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Optimal Plant Population and Nitrogen Fertility for Dryland Corn in Western Nebraska

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Water is the most limiting resource for dryland crop growth in semiarid areas of the U.S. Great Plains. Summer fallow, the practice of controlling all plant growth during the noncrop summer season, was quickly adopted to stabilize winter wheat production in the region. Wheat–fallow is the predominate cropping system in the Great Plains, but water storage efficiency during fallow is frequently less than 25 percent with conventional tillage. The advent of reduced- and no-till systems has greatly enhanced the ability to capture and retain precipitation in the soil during noncrop periods, making it possible to reduce the frequency of fallow and intensify cropping systems relative to wheat–fallow.

Nearly 75 percent of annual precipitation in the Great Plains occurs from April to September. Therefore, inclusion of a summer crop, e.g. corn or grain sorghum, in a three-year system of wheat–summer crop-fallow increases the efficient use of precipitation by reducing the frequency of summer fallow and using more water for crop transpiration. In addition to increased precipitation use efficiency and grain yield, more intensified dryland cropping systems increase potentially active surface soil organic C and N, effectively control winter annual grass weeds in winter wheat, increase net return and reduce financial risk.

Growers in Nebraska's panhandle have limited experience with dryland corn. Before 1997, fewer than 3,800 ha of dryland corn were planted each year. As more growers diversified and intensified rotations, land planted to corn grew to over 38,800 ha in 2000.

In one southwest Kansas study, dryland corn performed best when no-till-planted in early to mid-May at plant populations not exceeding 44,500 plants ha^{-1}. 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 60,000 plants ha^{-1}. However, in northwest Kansas, no yield differences were found for corn populations of 21,000, 24,700 and 37,100 plants ha^{-1}. In a summary of research results from locations across the U.S. and Canada, corn grain yields leveled off but did not decrease above the optimum plant population, except in fields with yield levels below 7,500 kg ha^{-1}. Modern hybrids typically have a greater tolerance of high plant density than older hybrids.

Nitrogen fertilizer recommendations for corn in Nebraska are based predominately on work conducted with irrigation in the central and eastern areas of the state where corn is extensively grown. As dryland corn production moves westward, the validity of the current algorithm for determining N rate recommendations in corn is questioned. In eastern Colorado, dryland corn grown in a no-till winter wheat–corn–fallow rotation averaged 4,520 kg ha^{-1} grain and required 1.1 kg N ha^{-1} uptake to produce 63 kg ha^{-1} grain. A study in 1994 found that in eastern Colorado, between 67 and 90 kg N ha^{-1} should be applied to corn grown in a no-till spring barley-corn rotation.

The objectives of this study were to determine proper plant population and N recommendations for dryland corn grown in western Nebraska.

Materials and Methods

Field studies were conducted in 1999 and 2000 at four Nebraska panhandle locations in each year. The experimental design was a randomized complete block with five replicate blocks per site. Factorial treatments were five corn plant populations and five N fertilizer rates. Corn was no-till–seeded in 76-cm rows into winter wheat or proso millet stubble at a rate of 103,000 seed ha^{-1}, and about three weeks after emergence, plants were thinned to densities of 17,300, 27,200, 37,100, 46,900 and 56,800 plants ha^{-1}. Ammonium nitrate was applied surface-broadcast after corn planting, but before emergence, at rates of 0, 34, 67, 101 and 134 kg N ha^{-1}. Plot size was 3 by 9.1 m.

Gravimetric soil water content was determined by collecting 10 soil cores per site just before planting in 0.3-m increments to a depth of 1.2 m. Before planting, soil samples were taken in depth increments of 0 to 20 cm for determination of organic matter, pH, Bray-P1 P, and residual soil NO_3-N content and 20 to 61 cm and 61 to 122 cm for determination of residual soil NO_3-N content according to recommended soil test procedures for corn in Nebraska. Soil analyses were performed according to recommended chemical soil test procedures for the North-Central U.S.

Six of the eight sites were on producer fields and managed by the producers. Weed control decisions were discussed with the producers, but they used their best judgment. In a couple of instances, hand weeding was performed to eliminate small weed patches.

Grain was harvested mechanically from the middle two rows of each four-row plot for a total harvest area of 13.6 m^2. Grain test weight and moisture were determined along with sample weight. Sample weights were adjusted to a 150 g kg^{-1} moisture content basis.

