Simulation Supplements Field Studies to Determine No-Till Dryland Corn Population Recommendations for Semiarid Western Nebraska

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MODELING

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ABSTRACT

In a 2-yr multiple-site field study conducted in western Nebraska during 1999 and 2000, optimum dryland corn (Zea mays L.) population varied from less than 1.7 to more than 5.6 plants m⁻², depending largely on available water resources. The objective of this study was to use a modeling approach to investigate corn population recommendations for a wide range of seasonal variation. A corn growth simulation model (APSIM-maize) was coupled to long-term sequences of historical climatic data from western Nebraska to provide probabilistic estimates of dryland yield for a range of corn populations. Simulated populations ranged from 2 to 5 plants m⁻². Simulations began with one of three levels of available soil water at planting, either 80, 160, or 240 mm in the surface 1.5 m of a loam soil. Gross margins were maximized at 3 plants m⁻² when starting available water was 160 or 240 mm, and the expected probability of a financial loss at this population was reduced from about 10% at 160 mm to 0% at 240 mm. When starting available water was 80 mm, average gross margins were less than $15 ha⁻¹, and risk of financial loss exceeded 40%. Median yields were greatest when starting available soil water was 240 mm. However, perhaps the greater benefit of additional soil water at planting was reduction in the risk of making a financial loss. Dryland corn growers in western Nebraska are advised to use a population of 3 plants m⁻² as a base recommendation.

Water is the most limiting resource for dryland crop growth in the semiarid areas of the U.S. Great Plains (Smika, 1970). Summer fallow, the practice of controlling all plant growth during the noncrop season, is commonly used to stabilize winter wheat (Triticum aestivum L.) production in this region of high environmental variability. Wheat–fallow is the predominate cropping system in the Great Plains, but water storage efficiency during fallow is frequently less than 25% with conventional tillage (McGee et al., 1997). The advent of reduced- and no-till systems has generally enhanced the ability to capture and retain precipitation in the soil during noncrop periods of the cropping cycle, making it more feasible to reduce the frequency of fallow and intensify cropping systems relative to wheat–fallow (Peterson et al., 1996).

In the Great Plains, annual precipitation is concentrated during the warm season from April to September. Hence, inclusion of a summer crop, e.g., corn or grain sorghum [Sorghum bicolor (L.) Moench], in a 3-yr system of wheat–summer crop–fallow increased the efficient use of precipitation by reducing the frequency of summer fallow and using more water for crop transpiration (Farahani et al., 1998). In addition to increased precipitation use efficiency and grain yield, more intensified dryland cropping systems increase potentially active surface soil organic C and N (Peterson et al., 1998), effectively control winter annual grass weeds in winter wheat (Daugaivish et al., 1999), and increase net return and reduce financial risk (Dhuyvetter et al., 1996).

Growers in the semiarid regions of western Nebraska have had limited experience with dryland corn. Before 1997, fewer than 3800 ha of dryland corn were planted each year in the western crop-reporting district. As more growers diversified and intensified their rotations, land planted to corn grew to more than 28 700 ha in 1999 (NASS, 2000). Growers were getting conflicting population recommendations and requested assistance from the University of Nebraska.

Determining population response of corn is a recurrent area of study, with modern hybrids having greater tolerance of high plant density than older hybrids (Tol- lenaar, 1991). In one southwest Kansas study, dryland corn performed best when no-till–planted in early to mid-May at plant populations not exceeding 4.45 plants m⁻² (Norwood and Currie, 1996). A more recent study from this same region achieved maximum yield and water use efficiency with a late May planting, combined with later-maturing hybrids and plant populations up to 6.0 plants m⁻² (Norwood, 2001). However, in northwest Kansas, no yield differences were found for corn populations of 2.1, 2.47, and 3.71 plants m⁻² (Havlin and Lamm, 1988). In a summary of research results from locations across the USA and Canada, corn grain yields leveled off but did not decrease above the optimum plant population, except in those fields with yield levels below 7500 kg ha⁻¹ (Paszkiewicz and Butzen, 2001).

Blumenthal et al. (2003) advised dryland corn growers to use a plant population of 2.7 plants m⁻², based on 2 yr of field research conducted at four locations each year. Unfortunately, summer precipitation was very different between the 2 yr of the study, and often the treatment resulting in the greatest yield in 1 yr provided the least yield in the other year. The standard analysis-of-variance approach used in that study did not allow for a satisfactory assessment of the production risks associated with the various population treatments.

Crop modeling has been a developing component of agronomic research for more than 30 yr (Sinclair and Seligman, 1996). Crop models have been successfully used to analyze management practice in regions where


a highly variable environment results in increased riskiness of production decisions (Meinke et al., 1993; Muchow et al., 1994). The effects of plant population on corn yields were simulated for semiarid areas of eastern Kenya using CERES-Maize (Keating et al., 1990). The Agricultural Production Systems Simulator (APSIM) is a comprehensive cropping-systems modeling platform (Keating et al., 2003), which incorporates a generic crop model template (Wang et al., 2002) that underpins a broad range of crop models. Production risk analyses based on simulation studies using APSIM have been used to link research with change in management practices via various participatory methods (Hammer et al., 1996a; Nelson et al., 2002). The APSIM-maize model has been used to examine risks associated with viability of cropping in northern Australia (Carberry et al., 1996).

