No-Till Dryland Sugarbeet Production in Semi-Arid Western Nebraska

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ABSTRACT

Sugarbeet (*Beta vulgaris L.*)is a common irrigated crop in the Nebraska Panhandle, eastern Colorado and Wyoming. There are occasions when it is difficult for growers to locate landlords willing to rent irrigated land for sugarbeet production. Although non-irrigated land may be available for rent, there is no history of dryland sugarbeet yields or production practices in this region. The primary objectives of this study were to determine yield potential and optimum plant population for no-till dryland sugarbeet. Field studies using no-till and glyphosate-tolerant sugarbeets were conducted at 10 dryland sites in the Nebraska Panhandle from 2008 through 2010. Mean root yields averaged across varieties ranged from 14.7 to 58.7 Mg ha^{-1}, with regression analysis predicting a maximum root yield of 43.5 Mg ha^{-1} at a plant density of 5.93 plants m^{-2}. Mean sugar concentrations ranged from 140 to 214 g kg^{-1}, and generally increased as plant population density increased. Mean sugar yields ranged from 2.3 to 9.52 Mg ha^{-1}, with regression analysis predicting a maximum sugar yield of 7.82 Mg ha^{-1} at a plant density of 6.24 plants m^{-2}. No-till, dryland sugarbeet production appears to be feasible in semi-arid western Nebraska.

Additional Key Words: *Beta vulgaris*

Irrigation is used for almost all sugarbeet production in the U.S.A. west of Longitude 100° W, where annual precipitation generally falls below 500 mm and climate is characterized as semi-arid or arid. Management practices for irrigated sugarbeet production have been well researched in the western U.S., including the Nebraska Panhandle, northeast Colorado and southeast Wyoming (Wilson et al. 2001).

Most growers in this region produce sugarbeet under contract with a cooperative. Growers are typically obligated to deliver sugarbeet roots from the number of irrigated hectares in their contract. Failure to deliver contracted production may result in a financial penalty. In 2007 and 2008, high prices for other commodities relative to sugarbeet made it difficult for some growers to rent sufficient irrigated land to meet their contracted production. At that point in time, the sugarbeet industry questioned whether some contracts could be fulfilled by producing sugarbeet on nonirrigated land (dryland). No research existed on the potential for dryland sugarbeet production in this or a similar climatic region.

The commercial introduction and industry acceptance of glyphosate-tolerant sugarbeet in 2008 made no-till sugarbeet production a possibility. No-till management maintains crop residues on the soil surface, which increases water storage efficiency (Peterson and Westfall 2004, Nielsen and Vigil 2010) and protects the soil from the erosive effects of water (Dickey et al. 1983) and wind (Fryrear 1995). Dryland farmers in the semiarid Central Great Plains have been able to intensify their winter wheat-fallow cropping systems by using no-till management to store more water in the soil between crops (Lyon and Peterson 2005).

A number of field studies have been conducted to determine the optimum plant density for irrigated sugarbeet using conventional tillage systems. Yonts and Smith (1997) found sugar yield in western Nebraska was maximized when using a 56 cm row width and when plant densities were between 40,000 and 100,000 plants ha^{-1}. Robinson and Worker (1969) investigated square spacing of sugarbeet in California and found sugar yield was maximized at a plant density of 100,000 plants ha^{-1}. Similarly, Parashar and Dastane (1973) in northern India found sugar yield was maximized at a plant density of 100,000 plants ha^{-1}. However, without irrigation in water-short environments such as semiarid western Nebraska, low plant densities are used in many crops to maximize the water available to each plant (Loomis and Conner 1992).

The objectives of this study were to ascertain the yield potential and optimum plant densities for root and sugar yield in dryland no-till production systems for the Nebraska Panhandle. A secondary objective, established in 2009, was to compare two press wheel designs, a solid wheel design and a basket-type design, for plant stand establishment.

MATERIALS AND METHODS

Multiple field studies were conducted each year from 2008 through 2010 for a total of 10 site-years. Two sites each year were located at the University of Nebraska High Plains Agricultural Laboratory (41°14' N, 103°0' W, 1320 m elevation) located near Sidney, NE. The soil type at these six site-years was a Duroc loam (fine-silty, mixed, super-active, mesic Pachic Haplustolls).

