producing canola under the highly variable precipitation and high growing season temperature conditions common to this region must be quantified. The purpose of this study was to use the newly developed CROPGRO-canola model in RZWQM2 (Saseendran et al., 2010a) to simulate spring canola production across a range of environmental conditions at nine central Great Plains locations to provide data about the average and range of yields that could be expected under various weather situations and various starting soil water conditions. Yield simulations for winter canola were not made because there is currently no winter canola model and because of the sporadic survival of winter canola seen in cultivar trials conducted in the central Great Plains.

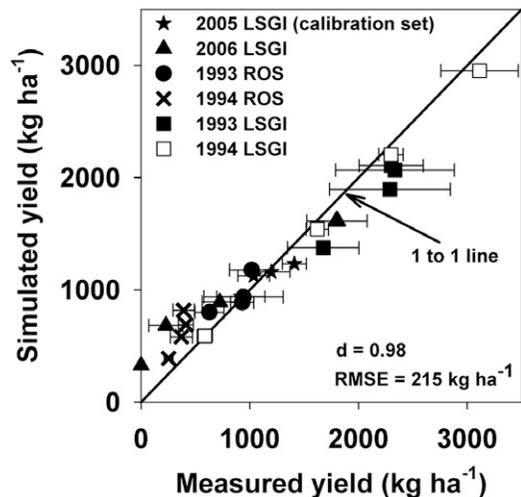


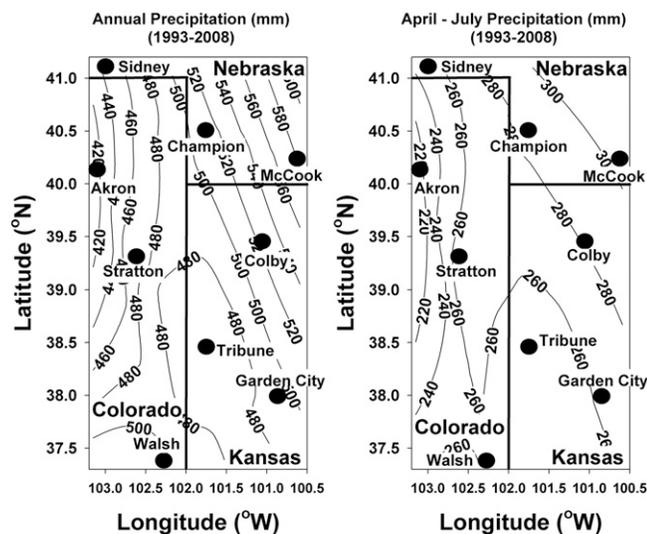
Fig. 1. Comparison of measured and simulated canola grain yield using CROPGRO-canola in the Root Zone Water Quality Model (RZWQM2) at Akron, CO. Error bars indicate one standard deviation about the mean; *d* is Willmott's index of agreement and RMSE is root mean square error (from Saseendran et al., 2010b; LSGI and ROS are experimental area designations).

## MATERIALS AND METHODS

The RZWQM2 is a process-oriented agricultural system model that integrates biological, physical, and chemical processes for simulating the impact of tillage, water, fertilizers and other agricultural chemicals, and crop management practices on soil water, crop production, and water quality. The model has been successfully used to simulate the growth, development, leaf area, biomass, and yield of corn, soybean, wheat, proso millet (*Panicum miliaceum* L.), foxtail millet (*Setaria italic* L. Beauv.), triticale (*X Triticosecale rimpaii* Wittm.), and canola and to simulate a wide variety of rotational cropping sequences across the central Great Plains region (Saseendran et al., 2010b). Values for the calibrated species-specific, ecological-group-specific, and cultivar-specific parameters used in the canola model (based on data collected for Westar and Hyola 401 canola) were given in Saseendran et al. (2010a). The specified simulation seeding rate was 630,000 seeds ha<sup>-1</sup>, with N fertilizer added at planting at a rate of 67 kg ha<sup>-1</sup>. A simulated planting date of 8 April was used for all nine locations identified below.

Sixteen years of daily weather data (1993–2008), collected under uniform instrumental and exposure conditions, were obtained for nine central Great Plains locations (Sidney, Champion, and McCook, NE; Akron, Stratton, and Walsh, CO; and Colby, Tribune, and Garden City, KS) to run the model (see locations in Fig. 2). The data sets included daily maximum and minimum ambient temperature, daily average relative humidity, and daily total wind run, solar irradiance, and precipitation. These data sets were acquired from the High Plains Regional Climate Center ([www.hprcc.unl.edu](http://www.hprcc.unl.edu)) at the University of Nebraska, Lincoln.