Seasonal rainfall was recorded at the Cheyenne County site in both years. On-site rainfall was collected at the other three sites in 2000. In 1999, rainfall data from the nearest automated weather station were used. These weather stations were as much as 30 km from a given site, and the data, particularly precipitation data, should be used with caution.

The data were analyzed two ways: first by standard analysis of variance for multi-environment trials, as described in the next paragraph, and subsequently by more in-depth analysis using environmental indices to quantify dependence of population effects on quality of environment. Data from the 2000 Banner County site were not used because the error variance was more than 10-fold smaller than for any other site-year combination. Sources of variation were environment, block within environment, population and fertilizer main effects, population x fertilizer interaction, experimental (between environment) error, and sampling (within environment) error. Because environments represented a target population of inference, they were considered random effects. Population effects were decomposed into contrasts to compare population densities of 17,300 vs. 27,200 plants ha^{-1}, for which previous experience suggested increases in yield should be observed, and among densities ≥ 27,200 plants ha^{-1}. The among densities ≥ 27,200 plants ha^{-1} comparisons were further decomposed into linear and nonlinear components to address questions concerning the effect, if any, of increased population density above 27,200 plants ha^{-1} on yield.

Aspects of the population effects appeared to depend on environment. Because standard analysis of variance lacks the power and sensitivity to adequately quantify this dependence, further analysis was computed to characterize the impact of environment on treatment effects. The procedure that was used defined the mean yield of an environment as the "environmental index" and then characterized yield as a function of separate regression over environmental quality for each treatment. SAS PROC MIXED was used for this analysis, with population as the treatment effect and the population effect decomposed into a 17,300 vs. 27,200 contrast and a linear above 27,200 contrast. Thus, for the analysis, the contrast effects change for a given environmental index according to the equation:

Effect at environmental index = main effect + regression coefficient x environmental index

Results and Discussion

With the exception of the Box Butte County site, summer precipitation was very different between the two years of the study, particularly during the grain fill period of late July and August. Soil water at planting also varied between the two years and between sites within the same year. With above-average August precipitation in 1999, average grain yields for the Banner, Box Butte, Cheyenne and Kimball County sites were 4,860, 2,920, 5,550 and 1,640 kg ha^{-1}, respectively. In 2000, when August precipitation was below average, grain yield averages were 93, 3,180, 2,180 and 1,220 kg ha^{-1} for the Banner, Box Butte, Cheyenne and Kimball County sites, respectively.

A large portion of potential dryland corn yields was captured in the seven environments in this analysis. Although this degree of variability results in some difficulties with data interpretation, it accurately represents the situation of the dryland farmer in western Nebraska who makes plant population and fertilizer decisions in a highly variable climate.

Plant Population. There was a significant interaction between computed environmental indices and the contrast comparing population densities of 17,300 and 27,200 plants ha^{-1} ($P \leq 0.001$). Yield changes from 17,300 to 27,200 plants ha^{-1} were estimated using the following function:

Yield = -642 + 0.32 x environmental index [1]

Kimball County in 2000 was the lowest-yielding environment analyzed in this study, with an environmental index of 1,220 kg ha^{-1}. Equation [1] predicts that, on average, yield decreased 249 kg ha^{-1} as population increased from 17,300 to 27,200 plants ha^{-1}. However, at Cheyenne County in 1999 (environmental index = 5550 kg ha^{-1}), Eq. [1] predicts yield increased 1,150 kg ha^{-1} with increasing population from 17,300 to 27,200 plants ha^{-1}. The breakeven environmental index, i.e., the environmental index at the point where the effect is 0, was estimated at 1,980 kg ha^{-1}. Yield increases, therefore, are anticipated as population is increased from 17,300 to 27,200 plants ha^{-1} if site productivity exceeds 1,980 kg ha^{-1}, as it did at five of seven environments in this study. Yield decreases are expected over this same population range when site yields are less than 1,980 kg ha^{-1}, e.g. Kimball County in 1999 and 2000. Yield decreases at these two environments were relatively small compared with the magnitude of yield increases estimated at the other environments.