The objective of this study was to use a modeling approach to investigate corn population recommendations for a wide range in seasonal variation. A corn growth simulation model (APSIM-maize) was coupled with long-term sequences of historical climatic data to provide probabilistic estimates of dryland yield for a range of corn populations. The insights gained by this approach may be used to supplement the recommendations made by Blumenthal et al. (2003) for semiarid western Nebraska.

**MATERIALS AND METHODS**

Experimental data from corn population by N rate field studies, conducted at the High Plains Agricultural Laboratory near Sidney, NE (41°12’ N, 103°0’ W), in 1999 and 2000 (Blumenthal et al., 2003) were used to validate the crop model. Seasonal precipitation in 1999 was near the 50-yr average for Sidney, but precipitation from flowering through early grain fill (mid-July through August) was in the top 20% of years. The 2000 season was extremely dry, with only one season in the previous 50 yr being drier. Average monthly temperatures were near normal for both growing seasons. Climatic data for the other sites in the study were collected at the nearest automated weather stations, which were as much as 30 km from a given study site. These data, particularly the precipitation data, were deemed to be insufficiently representative to allow for their use in model validation.

![Fig. 1. Observed vs. predicted corn grain yields at Sidney, NE, in 1999 and 2000. A N supply of 125 kg ha⁻¹ was used for the simulation, which was similar to the N available in the zero N rate treatment from the 1999 and 2000 field studies. Bars indicate ± 1 standard deviation from the mean.](image)

![Fig. 2. Simulated corn yield for the 54 yr of historical climate record at Sidney, NE, for a crop planted at a population of 3 plants m⁻² each year on 5 May with 160 mm of available soil water and 125 kg N ha⁻¹.](image)
The model required input data on soil characteristics, crop management, and cultivar attributes such as maturity. Details on inputs for relevant soil and crop modules have been reported by Keating et al. (2003). Soil parameters to be used with APSIM were obtained for a Duroc loam (fine-silty, mixed, superactive, mesic Pachic Haplustoll) from the Cheyenne County Soil Survey (USDA-NRCS, 1997). Drained upper limits and lower limits for each depth increment were set, within the limits of the soil, to best simulate results from 1999. These same values were then tested against the 2000 field data and found to provide an acceptable simulation. Similarly, input specifications for crop maturity were fitted to results from 1999 and then tested against the 2000 field data.

Once tested, the APSIM-maize model was run using long-term climatic data and a range of planting densities. Daily temperature and precipitation data were available for Sidney and North Platte (41°37’ N, 100°40’ W), NE, for 54 yr and for Harrisburg (41°37’ N, 103°57’ W), NE, for 92 yr. Daily radiation data were only available for 20 yr at Sidney. Long-term daily radiation data, where missing, were generated with RadEst 3.00 software using the Campbell–Donatelli model (Donatelli et al., 2003). The simulations were conducted for an early maturing cultivar with phenology characteristics similar to ‘Pioneer 3893’, the cultivar used in the field studies by Blumenthal et al. (2003). Corn crops were simulated at established plant populations of 2, 3, 4, and 5 plants m⁻². Simulations were started 5 May of each year when corn was planted into 4000 kg ha⁻¹ wheat residue. Grain yields were output at a 150 g kg⁻¹ moisture content basis. Management, and cultivar attributes such as maturity. Details on inputs for relevant soil and crop modules have been reported by Keating et al. (2003). Soil parameters to be used with APSIM were obtained for a Duroc loam (fine-silty, mixed, superactive, mesic Pachic Haplustoll) from the Cheyenne County Soil Survey (USDA-NRCS, 1997). Drained upper limits and lower limits for each depth increment were set, within the limits of the soil, to best simulate results from 1999. These same values were then tested against the 2000 field data and found to provide an acceptable simulation. Similarly, input specifications for crop maturity were fitted to results from 1999 and then tested against the 2000 field data.

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Hammer et al. (1996b) for wheat in Australia. At planting, maximum median yield was 5030 kg ha$^{-1}$ and was achieved at a population of 4 plants m$^{-2}$. At any given quantity of initial available soil water, the effect of increasing population from 2 to 5 plants m$^{-2}$ was to increase the variability in yield outcomes over time, in other words, to increase production risk. Although median yield was increased at all populations as available soil water at planting was increased from 160 to 240 mm, perhaps the greater effect of increased water supply at planting was to reduce production risk (Fig. 3).