The same soil type (a silt loam with a field capacity of 0.286 m<sup>3</sup> m<sup>-3</sup> and a wilting point of 0.136 m<sup>3</sup> m<sup>-3</sup>) was used for simulations at all nine locations. Silt loam soils occur on approximately 42% (about 5.2 million ha) of the central Great Plains region that is shown in the regional precipitation map



**Fig. 2. Geographic distribution of average (1993–2008) annual precipitation and growing season (April–July) precipitation across the central Great Plains region.**

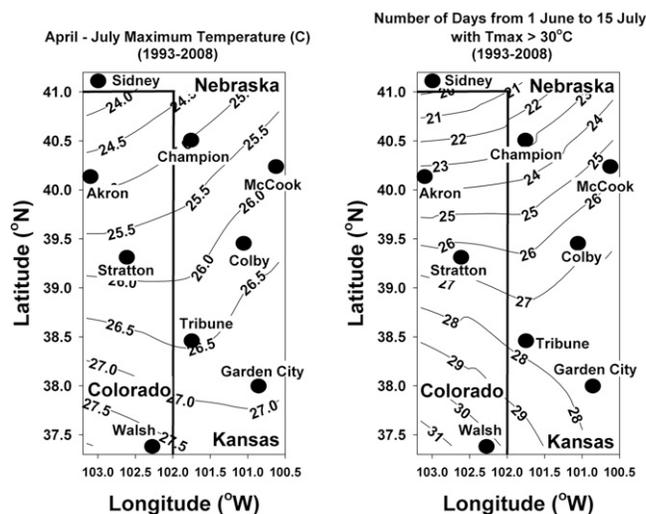
(Fig. 2). That percentage was calculated from county soils data (NRCS Web Soil Survey, <http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>). In our previous studies, we obtained better soil water predictions (smaller root mean square error and mean relative error, greater index of agreement) for the silt loam soils using uniform soil specifications rather than changing the soil texture and hydraulic properties with depth (Saseendran et al., 2009, 2010a).

The model was run for four starting soil water conditions (25, 50, 75, and 100% PAW, corresponding to 45, 90, 135, and 180 mm of PAW in the 0–120-cm soil profile). SigmaPlot for Windows (version 11.0, Systat Software) was used to create regional yield distribution maps, box plots of yield variability, and cumulative probability distributions of simulated canola yield.

## RESULTS AND DISCUSSION

The nine locations for which canola production was simulated presented average (1993–2008) annual precipitation conditions (Fig. 2) ranging from 409 mm (Akron) to 582 mm (McCook). The average canola growing season (April–July) precipitation ranged from 209 to 304 mm for those two locations, respectively. The average annual precipitation gradient from Akron to McCook (precipitation increasing by 80 mm per 100 km moving from west to east) is somewhat steeper than reported by Martin (2007) for the precipitation gradient across the entire state of Nebraska (63 mm per 100 km) due to the closer proximity to the Rocky Mountains of this region of the Great Plains. The west to east precipitation gradient for both annual precipitation and April to July precipitation diminishes moving south across the region.

The average maximum ambient temperatures for the canola growing season followed the expected pattern across the region of increasing from northwest to southeast, a result of both latitude and elevation differences (Fig. 3). For example, the average maximum ambient temperature during the April through July period was 26.3°C at Colby (elevation 966 m) compared with 24.8°C at Akron (elevation 1384 m). A similar pattern exists across the region for average number of days



**Fig. 3. Geographic distribution of average (1993–2008) growing season (April–July) maximum ambient temperature and number of days with maximum temperature >30°C (1 June–15 July) across the central Great Plains region.**

from 1 June to 15 July with a maximum temperature >30°C (<20 d at Sidney and >30 d at Walsh). The pattern indicates the increasing potential for yields to be reduced because of high ambient temperatures during flowering, pod development, and seed formation moving from northwest to southeast. The average maximum temperature in June was 26.8°C in Sidney (elevation 1315 m) and 30.1°C at Garden City (elevation 866 m) (data not shown).