There was a significant interaction between the environmental indices and the linear component of the contrast comparing among population densities ≥ 27,200 plants ha^{-1} ($P \leq 0.001$). Slope parameters were estimated using the following function:

Slope = -0.068 + 0.0000275 x environmental index [2]

Again, using Kimball County 2000 to represent the lowest-yielding environment, the estimate for linear slope above 27,200 plants ha^{-1} was -0.0349 kg ha^{-1} for each additional plant per hectare. At

Cheyenne County in 1999, the slope was estimated at 0.0844 kg ha^{-1}. Environments with indices above 2,480 kg ha^{-1} should benefit from population density increases above 27,200 plants ha^{-1}. Three of the seven environments in this study had environmental indices below 2,480 kg ha^{-1}, and yield at these sites declined as population density rose above 27,200 plants ha^{-1}. Although significant yield increases occurred in several environments as population increased above 27,200 plants ha^{-1}, a nearly equal number of cases saw significant yield decreases.

Use of environmental indices highlights that the response of grain yield to plant population is affected by the environment's influence on productivity. However, our ability to estimate the productivity of a site at, or before, planting is poor. Soil water at planting does not appear to be a good predictor of yield, e.g. soil water levels at planting at the Cheyenne County site were very similar in 1999 and 2000, but average yields in 2000 were less than 40 percent of 1999 yields. Research in northeast Colorado suggests that precipitation from July 15 through Aug. 25, or from flowering through early grain fill, can explain as much as 70 percent of the yield variation in dryland corn. Unfortunately, we are unable to accurately predict July and August precipitation at planting time.

Averaged across all environments, yield increased 353 kg ha^{-1} with increasing population from 17,300 to 27,200 plants ha^{-1}. In fields that yielded less than 1,980 kg ha^{-1}, yields did not increase with increasing population from 17,300 to 27,200 plants ha^{-1}. If the productivity at a site was greater than 2,480 kg ha^{-1}, then increasing the population above 27,200 plants ha^{-1} may further increase yield.

In a two-year study conducted in the U.S. Corn Belt, there was no yield penalty for planting above the optimum plant population, except at yield levels below 7,500 kg ha^{-1}. This flat yield response as population increased above the optimum allows growers in the Corn Belt to select planting rates on the high side to allow the crop to take full advantage of favorable conditions, knowing that with less favorable weather, the only loss is the extra seed cost. However, given the lower yield potential of dryland corn in western Nebraska than in the U.S. Corn Belt, seed costs have a proportionately larger effect on profitability than in more productive regions. Dryland corn growers in western Nebraska are advised to plant for an expected harvest population of 27,200 plants ha^{-1} and only increase above this level if they are willing to accept the greater risks.

Nitrogen Fertility. Nitrogen fertilization increased corn yields at six of eight sites. There was no interaction between plant population and fertilization rates. Two quadratic relationships, one for a plant population of 17,300 and one for plant populations >27,200, described corn yield as a function of N available before crop emergence. The two regression equations vary only in their intercept terms. Therefore, available soil NO_3 plus fertilizer N for maximum yield and economic optimal fertilizer rate were independent of plant population. Applying standard mathematical procedures, we determined that yields were maximized by 202 kg N ha^{-1} in the form of soil NO_3–N and fertilizer N available before crop emergence. Fertilizer N requirement for economic optimal yields with maximum return to fertilization were determined according to the following equation:

$$N_{fert.} = \frac{(10.6 \times P_{corn} - P_{fert.})}{(0.0526 \times P_{corn})} - N_{soil} \qquad [3]$$

where P_{corn} and P_{fert} are corn and fertilizer price (\$ kg^{-1}), respectively, N_{soil} is soil test NO_3–N (kg ha^{-1}) as determined by preplant soil test in a 0- to 120-cm soil sample, and $N_{fert.}$ is economic optimal fertilizer rate (kg ha^{-1}). Under the current price scenario (\$0.44 kg^{-1} N and \$0.08 kg^{-1} corn), 97 kg N ha^{-1} derived from soil and fertilizer N would be necessary to produce economic optimal yields. In a 1994 study on dryland corn grown in Colorado, an N supply of about 190 kg N ha^{-1} was needed to produce 95 percent of maximum yield, defined as the economic optimal yield level. The discrepancy between these values and those determined in our study most likely has two reasons: (1) corn yields we observed were, on average, 40 percent lower than the earlier study, likely the result of our more severe moisture constraints and lower heat unit accumulation associated with increased latitude and (2) corn and fertilizer price relationships were not considered in the earlier study.

