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

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ABSTRACT

Dryland corn (*Zea mays* L.) production increased more than 10-fold from 1995 through 2000 in semiarid western Nebraska. Corn population and N fertilizer management recommendations are needed for this area. The objectives of this study were to determine the influence of plant population and N fertility on corn yields in semiarid western Nebraska. In 1999 and 2000, experiments were conducted each year at four sites. Factorial experimental treatments were five plant populations (17 300, 27 200, 37 100, 46 900, and 56 800 plants ha^{-1}) and five N fertilizer rates (0, 34, 67, 101, and 134 kg N ha^{-1}) arranged in a randomized complete block with five blocks. Corn yields ranged from less than 100 kg ha^{-1} to more than 5550 kg ha^{-1}. Overall, grain yield increased 353 kg ha^{-1} with increasing population from 17 300 to 27 200 plants ha^{-1}. Population increases above 27 200 plants ha^{-1} resulted in inconsistent yield results. Nitrogen fertilization and plant population effects did not interact. Yields were maximized by 202 kg N ha^{-1} in the form of soil NO_3–N and fertilizer N available before crop emergence. Growers are advised to use a plant population of 27 200 plants ha^{-1}. Economic optimal fertilizer rate can be estimated using the equation: $N_{\text{fert.}} = (10.6 \times P_{\text{corn}} - P_{\text{fert.}})/(0.0526 \times P_{\text{corn}}) - N_{\text{soil}}$, where P_{corn} and $P_{\text{fert.}}$ 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 $N_{\text{fert.}}$ is economic optimal fertilizer rate (kg ha^{-1}).

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 summer season, was quickly adopted to stabilize winter wheat (*Triticum aestivum* L.) production in the region (Haas et al., 1974). 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 greatly enhanced the ability to capture and retain precipitation in the soil during noncrop periods. Increased storage makes it possible to reduce the frequency of fallow and intensify cropping systems relative to wheat–fallow (Peterson et al., 1996).

Nearly 75% of annual precipitation in the Great Plains occurs from April to September; therefore, 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 increases 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 (Wood et al., 1990; Pikul and Aase, 1995; Peterson et al., 1998), effectively control winter annual grass weeds in winter wheat (Daugovish et al., 1999), and increase net return and reduce financial risk (Dhuyvetter et al., 1996).

Growers in the Panhandle of Nebraska have limited experience with dryland corn. Before 1997, fewer than 3800 ha of dryland corn were planted each year. As more growers diversified and intensified their rotations, land planted to corn grew to more than 38 800 ha in 2000 (NASS, 2001).

Determining corn plant population response is a recurrent area of study. 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} (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 60 000 plants ha^{-1} (Norwood, 2001). However, in northwest Kansas, no yield differences were found for corn populations of 21 000, 24 700, and 37 100 plants ha^{-1} (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). Modern hybrids typically have a greater tolerance of high plant density than older hybrids (Tollenaar, 1991).

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 4520 kg ha^{-1} grain and required 1.1 kg N ha^{-1} uptake to produce 63 kg ha^{-1} grain (Kolberg et al., 1996). Halvorson and Reule (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 (*Hordeum vulgare* L.)–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 (Table 1). The experimental design was a randomized complete block with five replicate blocks per site. Factorial treatments were five corn

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Table 1. Site description for each of the eight Nebraska Panhandle corn experiments.

Site	Year	Soil classification	Lat., long.	Elevation
				m
Banner County	1999	Tripp very fine sandy loam (Aridic Haplustoll)	41°34′59″ N, −103°27′7″ W	1260
Box Butte County	1999	Creighton very fine sandy loam (Aridic Haplustoll)	42°9′25″ N, −103°12′29″ W	1310
Cheyenne County	1999	Duroc loam (Pachic Haplustoll)	41°13′52″ N, −103°1′12″ W	1310
Kimball County	1999	Rosebud loam (Calcidic Argiustoll)	41°7′55″ N, −103°44′31″ W	1520
Banner County	2000	Tripp very fine sandy loam (Aridic Haplustoll)	41°35′6″ N, −103°27′14″ W	1260
Box Butte County	2000	Alliance loam (Aridic Argiustoll)	42°8′49″ N, −103°11′2″ W	1310
Cheyenne County	2000	Keith silt loam (Aridic Argiustoll)	41°14′6″ N, −103°1′1″ W	1310
Kimball County	2000	Tripp loam (Aridic Haplustoll)	41°18′25″ N, −103°54′4″ W	1520

