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^{-1}) at Champion, NE, in the north-central area and lowest (975 kg ha^{-1}) 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^{-1} mm^{-1}. 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 (Starner 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^{-1}) and W is water use or evapotranspiration (mm). The slope of 7.72 kg ha^{-1} mm^{-1} is lower than found for the C_3 grain crop winter wheat (12.49 kg ha^{-1} mm^{-1}) and the C_4 grain crop corn (*Zea mays* L.) (25.67 kg ha^{-1} mm^{-1}) but similar to two other C_3 oilseeds (6.64 kg ha^{-1} mm^{-1} for sunflower [*Helianthus annuus* L.] and 6.53 kg ha^{-1} mm^{-1} 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_3 or C_4) 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^{-1}, with a yield range of 314 to 2643 kg ha^{-1}. 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.

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

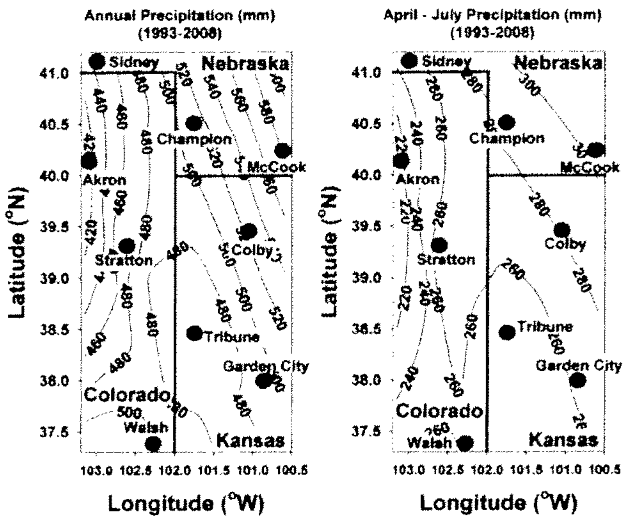

Fig. 2. Geographic distribution of average (1993–2008) annual precipitation and growing season (April–July) precipitation across the central Great Plains region.

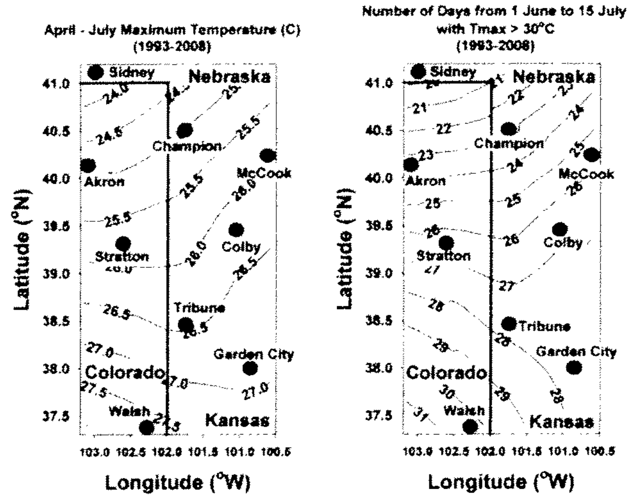

Fig. 3. Geographic distribution of average (1993–2008) growing season (April–July) maximum ambient temperature and number of days with maximum temperature >30°C (1 June–15 July) across the central Great Plains region.

(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 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^{-1}, only 8% less than the average yield of 1140 kg ha^{-1} 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^{-1} at Walsh to 1230 kg ha^{-1} 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^{-1} at Champion. Linear regression analysis of the effect of PAW at planting on canola yields showed slopes ranging from 4.39 kg ha^{-1} mm^{-1} at Champion to 6.07 kg ha^{-1} mm^{-1} 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^{-1} mm^{-1} ($P < 0.01$). 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