An on-farm site was located west of Gurley, NE in 2009 and 2010 (41°20' N, 103°05' W, 1310 m elevation), where the soil was a Kuma loam (fine-silty, mixed, superactive, mesic Pachic Argiustolls) in 2009 and a Duroc loam in 2010. On-farm sites were also located south of Hemingford, NE in 2009 and 2010 (42°15' N, 103°05' W, 1330 m eleva-tion), where the soil was a Rosebud loam (fine-loamy, mixed, superac-tive, mesic Calcidic Argiustolls).

The experimental design was a randomized complete block with six replications and a 2 by 4 factorial treatment arrangement consisting of two sugarbeet cultivars and four target plant population densities. Sugarbeet cultivars in 2008 were Hilleshog 9027RR and the noncom-mercial cultivar Hilleshog 0700601001. These two cultivars were se-lected based on their elongated root shape, which was thought to be beneficial under dryland production conditions. Hilleshog 9024RR and Betaseed 66RR70 cultivars were used in 2009 and 2010. These were two of the most popular cultivars grown in western Nebraska at the time the study was conducted and were thought to have the best over-all yield potential for the area. All cultivars were glyphosate-tolerant. Target plant population densities were 2.47, 4.94, 7.41, and 9.88 plants m^{-2} in 2008. In 2009 and 2010, target plant populations were 1.48, 2.97, 4.45, and 5.93 plants m^{-2}. A 50% emergence rate was used to set the seeding rates.

Planting dates in 2008 were 28 April and 19 May. Planting dates ranged from 29 April to 20 May in 2009 and from 3 to 11 May in 2010. In 2009 and 2010, the first and last planting dates were associated with plots located at Sidney, with the Gurley and Hemingford sites being planted between these two dates. Commercially available seed, in 4M pellet form, was used in all three years. Seed was treated with clothianidin + beta-cyfluthrin insecticides in 2009 and 2010. Plot size was 9.1 by 3 m in 2008 and 12.2 by 3 m in 2009 and 2010. A four-row border was planted around the outside edge of the studies, and alleys were also planted. A Monosem (Monosem Inc., Edwardsville, KS) four-row precision no-till planter with pneumatic meter set at a 76-cm row spacing was used each year at all sites. The planter was equipped with no-till coulters and row cleaners. In 2008, the row cleaners were a fixed design, while in 2009 and 2010 a floating design was used.

In 2009 and 2010, two of four planter rows on one side of the planter were equipped with original paired press wheels that were closer together at the bottom and rear. The other two rows were

equipped with Posi-Close press wheels manufactured by Schlagel Mfg. of Torrington, WY.   These Posi-Close wheels are open, basket-type press wheels designed to leave the surface loose and cloddy to resist soil crusting. The logic for two types of press wheels in 2009 and 2010 was that one press wheel type might minimize soil crusting, which was expected when planting into a wet soil surface condition found under heavy crop residue.

The previous crop was winter wheat at each site for all years. The wheat at Sidney was harvested using a combine with a stripper head, which removed the grain from the head and left the entire wheat stem standing. Most of this standing residue was flattened over the winter by snowfall, which left a heavy and nearly complete ground cover the following spring. The other wheat fields were harvested using combines with a standard cutter-bar type header, which left a shorter standing stubble and spread the cut-off straw and chaff behind the combine.

Eight soil cores were taken from each site prior to planting to ascertain gravimetric soil water and nutrient needs. The cores were divided into 30-cm depth increments to a total depth of 120 cm. Ammonium sulfate was broadcast applied at a rate sufficient for a 34 Mg ha^{-1} yield goal when beet plants had two true leaves fully emerged. Glyphosate was applied for weed control twice per season at each site. The application rate was 1.12 kg ai ha^{-1}. Lambda-cyhalothrin insecticide was applied in 2009 and 2010 at the Sidney sites to control large grasshopper (*Melanoplus* spp.) populations.

Established plant population densities were determined after final emergence, when plants had 4 to 6 true leaves, by counting the number of plants in the entire length of the middle two rows of each plot. Sites were harvested between 21 and 27 October each year. Foliage was mechanically removed immediately prior to machine harvesting the middle two rows of each plot. A harvester-mounted scale was used to measure the pre-wash weight of all harvested roots. Two representative sub-samples of approximately 12 kg each were collected from each plot and sent to Western Sugar Cooperative (Gering, NE) to determine soil tare, sugar concentration, and impurity analyses. Soil tare was deducted from total harvest weight to determine sugarbeet root yield. Sugar yield was estimated by multiplying sugarbeet root yield by sugar concentration within respective plots.