Average profits at Sidney were maximized at 3 plants m$^{-2}$, with profits of $127.04 and $181.13 ha$^{-1}$ when available soil water at planting was 160 or 240 mm, respectively (Fig. 4). In addition to maximizing average profits at a population of 3 plants m$^{-2}$, the number of years in which financial loss occurred, i.e., the risk of loss, was less at this population than at greater populations. Growers are likely to accept the very small increase in risk of loss that occurred as population was increased from 2 to 3 plants m$^{-2}$ to capture increased average profits of about $24.58 and $58.98 ha$^{-1}$ at 160 and 240 mm of available soil water at planting, respectively (Fig. 4). With 80 mm of available water at planting, maximum average profit was $14.98 ha$^{-1}$ at 2 plants m$^{-2}$. The risk of a financial loss was 43%. Hence, planting corn when available soil water at planting is ≤80 mm is not advisable.

In western Nebraska, average precipitation declines from east to west. This is caused by the rain shadow.
effect of the Rocky Mountains where elevations exceed 4200 m. The effect of summer precipitation on population recommendations was investigated by using long-term historical climate data from Harrisburg, Sidney, and North Platte, NE. Full-season (planting to physiological maturity) precipitation averaged 216, 283, and 317 mm at Harrisburg, Sidney, and North Platte, respectively (Fig. 5). Postflower (flowering to physiological maturity) precipitation at these three sites averaged 48, 67, and 78 mm, respectively. In general, average profit was reduced and risk of loss increased from North Platte in the east to Harrisburg in the west (Fig. 6).

At North Platte, with available soil water at planting of 160 mm, average profit was maximized at $177.70 ha$^{-1}$ with a population of 4 plants m$^{-2}$. Risk of loss was 4%. At Sidney, 3 plants m$^{-2}$ maximized average profit at $127.04$ ha$^{-1}$ with an 11% risk of economic loss. Average profit was maximized at Harrisburg at $83.74$ with a population of 2 plants m$^{-2}$. As previously discussed for Sidney, median yields increased and risk of economic loss decreased at all locations as soil water at planting increased. With 240 mm of available soil water at planting, average profits were maximized at Harrisburg, Sidney, and North Platte at populations of 3, 3, and 4 plants ha$^{-1}$, respectively. When available soil water at planting was 80 mm, average profits at Harrisburg were negative at all populations, and risk of loss exceeded 73%. At North Platte, average profits were maximized at $55.84$ ha$^{-1}$ with 3 plants ha$^{-1}$, but risk of economic loss was 32%. Planting corn when soil water at planting is $\leq 80$ mm is not advised at any of the sites in this study.

Using data from seven site-year combinations collected in 1999 and 2000, Blumenthal et al. (2003) advised western Nebraska corn growers to use a population of 2.7 plants m$^{-2}$. However, in this semiarid environment, with its high rainfall variability, seven site-year combinations do not provide sufficient information to assess the effect that management decisions have on production and economic risks. Coupling a crop growth simulation model to long-term sequences of climatic data provides probabilistic estimates of yield for a range of seasons and is a good way to supplement findings from short-term field studies (Muchow et al., 1994). Although the use of this approach has not resulted in a distinctly different population recommendation than made by Blumenthal et al. (2003), it has provided a more complete understanding of the risks associated with the plant population decision. It has also highlighted the importance of knowing the amount of available soil water at planting when making the decision about population.

Growers who have only recently incorporated corn into their dryland rotations have tended to use a popula-
Fig. 6. Average profit vs. risk of making a loss for a range of fixed corn populations (2–5 plants m$^{-2}$) with 160 mm of available soil water at planting. Profit and risk data were derived from simulated corn yields for the 54 yr of historical climate record at Sidney and North Platte, NE, and the 92-yr record at Harrisburg, NE.

Selection of the appropriate population for any given year could be greatly enhanced by access to skillful seasonal forecasts. The Southern Oscillation Index phase system (Stone and Auliciems, 1992; CINRS, 2002) has shown promise for use in tactical management of crops in northeastern Australia, a region of extremely variable climate (Hammer et al., 1996b.). However, use of the Southern Oscillation Index phase system did not appear to provide significant skill for forecasting in western Nebraska (data not shown). This lack of skill may be due to variability in the intensity of the teleconnection of the El Niño–Southern Oscillation with summer rainfall in the central United States (Hu and Feng, 2001). With improvement in skill of seasonal forecasts in the central United States, it may be feasible to alter corn population to fit a specific seasonal forecast. Until that time, however, no-till dryland corn growers in western Nebraska are advised to use a population of 3 plants m$^{-2}$ as a base recommendation. Adjustments to this base recommendation of about 1 plant m$^{-2}$ may be made in response to available soil water at planting; amount and quality of crop residue; changes in corn and/or seed prices; average seasonal precipitation relative to Sidney, NE; and the grower’s attitude to risk. The estimates of yield probabilities presented in this paper can help dryland corn growers in semiarid regions of western Nebraska with this decision-making process.

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Fig. 7. Simulated gross margins obtained at a population of 3 plants m\(^{-2}\) minus simulated gross margins obtained at a population of 4 plants m\(^{-2}\) for a crop planted each year on 5 May with 160 mm available soil water and 125 kg N ha\(^{-1}\) and for the 54-yr record of historical climate record at Sidney, NE.

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