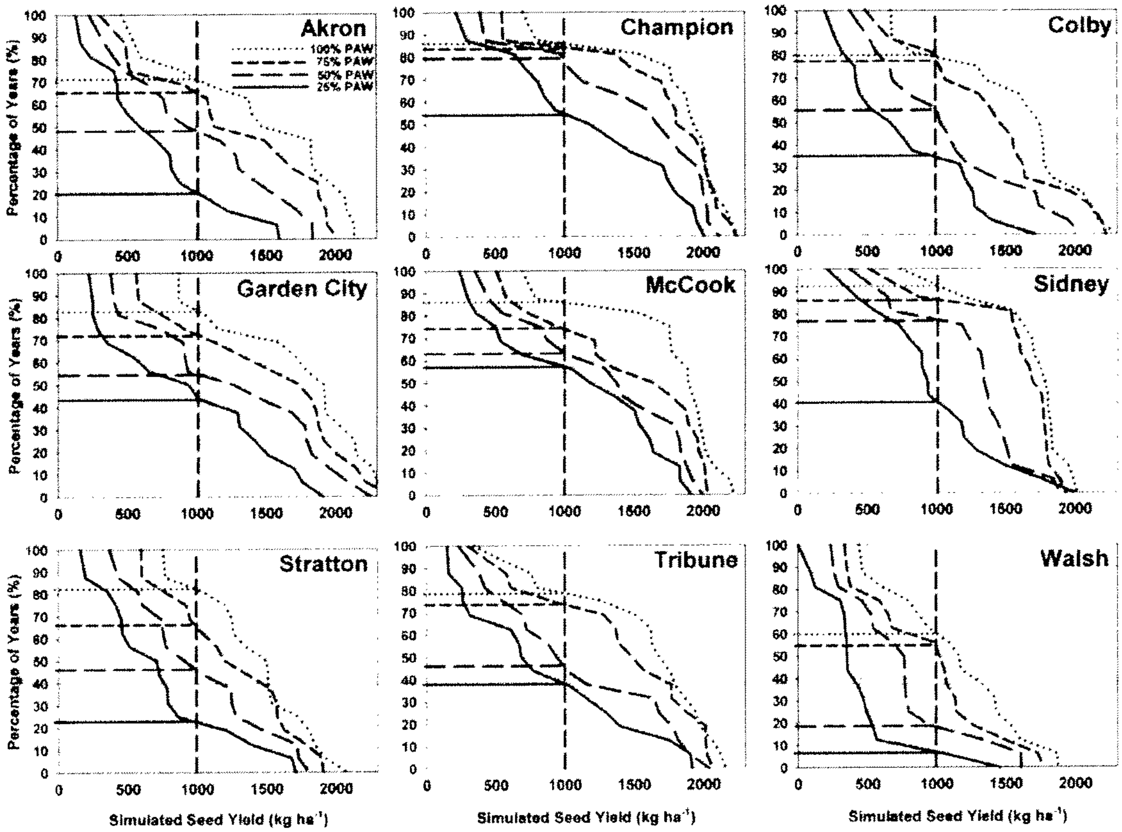

Fig. 6. Cumulative probability distributions of simulated canola yield (kg ha^{-1} at 100 g kg^{-1} moisture content) for nine central Great Plains locations. Yields were simulated with CROPGRO-canola in the Root Zone Water Quality Model (RZWQM2) using weather data from 1993 to 2008 and four plant-available 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 kg ha^{-1} at Sidney with 100% PAW at planting. The largest range in yield was 1880 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 kg ha^{-1}) and least at Sidney (310 kg ha^{-1}). It is not readily apparent why yield variability would be so different between Sidney and Akron (996 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 kg ha^{-1} yield appears in each graph. This line indicates a yield slightly greater than the break-even yield (910 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 kg ha^{-1} or greater yield. For example, at Akron the probability of achieving at least 1000 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 m^3 m^{-3} wilting point used in the current simulations to those profile volumetric water contents (averaging 0.243 m^3 m^{-3}) gives an average available water value of 128 mm in the 0- to 120-cm

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