Analyses of variance were performed using the general linear models procedure in SAS (Littell et al. 2002). An α level of 0.05 was used for declaring significant treatment differences. Regression analysis was used to determine yield parameter responses to established plant population density. Linear regression equations were selected unless the quadratic term was significant at an α level of 0.05 and the R^2 was increased by at least 0.05 compared to the linear equation. Maximum predicted root and sugar yields were determined by calculating the first derivative for each regression equation with y = 0. The estimated

Table 1. Monthly precipitation totals, monthly average temperatures, and 30-yr monthly normals (1971-2000) at Sidney, NE for the 2008, 2009, and 2010 growing seasons.

	Precipitation				Temperature			
Month	2008	2009	2010	30-yr avg.	2008	2009	2010	30-yr avg
	mm				*C*			
May	53	39	53	73	11.7	13.3	11.5	12.4
June	63	209	91	68	17.7	17.5	19.3	18.1
July	61	48	72	58	23.5	20.9	22.7	21.6
August	37	61	36	49	21.0	20.1	23.1	20.8
September	50	42	1	34	15.4	15.8	17.4	15.7
October	20	41	22	20	9.1	4.1	11.2	8.5
May - October	284	439	275	303	16.4	15.3	17.5	16.2

Table 2. Gravimetric soil water content by depth, and averaged across depths, prior to planting at each location from 2008 through 2010.

	2008		2009				2010			
Soil depth	Sidney 1	Sidney 2	Sidney 1	Gurley	Hemingford	Sidney 2	Sidney 1	Gurley	Hemingford	Sidney 2
cm					*g g^{-1}*					
0-30	0.227	0.235	0.237	0.227	0.227	0.227	0.245	0.243	0.205	0.233
30-60	0.163	0.185	0.233	0.217	0.250	0.223	0.230	0.230	0.228	0.225
60-90	---[†]	---	0.237	0.187	0.247	0.217	0.250	0.225	0.203	0.213
90-120	---	---	0.140	0.103	0.213	0.130	0.245	0.188	0.180	0.220
0-120	---	---	0.212	0.183	0.234	0.199	0.243	0.221	0.205	0.223

[†] Unable to sample at these soil depths due to very dry soil conditions.

maximum root or sugar yield value was then inserted for x and the equation solved for y to determine the plant density at which maximum yield was predicted.

RESULTS

Western Nebraska is characterized by a highly variable climate. Precipitation and temperature varied considerably among the three years of these field studies. Table 1 presents precipitation and temperature data for Sidney, where an automated weather data network station operated by the High Plains Regional Climate Center in Lincoln, NE was located within 1 km of all Sidney sites. The 2008 season was characterized by slightly below normal precipitation and slightly above normal average temperatures, with the average July temperature being 1.9°C greater than the 30-yr climatic normal temperature. The 2009 season was the wettest of the three seasons, primarily the result of record June rainfall. The 2009 season was also the coolest of the three seasons, with June, July, and August average temperatures being 0.6 to 0.7°C below the 30-yr climatic normal temperatures. The 2010 season started off cool and dry in May, turned wet and warm in June and July, and then turned dry and warm for the remainder of the season.

The nearest weather collection sites to the on-farm experiments were operated by the National Weather Service and were located approximately 8 to 10 km from the Hemingford sites and 15 km from the Gurley sites. The same precipitation and temperature trends described for Sidney were observed at the Gurley and Hemingford sites (data not shown). In 2009, both the Gurley and Hemingford sites experienced a severe hail event in July, which resulted in significant crop defoliation and a probable yield reduction at harvest.

Initial soil water levels were the lowest at the start of the 2008 season, when dry soil conditions prevented soil sampling more than a few cm below the 60-cm depth with a tractor-mounted hydraulic soil probe (Table 2). Except at the Hemingford site, initial soil water levels were greatest in 2010, when gravimetric soil water contents were at least 0.18 g g^{-1} at all four soil depth increments and were frequently near the field capacity (approximately 0.25 g g^{-1}) for all of the soils in this study.