Under all four levels of PAW at planting, a similar pattern of simulated mean canola yields was seen across the region (Fig. 4), presumably primarily in response to the precipitation and temperature gradients described above. Yields were lowest at Walsh and increased with distance moving northeast until just east of the Nebraska border, where a yield plateau was simulated between Colby and Tribune, KS. Because of this pattern, mean yields at Akron and Stratton were nearly the same, and mean yields at Tribune and Colby were not greatly different from one another. The mean canola yield simulated for Akron with 50% PAW (90 mm in the 0–120-cm profile) at planting was 1050 kg ha<sup>-1</sup>, only 8% less than the average yield of 1140 kg ha<sup>-1</sup> that Nielsen (1997) estimated using a production function based only on crop water use and assuming 102 mm of soil water extraction. The greatest mean yields under all four starting PAW levels were always simulated at Champion. The simulated mean yields with 25% PAW at planting ranged from 450 kg ha<sup>-1</sup> at Walsh to 1230 kg ha<sup>-1</sup> at Champion (see also the dashed lines in the box plots in Fig. 5). With 100% PAW at planting, the simulated mean yields ranged from 1150 at Walsh to 1800 kg ha<sup>-1</sup> at Champion. Linear regression analysis of the effect of PAW at planting on canola yields showed slopes ranging from 4.39 kg ha<sup>-1</sup> mm<sup>-1</sup> at Champion to 6.07 kg ha<sup>-1</sup> mm<sup>-1</sup> at Colby, but the slopes were not different among locations ( $P = 0.68$ ). Averaged across locations, the yield increase with increasing PAW at planting was 5.31 kg ha<sup>-1</sup> mm<sup>-1</sup> ( $P < 0.01$ ). These results confirm the important management recommendation for farmers in the semiarid central Great Plains to use no-till systems to increase precipitation storage efficiency and maximize dryland crop

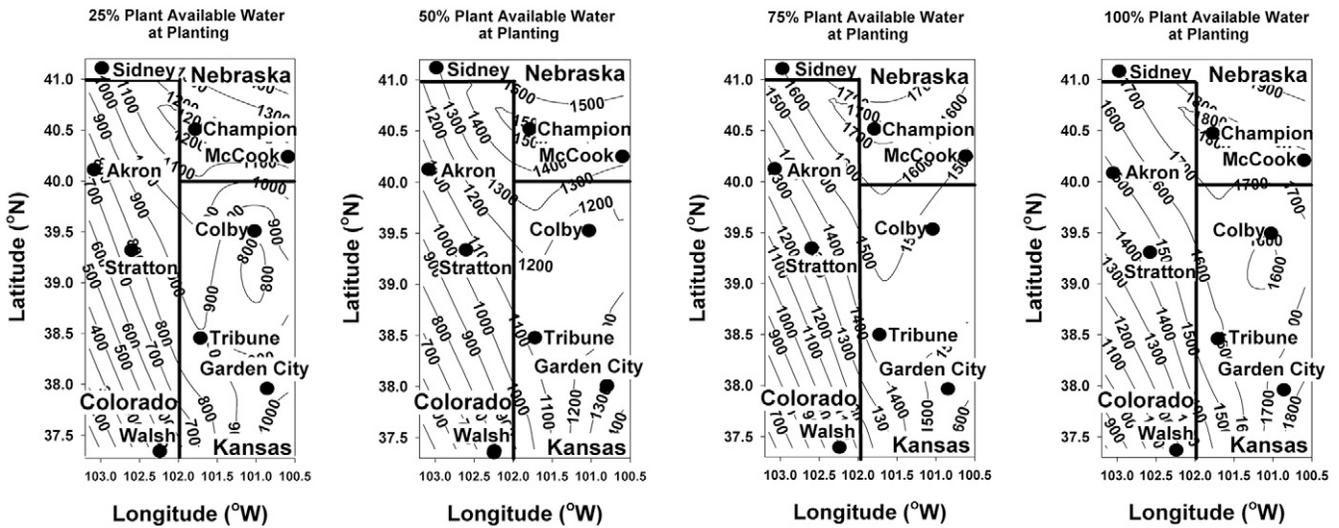


Fig. 4. Geographical distribution of average simulated canola yields ( $\text{kg ha}^{-1}$  at  $100 \text{ g kg}^{-1}$  moisture content) across the central Great Plains region for four levels of plant-available water at planting. Yields were simulated with CROPGRO-canola in the Root Zone Water Quality Model (RZWQM2) using weather data from 1993 to 2008.