plant populations and five N fertilizer rates. Corn, ‘Pioneer 3893’, was no-till–seeded in 76-cm rows into winter wheat or proso millet (*Panicum miliaceum* L.) stubble at a rate of 103 000 seed ha^{-1}, and about 3 wk 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 and bulking 10 soil cores per site taken just before planting in 0.3-m increments to a depth of 1.2 m (Table 2). 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 (Shapiro et al., 2001). Soil analyses were performed at the University of Nebraska Soil and Plant Analysis Laboratory, Lincoln, NE, according to the recommended chemical soil test procedures for the North-Central region of the USA (Anonymous, 1998) (Table 3).

Six of the eight sites were located on producer fields and were managed by the producers. Weed control decisions were discussed with the producers, but they used their best judgment when making weed control decisions. 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 multienvironment 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 in the analysis 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 × fertilizer interaction, experimental (between environment) error, and sampling (within environment) error. Because environments represented a target population of inference, they were considered random effects. The analysis was computed using SAS PROC MIXED (SAS Inst., 1999) using the model and procedures described by Littell et al. (1996, p. 78 and 83–85). 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 $\geq$27 200 plants ha^{-1}. The among densities $\geq$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. Fertilizer effects were partitioned in linear, quadratic, cubic, etc., polynomial regression effects. Fertilizer rates for maximum yield and for economic optimum yield were calculated as described by Black (1993).

Table 2. Gravimetric soil water content in the surface 1.2 m of soil at planting for each of the eight Nebraska Panhandle corn experiments.

	Gravimetric soil water content	
Site	1999	2000
	kg kg^{-1}	
Banner County	0.141†	0.086
Box Butte County	0.093†	0.153
Cheyenne County	0.175	0.177
Kimball County	0.174‡	0.188

† Gravimetric soil water content determined for the surface 0.9 m of soil at planting because of dry soil conditions that prevented deeper core collection.

‡ Gravimetric soil water content determined for the surface 0.3 m of soil at planting because of a shallow soil profile.

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 using an adaptation of a method suggested by Eberhart and Russell (1966) to characterize the impact of environment on treatment effects. The Eberhart–Russell procedure defined the mean yield of an environment as the “environmental index” and then characterized yield as a function of separate regression over environmental quality, as measured by the index, for each treatment. Littell et al. (2002) demonstrate how to implement this analysis using SAS PROC MIXED. This procedure was used for this analysis,

Table 3. Soil chemical properties for each of the eight Nebraska Panhandle corn experiments.†

Site	pH	Organic matter	NO$_3$–N	Bray P-1
		g kg^{-1}	mg kg^{-1}	
		1999		
Banner County	6.9	12	2.37	36.3
Box Butte County	6.8	11.1	2.26	16.9
Cheyenne County	6.4	31.6	5.38	7.2
Kimball County	7	12.4	6.67	30.1
		2000		
Banner County	6.1	14.9	1.08	30.1
Box Butte County	6.6	11.7	1.91	16.2
Cheyenne County	6.5	22.4	5.49	27.8
Kimball County	6.3	8.5	0.73	24.6

† Test results for organic matter, pH, and Bray P-1 in the 0–20 cm depth and NO$_3$–N in the 0–120 cm depth, except for the Kimball County site in 1999 where soil depth only allowed sampling to a maximum depth of 30 cm.