The independent variable for regression analysis was plant population density, which was determined when plants had 4 to 6 true leaves. In 2008, plant population density data were also collected just prior to harvest. Plant population densities averaged 15% greater just prior to harvest than at the 4 to 6 true leaf stage (data not shown). It is not clear if this discrepancy was the result of subsequent plant emergence or counting error, i.e., the difficulty of seeing small seedlings in heavy crop residues.
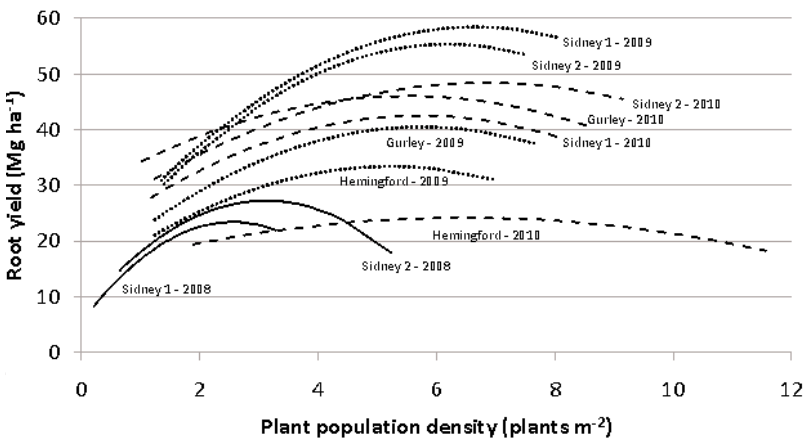
Root yield.

There was a significant site by variety and site by population interaction for root yield. Variety affected root yield at just three of the ten site-years: Sidney 1 in 2009, Sidney 2 in 2010, and Hemingford in 2010. In the overall analyses, there was no significant effect of variety on root yield.

Root yield was affected by plant population at all sites. A quadratic response curve for root yield relative to plant population was the best fit for the data at each location (Table 3, Fig. 1). The greatest root yields

Table 3. Regression equations relating clean root yield in Mg ha^{-1} (y) to plant density in plants m^{-2} (x) at ten sites in the Nebraska Panhandle from 2008 through 2010.

Site-year	Equation	R^2	P-value	n
Sidney 1 - 2008	$y = 5.45 + 14x - 2.74x^2$	0.494	<0.001	48
Sidney 2 - 2008	$y = 7.27 + 12.8x - 2.06x^2$	0.403	<0.001	48
Sidney 1 - 2009	$y = 15.2 + 13x - 0.976x^2$	0.851	<0.001	48
Gurley - 2009	$y = 13.4 + 9.41x - 0.818x^2$	0.676	<0.001	48
Hemingford - 2009	$y = 12.3 + 8.08x - 0.773x^2$	0.724	<0.001	48
Sidney 2 - 2009	$y = 13.5 + 13.5x - 1.09x^2$	0.818	<0.001	48
Sidney 1 - 2010	$y = 19.3 + 8.12x - 0.709x^2$	0.625	<0.001	47
Gurley - 2010	$y = 28.4 + 6.38x - 0.578x^2$	0.214	<0.004	48
Hemingford - 2010	$y = 14.6 + 2.98x - 0.23x^2$	0.271	<0.001	48
Sidney 2 - 2010	$y = 22.7 + 7.53x - 0.55x^2$	0.686	<0.001	46

Figure 1. Response of no-till dryland sugarbeet root yield to established plant population density at ten site-years in western Nebraska from 2008 through 2010. Regression equations for each site-year are provided in Table 3.

were obtained at Sidney in 2009, with maximum root yields estimated at 58.5 and 55.3 Mg ha^{-1} at plant densities of 6.66 and 6.19 plants m^{-2} at Sidney 1 and 2, respectively (Fig. 1). Excellent soil water at planting (Table 2), much above average seasonal precipitation, and growing season temperatures that averaged 0.9°C below the 30-yr normal (Table 1), all contributed to excellent root yields at these two sites.

Maximum estimated root yields were lowest at Sidney in 2008 and at Hemingford in 2010. At Sidney in 2008, maximum root yields were estimated at 23.3 and 27.2 Mg ha^{-1} at plant densities of 2.55 and 3.11 plants m^{-2} at Sidney 1 and 2, respectively. Soil water at planting in 2008 was poor (Table 2), growing season precipitation was below normal, and temperatures were above normal, particularly in July when the average temperature was 1.9°C above the 30-yr normal (Table 1). At Hemingford in 2010, maximum root yield was estimated at 24.3 Mg ha^{-1} at a plant density of 6.48 plants m^{-2}. The reason for this response is not clear. Plant stands at this site were the best of any of the sites, suggesting excellent conditions at planting. Evidently, dry conditions at this site after crop establishment limited root development.