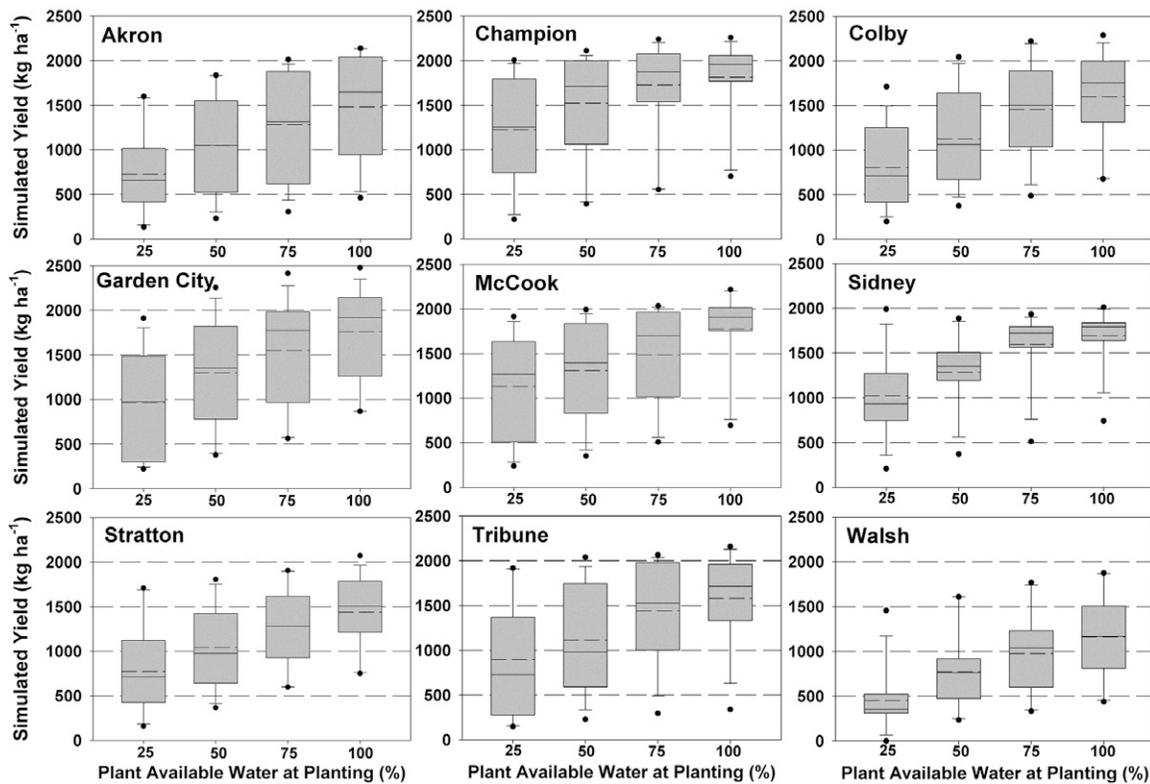
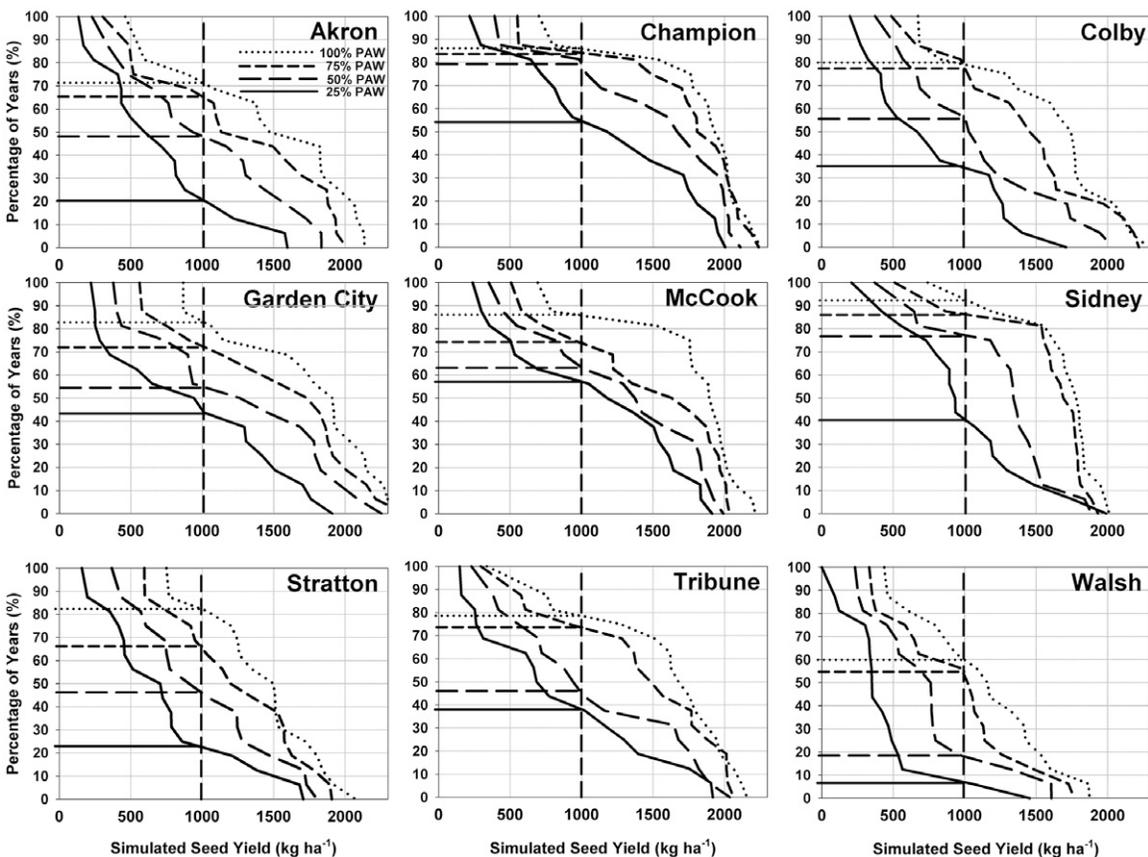