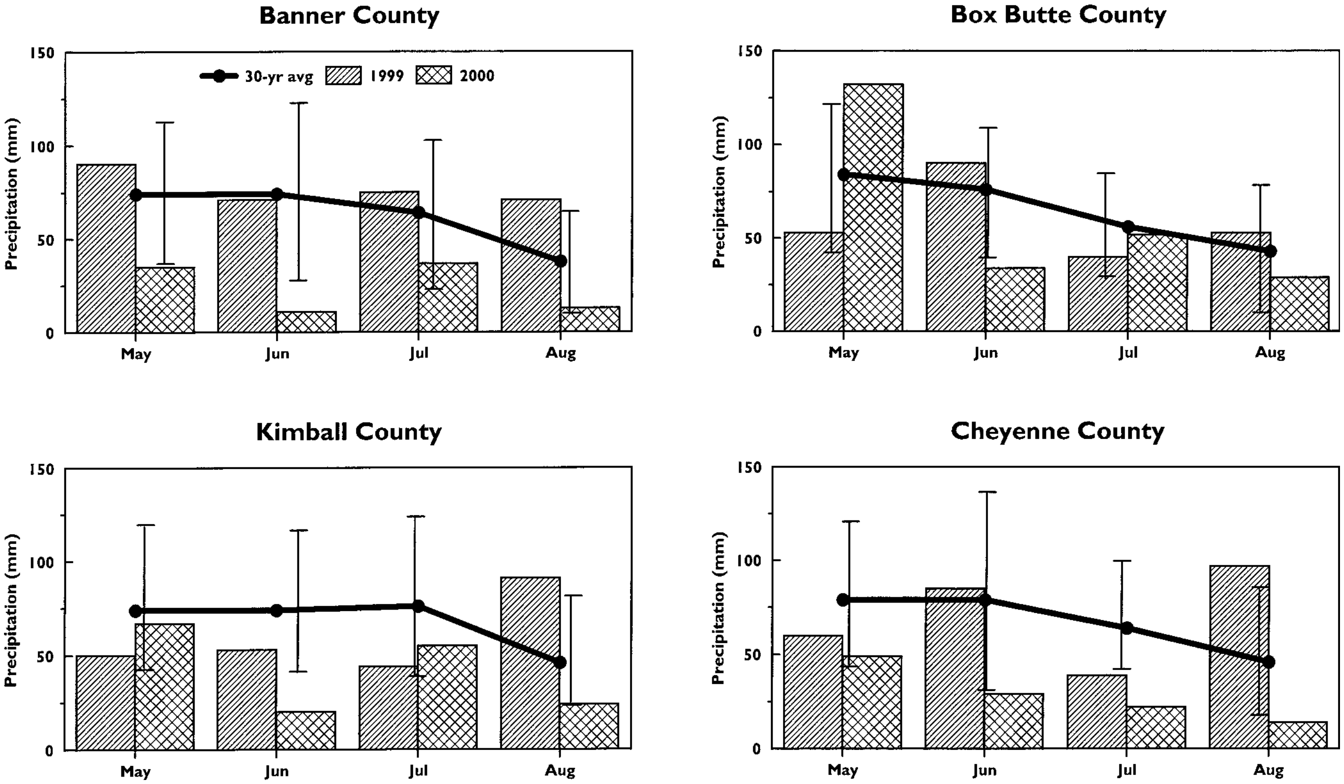

Fig. 1. Monthly (May through August) precipitation at the Banner, Box Butte, Cheyenne, and Kimball County sites in 1999 and 2000. Area within the bars represent + or − one standard deviation from the 30-yr (1961–1990) average monthly precipitation.

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:

$$\text{Effect at environmental index} = \text{main effect} + \text{regression coefficient} \times \text{environmental index}$$

RESULTS AND DISCUSSION

With the exception of the Box Butte County site, summer precipitation was very different between the 2 yr of the study, particularly during the grain fill period of late July and August (Fig. 1). Soil water at planting also varied between the 2 yr and between sites within the same year (Table 2). With above-average August precipitation in 1999, average grain yield for the Banner, Box Butte, Cheyenne, and Kimball County sites were 4860, 2920, 5550, and 1640 kg ha^{-1}, respectively. In 2000, when August precipitation was below average, grain yield averages were 93, 3180, 2180, and 1220 kg ha^{-1} for the Banner, Box Butte, Cheyenne, and Kimball County sites, respectively.