Nitrogen fertilizer recommendations for corn in humid environments or under irrigation commonly do not expressively include corn–fertilizer price relationships. The reason for this is that the relationship between corn yield and available N is very steep, and changes in the corn/fertilizer price ratio affect economic optimal fertilization under these conditions very little. For dryland corn grown in a semiarid environment, however, the relationship between yield and available N is rather flat; therefore, changes in the corn/fertilizer price ratio have greater impact on economic optimal fertilization. As an example, corn prices varied between \$0.069 and \$ 0.127 kg^{-1} from 1995 to 2000. Assuming a fertilizer price of \$0.44 kg^{-1} N and applying the above equation, 80 kg N ha^{-1} derived from soil and fertilizer N would be necessary to produce economic optimal yields at the lowest corn price for this period and 135 kg N ha^{-1} at the high corn price, respectively.

Conclusions

Our results document the tremendous variability in dryland corn grain yields in western Nebraska. Over the long run, our results suggest that dryland corn growers in western Nebraska would optimize yield and profitability by choosing a population of about 27,200 plants ha^{-1}. Improved ability to estimate potential yield at planting may allow growers to adjust plant populations to take advantage of productive environments and protect against loss in unproductive ones. Economic optimal N fertilizer rate did not depend on plant population. Estimating economic optimal N fertilizer rate requires a preplant soil test in addition to fertilizer and corn prices.

***Editor's note:** Content was adapted from the paper "Optimal Plant Population and Nitrogen Fertility for Dryland Corn in Western Nebraska," which was published in Agronomy Journal Vol. 95, July-August 2003, and is courtesy of Jürg M. Blumenthal, Drew J. Lyon* and Walter W. Stroup.*

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Optimal Plant Population and Nitrogen Fertility for Dryland Corn in Western Nebraska
March Self-Study Examination

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1. The most limiting resource for dryland crop growth in semiarid regions of the country is:
[ ] a. nitrogen.
[ ] b. phosphorus.
[ ] c. water.
[ ] d. sunlight.

2. With conventional tillage, water storage efficiency during summer fallow is frequently less than:
[ ] a. 25%.
[ ] b. 27%.
[ ] c. 29%.
[ ] d. 30%.

3. Of the annual precipitation in the Great Plains, nearly:
[ ] a. 55% occurs between April and September.
[ ] b. 65% occurs between April and September.
[ ] c. 75% occurs between April and September.
[ ] d. 85% occurs between April and September.

4. The number of hectares planted in corn in western Nebraska from 1997-2000 has increased:
[ ] a. 2 fold.
[ ] b. 5 fold.
[ ] c. 8 fold.
[ ] d. 10 fold.

5. Soil water at planting:
[ ] a. appears to be an excellent predictor of yield.
[ ] b. does not appear to be a good predictor of yield.
[ ] c. is difficult to measure.
[ ] d. is indirectly related to yield.

6. A study in northeastern Colorado suggests that precipitation from mid July through late August can explain as much as:
[ ] a. 60% of the yield variation.
[ ] b. 65% of the yield variation.
[ ] c. 70% of the yield variation.
[ ] d. 75% of the yield variation.

7. Averaged across all environments, as population increased from 17,300 to 27,200 plants ha^{-1}:
[ ] a. yield decreased 353 kg ha^{-1}.
[ ] b. yield decreased 112 kg ha^{-1}.
[ ] c. yield increased 929 kg ha^{-1}.
[ ] d. yield increased 353 kg ha^{-1}.

8. Nitrogen fertilization increased corn yields at:
[ ] a. 5 of 8 sites.
[ ] b. 6 of 8 sites.
[ ] c. 7 of 8 sites.
[ ] d. all of the sites.

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9. Results in this study suggest dryland corn growers in western Nebraska would optimize yield and profitability by choosing a population of about:

[ ] a. 25,200 plants ha^{-1}.
[ ] b. 26,200 plants ha^{-1}.
[ ] c. 27,200 plants ha^{-1}.
[ ] d. 28,200 plants ha^{-1}.

10. If the current N fertilizer cost is \$0.39 kg^{-1} N and the current corn price is \$0.09 kg^{-1} corn, then optimal dryland corn yield in western Nebraska should be achieved when soil + fertilizer N is:

[ ] a. 97 kg N ha^{-1}.
[ ] b. 190 kg N ha^{-1}.
[ ] c. 80 kg N ha^{-1}.
[ ] d. 119 kg N ha^{-1}.

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