Fig. 5. Box plots of simulated canola yield distribution ( $\text{kg ha}^{-1}$  at  $100 \text{ g kg}^{-1}$  moisture content) for nine central Great Plains locations. Yields were simulated with CROPGRO-canola in the Root Zone Water Quality Model (RZWQM2) using weather data from 1993 to 2008 and four plant-available water contents at planting. The box boundary closest to zero indicates the 25th percentile, the solid line within the box marks the median, the dashed line within the box marks the mean, the box boundary farthest from zero indicates the 75th percentile, the whiskers below and above the box indicate the 10th and 90th percentiles, and the dots below and above the whiskers indicate the minimum and maximum values.

yields (Nielsen and Vigil, 2010; Nielsen et al., 2005). The distributions of mean yields across the region for each of the four PAW levels at planting (Fig. 4) indicate that, regardless of starting PAW, the range of yields due to weather differences at various locations is about  $1000 \text{ kg ha}^{-1}$ .

Many studies including those in Iran (Hokmalipour et al., 2011), North Dakota (Johnson et al., 1995), and Turkey (Ozer,

2003) have indicated declining spring canola yields with delayed planting date. A study in western Nebraska (Pavlista et al., 2011), however, found a 60% yield decline when canola was planted on 21 April vs. 7 April in 1 yr but no yield reduction between the two planting dates in the second year of the study. Because we used the same planting date (8 April) at all nine locations, it is possible that the simulated yields at Tribune, Garden City, and



**Fig. 6.** Cumulative probability distributions of simulated canola yield ( $\text{kg ha}^{-1}$  at  $100 \text{ g kg}^{-1}$  moisture content) for nine central Great Plains locations. Yields were simulated with CROPGRO-canola in the Root Zone Water Quality Model (RZWQM2) using weather data from 1993 to 2008 and four plant-available water (PAW) contents at planting.

Walsh would have been greater if we had used an earlier planting date at those locations, but further studies will be needed to verify the model's ability to accurately simulate planting date effects on spring canola yield across this region.

The model results of simulated yield during the 1993 to 2008 period allow characterization of the yield variability that would be encountered across the region. Box plots of simulated yield for each of the nine locations (Fig. 5) indicate large year-to-year variability in canola yield in response to growing season environmental conditions. The smallest range of simulated yields (difference between maximum and minimum values, dots in box plots) was  $1270 \text{ kg ha}^{-1}$  at Sidney with 100% PAW at planting. The largest range in yield was  $1880 \text{ kg ha}^{-1}$  at Garden City with 50% PAW at planting. There was no consistent change in yield variability with changes in PAW at planting, as noted by the size of boxes (the difference between the yield in the 25th and 75th percentiles) in Fig. 5. For example, yield variability tended to increase with more soil water at planting at Akron and Walsh but decreased with increasing PAW at planting at Champion, Garden City, McCook, and Tribune. Averaged across all four levels of PAW, yield variability (length of box) was greatest at Garden City ( $1030 \text{ kg ha}^{-1}$ ) and least at Sidney ( $310 \text{ kg ha}^{-1}$ ). It is not readily apparent why yield variability would be so different between Sidney and Akron ( $996 \text{ kg ha}^{-1}$ ) because these two locations are only 120 km apart.