A large portion of the potential dryland corn yields for the region was captured within the seven environments used 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 has to make plant population and fertilizer decisions in a highly variable climate.

Plant Population

Linear relationship between plant population and corn yields for each environment are shown in Fig. 2. 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:

$$\text{Yield} = -642 + 0.32 \times \text{environmental index} \quad [1]$$

Kimball County in 2000 was the lowest-yielding environment analyzed in this study, with an environmental index of 1220 kg ha^{-1} (Table 4). 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 1150 kg ha^{-1} with increasing population from 17 300 to 27 200 plants ha^{-1}. The break-even environmental index, i.e., the environmental index at the point where the effect is 0, was estimated at 1980 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 1980 kg ha^{-1}, as it did at five of seven environments in this study (Table 4). Yield decreases are expected over this same population range when site yields are less than 1980 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 (Table 4).

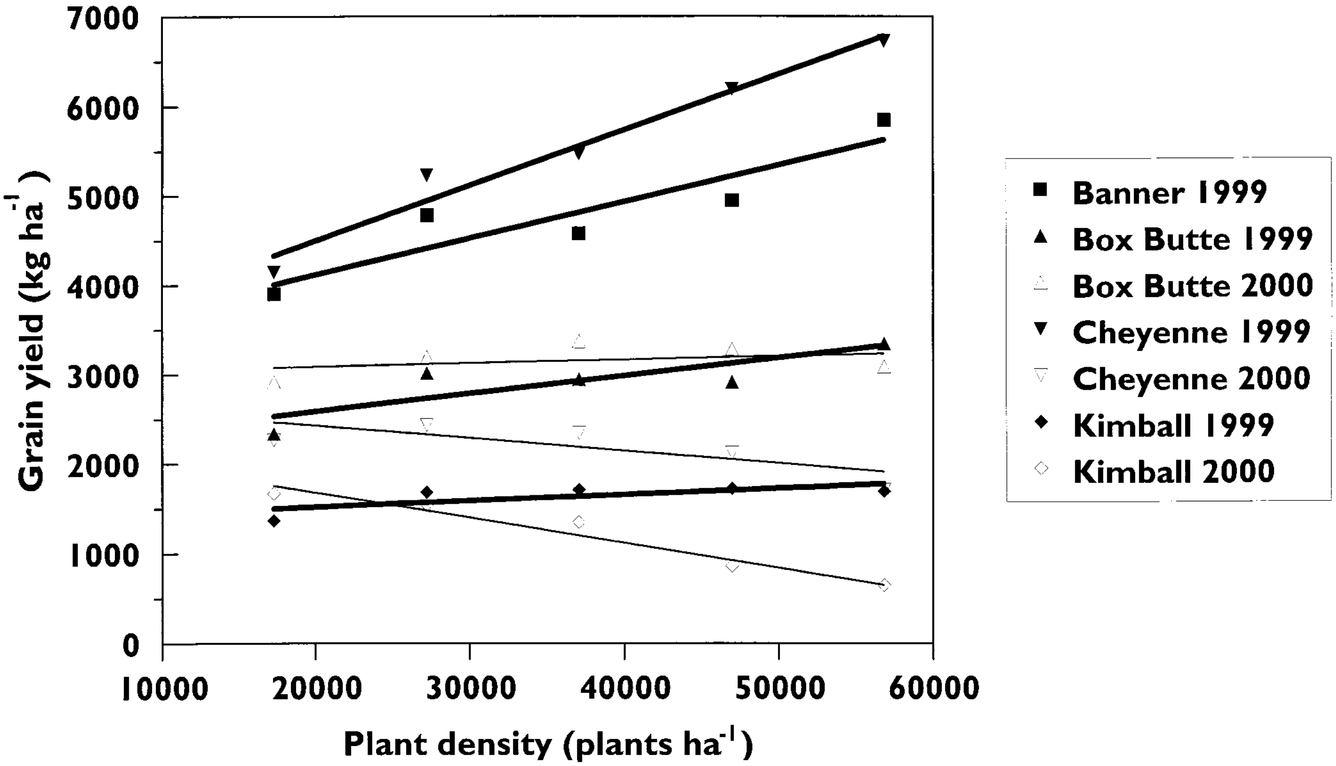

Fig. 2. Linear relationships between corn yields and plant populations at the Banner County site in 1999 and Box Butte, Cheyenne, and Kimball County sites in 1999 and 2000. At each environment, yield data were averaged over fertilizer N treatments as there was no interaction between the population and the fertilizer effect ($P > 0.05$).