Sugar concentration.
There was a significant site by variety and site by population interaction for sugar concentration. Variety affected sugar concentration at eight of the 10 site-years (data not shown). Variety did not affect sugar concentration at Sidney 1 or 2 in 2009. In 2008, Hilleshog 9027RR and Hilleshog 0700601001 had average sugar concentrations of 166 and 173 g kg^{-1}, respectively. In 2009 and 2010, sugar concentration, averaged across the six site-years where there was a significant effect of variety on sugar concentration, averaged 189 and 183 g kg^{-1} for Hilleshog 9024RR and Betaseed 66RR70, respectively.

Sugar concentration was affected by plant population at all site-years. A linear response for sugar concentration relative to plant population was the best fit for the data at four of the 10 site-years (Table 4, Fig. 2). A quadratic response curve was deemed most appropriate at six of the 10 site-years.

Sugar concentrations were greatest in 2010 (Fig. 2), which was a year with good soil water at planting and generally wet conditions for the first half of the growing season, followed by warm and dry conditions through the second half of the season. The greatest sugar concentrations were at Gurley in 2010, where maximum sugar concentration was estimated to be 216 g kg^{-1} at a plant population density of 7.42 plants m^{-2}. The lowest estimated sugar concentrations occurred in 2009, which was a cool, wet year. In 2009, the lowest estimated sugar concentrations were observed at Sidney, which is also where the greatest root yields were attained (Fig. 1). Sugar concentrations at both Sidney 1 and 2 in 2009 were best described by a linear regression equation (Table 4, Fig. 2), with estimated sugar concentration increasing by 3.33 and 1.73 g kg^{-1} for every 1 plant m^{-2} increase in

plant population density, respectively.

It is interesting to note the relatively large range in sugar concentrations observed over the course of this dryland study. Estimated sugar concentrations varied from a low of 140 g kg^{-1} at the target population of 1.48 plants m^{-2} at Sidney 1 in 2009 to a high of 214 g kg^{-1} at the target population of 5.93 plants m^{-2} at Gurley in 2010. Yonts and Smith (1997) reported sugar concentrations in irrigated sugarbeet that ranged from 149 to 192 g kg^{-1}.

Table 4. Regression equations relating sugar concentration in the root in g kg^{-1} (y) to plant density in plants m^{-2} (x) at ten sites in the Nebraska Panhandle from 2008 through 2010.

Site-year	Equation	R^2	*P*-value	n
Sidney 1 - 2008	$y = 156 + 4.05x$	0.088	0.041	48
Sidney 2 - 2008	$y = 156 + 15.1x - 2.3x^2$	0.255	0.001	48
Sidney 1 - 2009	$y = 135 + 3.33x$	0.646	<0.001	48
Gurley - 2009	$y = 141 + 8.31x - 0.658x^2$	0.721	<0.001	48
Hemingford - 2009	$y = 161 + 1.49x$	0.321	<0.001	48
Sidney 2 - 2009	$y = 144 + 1.73x$	0.456	<0.001	48
Sidney 1 - 2010	$y = 169 + 9.57x - 0.637x^2$	0.713	<0.001	47
Gurley - 2010	$y = 183 + 8.95x - 0.603x^2$	0.483	<0.001	48
Hemingford - 2010	$y = 183 + 3.88x - 0.228x^2$	0.279	0.001	48
Sidney 2 - 2010	$y = 167 + 7.91x - 0.467x^2$	0.589	<0.001	46