Production risk can be assessed across the central Great Plains region through the cumulative probability distribution

graphs (Fig. 6) created by ordering the simulated yields from smallest to largest. For reference, a dashed vertical line indicating the  $1000 \text{ kg ha}^{-1}$  yield appears in each graph. This line indicates a yield slightly greater than the break-even yield ( $910 \text{ kg ha}^{-1}$ ) for the cost and price conditions described below. That line intersects each of the cumulative probability lines at the probability of achieving at least  $1000 \text{ kg ha}^{-1}$  or greater yield. For example, at Akron the probability of achieving at least  $1000 \text{ kg ha}^{-1}$  is 20% with 25% PAW at planting and rises to about 71% with 100% PAW at planting. These probability distributions can be used by farmers as risk assessment tools as they contemplate incorporating canola production into their cropping systems. For any yield that a farmer determines to be his required yield to obtain the desired profit, the appropriate panel of Fig. 6 can be used to determine the probability of obtaining at least that yield at that location with the given moisture condition at planting.

The question might be raised as to which of the four starting soil water contents used in the simulations is most appropriate for a wheat–canola–fallow cropping system. Although we do not have regional starting water content at the beginning of April following wheat harvest the previous July, Nielsen and Vigil (2010) published a 10-yr average volumetric soil water profile on 1 May at Akron, CO, following wheat harvest under no-till fallow management. Applying the  $0.136 \text{ m}^3 \text{ m}^{-3}$  wilting point used in the current simulations to those profile volumetric water contents (averaging  $0.243 \text{ m}^3 \text{ m}^{-3}$ ) gives an average available water value of 128 mm in the 0- to 120-cm

**Table 1. Prices received and costs of production used in economic analysis of canola production in the central Great Plains of the United States.**

Parameter†	Value	Notes
<u>Revenue</u>		
Price received, US\$ kg <sup>-1</sup>	0.53	
<u>Costs</u>		
Seed, US\$ kg <sup>-1</sup>	17.64	7.8 kg ha <sup>-1</sup> planted
N fertilizer, US\$ kg <sup>-1</sup>	1.65	67 kg ha <sup>-1</sup> applied at planting
Glyphosate, US\$ L <sup>-1</sup>	9.51	applied twice, 0.95 L applied each time
Glyphosate application, US\$ ha <sup>-1</sup>	17.29	applied twice
Planting, US\$ ha <sup>-1</sup>	30.88	
Swathing, US\$ ha <sup>-1</sup>	29.64	
Combining, US\$ ha <sup>-1</sup>	86.45	
Combine cost for yield > 1400 kg ha <sup>-1</sup> US\$ (kg ha <sup>-1</sup> ) <sup>-1</sup>	0.0882	
Hauling, US\$ (kg ha <sup>-1</sup> ) <sup>-1</sup>	0.0705	

† Price received was the price quoted by Northern Sun, Division of Archer Daniels Midland Co., Goodland, KS, on 20 Dec. 2011. Seed and fertilizer costs were current values at Akron, CO (Merle F. Vigil, personal communication, 2011). All other costs were obtained from Tranel et al. (2012).

soil profile on 1 May at Akron, CO, or about 72% of field capacity. Consequently, using the simulated yield values generated from the 50 and 75% PAW scenarios is probably most appropriate for the average soil water condition that would be found in a wheat–canola–fallow system. Comparing the cumulative probability distributions (Fig. 6) from the 75% PAW scenarios at the nine locations indicates that the lowest probability of achieving a yield of at least 1000 kg ha<sup>-1</sup> would occur at Walsh (55%), followed by Akron (65%), Stratton (67%), Garden City (72%), Tribune (73%), McCook (74%), Colby (77%), Sidney (86%), and Champion (95%).

An economic analysis for expected net returns was performed using the average simulated yields at each of the nine locations and the price received and costs of production shown in Table 1. Negative net returns were noted for the driest starting PAW condition (25%) at Akron, Colby, Stratton, Tribune, and Walsh and for the 50% PAW condition at Walsh (Table 2). Positive returns were seen for all four PAW conditions at Champion, Garden City, McCook, and Sidney. The most profitable location for canola production based on these simulation results was Champion, NE, with average net returns ranging from US\$165 ha<sup>-1</sup> (25% PAW) to US\$468 ha<sup>-1</sup> (100% PAW). The least profitable location for canola production was Walsh, CO, probably a result of this location's lower annual and growing season precipitation, higher growing season maximum temperatures, and number of days with maximum ambient temperatures >30°C. Net returns at Walsh ranged from a loss of US\$240 ha<sup>-1</sup> (25% PAW) to a profit of US\$131 ha<sup>-1</sup> (100% PAW). Net returns with 75% PAW at planting (the PAW condition closest to the 10-yr average condition following no-till fallow at Akron) ranged from US\$34 ha<sup>-1</sup> at Walsh to US\$423 ha<sup>-1</sup> at Champion. Using this set of input costs and price received, the break-even yield would be 910 kg ha<sup>-1</sup>.