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:

$$\text{Slope} = -0.068 + 0.0000275 \times \text{environmental index} \quad [2]$$

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 (Table 4). At Cheyenne County in 1999, the slope was estimated at 0.0844 kg ha^{-1}. Those environments with indices greater than 2480 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 less than 2480 kg ha^{-1}, and yield at these sites was reduced as population density increased above 27 200 plants ha^{-1} (Table 4). Although significant yield increases occurred in several environments as population was increased above 27 200 plants ha^{-1}, in a nearly equal number of cases, significant yield decreases occurred.

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 (Table 2), but average yields in 2000 were less than 40% of 1999 yields. Research in northeast Colorado suggests that precipitation during the 6 wk from 15 July through 25 August, or from flowering through early grain fill, can explain as much as 70% of the yield variation in dryland corn (D. Nielsen,

Table 4. Environmental indices and estimates of the effects of plant population density on yield at seven site-year combinations (environments) in western Nebraska in 1999 and 2000.

		Population increase from 17 300 to 27 200 plants ha^{-1}		Population increase above 27 200 plants ha^{-1}	
Environment	Environmental index†	Est. yield change	SE (estimate)	Est. yield change/ additional plant ha^{-1}	SE (estimate)
County and year	kg ha^{-1}			kg ha^{-1}	
Banner 1999	4860	929	79.5	0.0652	0.0051
Box Butte 1999	2920	301	51.1	0.0118	0.0033
Box Butte 2000	3180	385	51.0	0.019	0.0032
Cheyenne 1999	5550	1150	98.8	0.0844	0.0063
Cheyenne 2000	2180	62	59.1	−0.0084	0.0038
Kimball 1999	1640	−112	70.2	−0.0232	0.0045
Kimball 2000	1220	−249	80.8	−0.0349	0.0052
Average	3080	353	50.8	0.0163	0.0032

† Mean yield of an environment.

personal communication, 2001). 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 1980 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 2480 kg ha^{-1}, then increasing the population above 27 200 plants ha^{-1} may further increase yield.

In a 2-yr 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 7500 kg ha^{-1} (Paszkiewicz and Butzen, 2001). 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 (Hoeft et al., 2000). 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 affect 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 associated with that decision.

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 (Fig. 3). 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. Using the relationship in Fig. 3 and applying standard mathematical procedures as described by Black (1993), 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. Applying standard procedures as described by Black (1993), fertilizer N requirement for economic optimal yields with maximum return to fertilization were determined according to the following equation:

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

where P_{corn} and $P_{\text{fert.}}$ 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 $N_{\text{fert.}}$ 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. Halvorson and Reule (1994) reported for a study on dryland corn grown in Colorado that a N supply of about 190 kg N ha^{-1} was needed to produce 95% of maximum yield, which they defined as the economic optimal yield level. The discrepancy between these val-