**Table 2. Average (1993–2008) net returns for canola production at nine locations across the central Great Plains of the United States at four levels of plant-available water (PAW) at planting.**

Location	Avg. net return			
	25% PAW	50% PAW	75% PAW	100% PAW
US\$ ha <sup>-1</sup>				
Akron, CO	-97	72	192	297
Champion, NE	165	319	423	468
Colby, KS	-55	111	282	359
Garden City, KS	28	204	333	440
McCook, NE	115	210	298	450
Sidney, NE	58	195	357	406
Stratton, CO	-71	69	192	276
Tribune, KS	8	107	275	347
Walsh, CO	-240	-73	34	131

## CONCLUSIONS

Canola yields simulated by the CROPGRO-canola model used within RZWQM2 followed a regional pattern across the central Great Plains consistent with what would be expected based on precipitation and temperature patterns. Average yields were highest at Champion, NE, in the north-central area and lowest at Walsh, CO, in the south-central area. Simulated yields increased with increasing PAW at planting at an average rate of 5.31 kg ha<sup>-1</sup> mm<sup>-1</sup>.

Variability of dryland canola production is likely to be large, as indicated by the results of these simulations, due to the highly variable nature of precipitation in both amount and timing and due to occurrences of high temperatures throughout the growing season but particularly during the flowering, pod development, and early seed development growth stages that occur during June in this region. Yield variability was simulated to be lowest at Sidney, NE, Stratton, CO, and Walsh, CO, and highest at Akron, CO, Tribune, KS, and Garden City, KS. Yield variability did not consistently change with the amount of PAW across the region.

With 75% PAW at planting, the probability of producing a canola seed yield of at least 1000 kg ha<sup>-1</sup> was >70% at all locations except Stratton (66%), Akron (65%), and Walsh (55%). Average net returns calculated from current prices and costs of production indicate that profitable canola production is possible across a large portion of the central Great Plains. Positive average net returns were estimated for all nine locations with 50% PAW or greater soil water content at planting except at Walsh with 50% PAW. The simulation results presented in this study provide a broad set of data from which farmers, agricultural lenders, and crop insurance providers can make decisions regarding the potential for cropping systems to be diversified in the central Great Plains with the introduction of canola as a crop choice. The model results should be viewed as a first approximation, however, regarding the production potential of canola in the region that quantifies expected relative yield differences due to climate variation. We recommend that field studies be initiated to confirm these model results.

## REFERENCES

- Ahuja, L.R., K.W. Rojas, J.D. Hanson, M.J. Shafer, and L. Ma, editors. 2000. Root Zone Water Quality Model: Modeling management effects on water quality and crop production. Water Resour. Publ., Highlands Ranch, CO.
- Blackshaw, R., E. Johnson, Y. Gan, W. May, D. McAndrew, V. Barthet, et al. 2011. Alternative oilseed crops for biodiesel feedstock on the Canadian prairies. *Can. J. Plant Sci.* 91:889–896. doi:10.4141/cjps2011-002
- Boote, K.J., M.I. Minquez, and F. Sau. 2002. Adapting the CROPGRO legume model to simulate growth of faba bean. *Agron. J.* 94:743–756. doi:10.2134/agronj2002.0743
- Gan, U., S.V. Andgadi, H. Cutforth, D. Potts, V.V. Angadi, and C.L. McDonald. 2004. Canola and mustard response to short periods of temperature and water stress at different developmental stages. *Can. J. Plant Sci.* 84:697–704.
- Hergert, G.W., J. Margheim, A. Pavlista, P. Bergener, D. Lyon, A. Hazen, et al. 2011. Yields and ET of deficit to fully irrigated canola and camelina. In: Proceedings of the 23rd Annual Central Plains Irrigation Conference, Burlington, CO. 22–23 Feb. 2011. Central Plains Irrig. Assoc., Colby, KS. [www.ksre.ksu.edu/irrigate/OOW/P11/Hergert11.pdf](http://www.ksre.ksu.edu/irrigate/OOW/P11/Hergert11.pdf) (accessed 9 Jan. 2012).
- Hokmalipour, S., A. Tobe, B. Jafarzadeh, and M.H. Darbandi. 2011. Study of sowing date on some morphological traits of spring canola (*Brassica napus* L.) cultivars. *World Appl. Sci. J.* 14:531–538.
- Johnson, B., K. McKay, A. Scheiter, B. Hanson, and B. Schatz. 1995. Influence of planting date on canola and crambe production. *J. Prod. Agric.* 8:594–599.
- Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, et al. 2003. The DSSAT cropping system model. *Eur. J. Agron.* 18:235–265. doi:10.1016/S1161-0301(02)00107-7
- Kiniry, J.R., D.J. Major, R.C. Izaurrealde, J.R. Williams, P.W. Gassman, M. Morrison, et al. 1995. EPIC model parameters for cereal, oilseed, and forage crops in the northern Great Plains region. *Can. J. Plant Sci.* 75:679–688. doi:10.4141/cjps95-114
- Kutcher, H.R., J.S. Warland, and S.A. Brandt. 2010. Temperature and precipitation effects on canola yields in Saskatchewan, Canada. *Agric. For. Meteorol.* 150:161–165. doi:10.1016/j.agrformet.2009.09.011
- Martin, D. 2007. Impact of advances in irrigation engineering and management. Paper presented at: The Future of Water Use in Agriculture: 2007 Water Law, Policy and Science Conference, Lincoln, NE. 26–27 Mar. 2007. [watercenter.unl.edu/WaterConference/2007WLPS/PPTs/Martin.pdf](http://watercenter.unl.edu/WaterConference/2007WLPS/PPTs/Martin.pdf) (accessed 31 Dec 2011).
- Nielsen, D.C. 1997. Water use and yield of canola under dryland conditions in the central Great Plains. *J. Prod. Agric.* 10:307–313.
- Nielsen, D.C. 1998. Comparison of three alternative oilseed crops for the central Great Plains. *J. Prod. Agric.* 11:336–341.
- Nielsen, D.C., P.W. Unger, and P.R. Miller. 2005. Efficient water use in dryland cropping systems in the Great Plains. *Agron. J.* 97:364–372. doi:10.2134/agronj2005.0364
- Nielsen, D.C., and M.F. Vigil. 2010. Precipitation storage efficiency during fallow in wheat–fallow systems. *Agron. J.* 102:537–543. doi:10.2134/agronj2009.0348
- Nielsen, D.C., M.F. Vigil, and J.G. Benjamin. 2011. Evaluating decision rules for dryland crop selection. *Field Crops Res.* 120:254–261. doi:10.1016/j.fcr.2010.10.011
- Ozer, H. 2003. Sowing date and nitrogen rate effects on growth, yield and yield components of two summer rapeseed cultivars. *Eur. J. Agron.* 19:453–463. doi:10.1016/S1161-0301(02)00136-3
- Patil, P.D., and S. Deng. 2009. Optimization of biodiesel production from edible and non-edible vegetable oils. *Fuel* 88:1302–1306. doi:10.1016/j.fuel.2009.01.016
- Pavlista, A.D., and D.D. Baltensperger. 2007. Phenology of oilseed crops for biodiesel production in the High Plains. In: J. Janick and A. Whipkey, editors, Issues in new crops and new uses. ASHS Press, Alexandria, VA. p. 60–63.
- Pavlista, A.D., D.K. Santra, T.A. Isbell, D.D. Baltensperger, G.W. Hergert, J. Krall, et al. 2011. Adaptability of irrigated spring canola oil production to the US High Plains. *Ind. Crops Prod.* 33:165–169. doi:10.1016/j.indcrop.2010.10.005
- Saseendran, S.A., D.C. Nielsen, D.J. Lyon, L. Ma, D.G. Felter, D.D. Baltensperger, et al. 2009. Modeling responses of dryland spring triticale, proso millet and foxtail millet to initial soil water in the High Plains. *Field Crops Res.* 113:48–63. doi:10.1016/j.fcr.2009.04.008
- Saseendran, S.A., D.C. Nielsen, L. Ma, and L.R. Ahuja. 2010a. Adapting CROPGRO for simulating spring canola growth with both RZWQM2 and DSSAT4.0. *Agron. J.* 102:1606–1621. doi:10.2134/agronj2010.0277
- Saseendran, S.A., D.C. Nielsen, L. Ma, L.R. Ahuja, and M.F. Vigil. 2010b. Simulating alternative dryland rotational cropping systems in the central Great Plains with RZWQM2. *Agron. J.* 102:1521–1534. doi:10.2134/agronj2010.0141
- Starnes, D.E., A.A. Hamama, and L. Bhardwaj. 1999. Canola oil yield and quality as affected by production practices in Virginia. In: J. Janick, editor, Perspectives on new crops and new uses. ASHS Press, Alexandria, VA. p. 254–256.
- Tranel, J.E., R.L. Sharp, and J. Deering. 2012. Custom rates for Colorado farms and ranches in 2010. Colorado State Univ. Ext., Fort Collins. [www.coopext.colostate.edu/abm/custrates10.pdf](http://www.coopext.colostate.edu/abm/custrates10.pdf) (accessed 7 Feb. 2012).