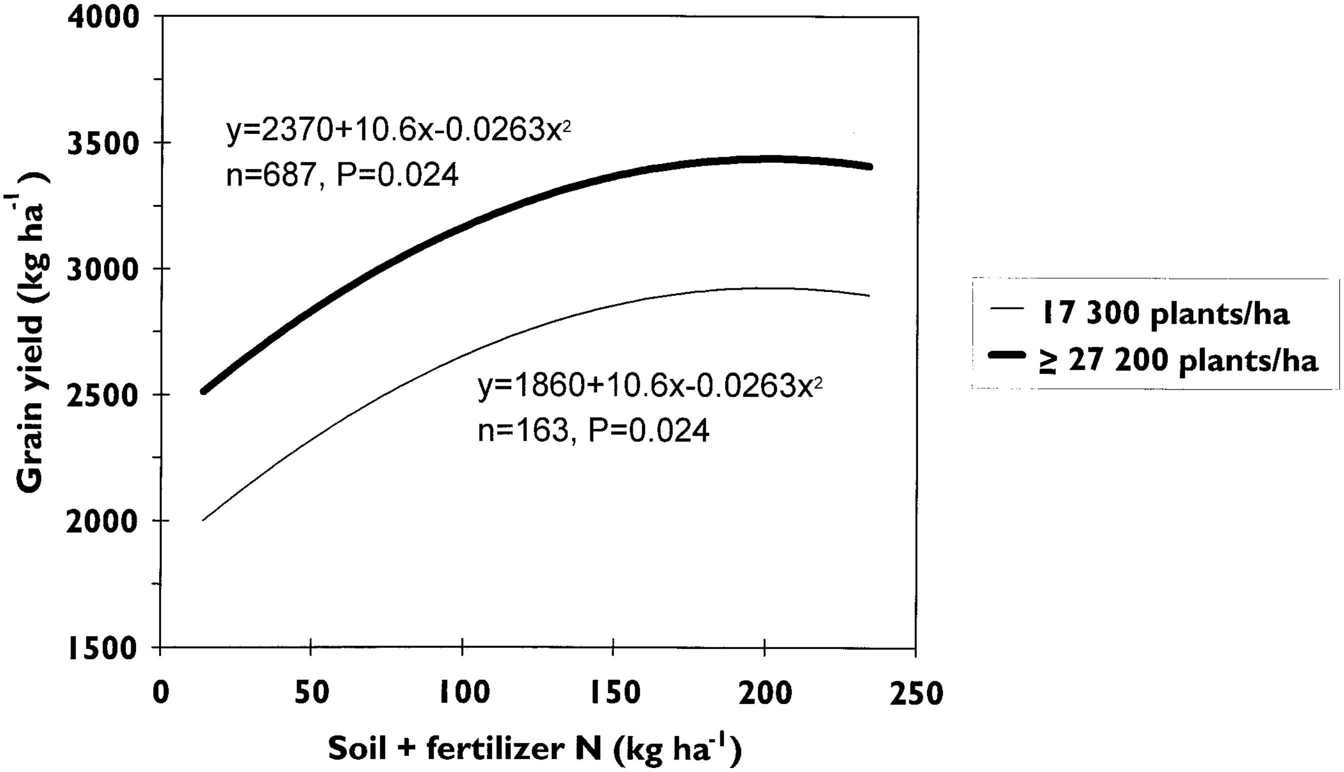

Fig. 3. Relationship between available N before crop emergence (soil test N measured to a depth of 120 cm and N from fertilizer) and dryland corn yield in western Nebraska in 1999 and 2000.

ues and the values determined in our study most likely have two reasons: (i) the corn yields we observed were, on average, 40% lower than theirs, likely the result of our more severe moisture constraints and lower heat unit accumulation associated with increased latitude and (ii) corn and fertilizer price relationships were not considered in their study.

Nitrogen fertilizer recommendations for corn grown in humid environments or under irrigation commonly do not expressively include corn–fertilizer price relationships (Shapiro et al., 2001). 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 (C. Shapiro, personal communication, 2001). For dryland corn grown in a semiarid environment, however, the relationship between corn yield and available N is rather flat (Halvorson and Reule, 1994); therefore, changes in the corn/fertilizer price ratio have a more profound impact on economic optimal fertilization. As an example, corn prices varied between \$0.069 and \$ 0.127 kg^{-1} over the period from 1995–2000 (NASS, 2001). 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 grain yield and profitability by choosing a plant population of about 27 200 plants ha^{-1}. Improved ability to estimate potential grain yield at planting may allow growers to adjust plant populations to take advantage of productive environments and protect against loss in unproductive environments. 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.

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