Figure 2. Response of no-till dryland sugarbeet sugar concentration to established plant population density at ten site-years in western Nebraska from 2008 through 2010. Regression equations for each site-year are provided in Table 4.
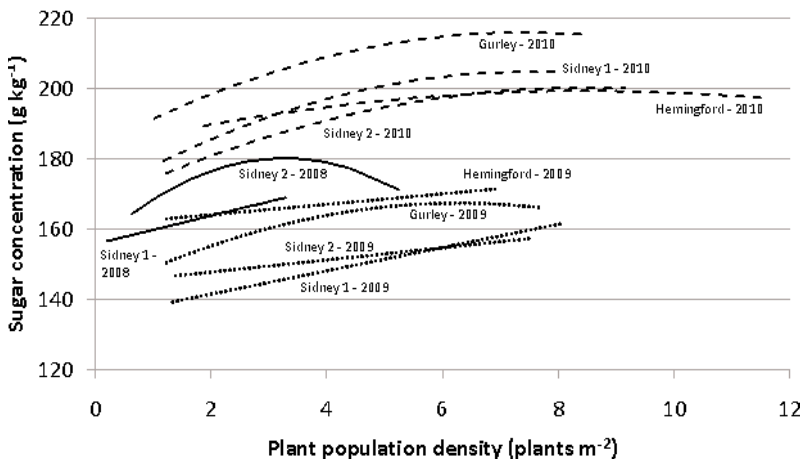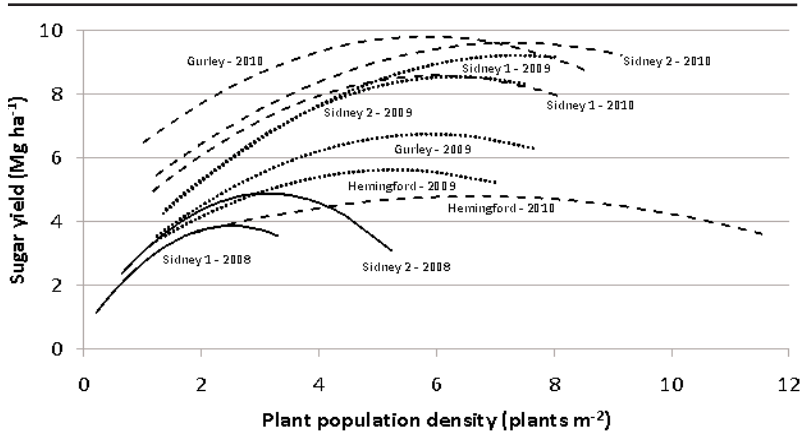
Sugar yield.

Treatment effects on root yield and sugar concentration interact to affect sugar yield. Significant treatment interactions for sugar yield included site by variety, site by population, and site by variety by population. Although variety affected sugar yield at half the study sites, the effect was not consistent across sites and it is difficult to make a recommendation for variety from these data.

As observed for root yield and sugar concentration, sugar yield was

Table 5. Regression equations relating sugar yield in Mg ha^{-1} (y) to plant density in plants m^{-2} (x) at ten sites in the Nebraska Panhandle from 2008 through 2010.

Site-year	Equation	R^2	*P*-value	n
Sidney 1 - 2008	$y = 0.633 + 2.58x - 0.511x^2$	0.516	<0.001	48
Sidney 2 - 2008	$y = 0.897 + 2.55x - 0.408x^2$	0.444	<0.001	48
Sidney 1 - 2009	$y = 1.82 + 2x - 0.135x^2$	0.901	<0.001	48
Gurley - 2009	$y = 1.63 + 1.74x - 0.147x^2$	0.746	<0.001	48
Hemingford - 2009	$y = 1.84 + 1.44x - 0.136x^2$	0.757	<0.001	48
Sidney 2 - 2009	$y = 1.69 + 2.17x - 0.171x^2$	0.818	<0.001	48
Sidney 1 - 2010	$y = 2.99 + 1.86x -0.154x^2$	0.738	<0.001	47
Gurley - 2010	$y = 4.93 + 1.68x - 0.145x^2$	0.371	<0.001	48
Hemingford - 2010	$y = 2.58 + 0.667x - 0.05x^2$	0.321	<0.001	48
Sidney 2 - 2010	$y = 3.61 + 1.65x - 0.113x^2$	0.761	<0.001	46

Figure 3. Response of no-till dryland sugarbeet sugar yield to established plant population density at ten site-years in western Nebraska from 2008 through 2010. Regression equations for each site-year are provided in Table 5.

affected by plant population at all sites. A quadratic response curve for root yield relative to plant population was the best fit for the data at each location (Table 5, Fig. 3). Maximum estimated sugar yields were determined in the same manner described previously for root yield.

The maximum estimated sugar yields were greatest at Sidney 1 in 2009 and at Gurley and Sidney 2 in 2010. Maximum sugar yields were estimated at 9.23, 9.8, and 9.63 Mg ha^{-1} at plant densities of 7.41, 5.79, and 7.3 plants m^{-2} at Sidney 1 in 2009, Gurley in 2010, and Sidney 2 in 2010, respectively. As observed for root yield, the lowest estimated sugar yields were at Sidney in 2008 and at Hemingford in 2010. At Sidney in 2008, maximum sugar yields were estimated at 3.89 and 4.88 Mg ha^{-1} at plant densities of 2.52 and 3.13 plants m^{-2} at Sidney 1 and 2, respectively. At Hemingford in 2010, maximum sugar yield was estimated at 4.8 Mg ha^{-1} at a plant density of 6.67 plants m^{-2}.

Although the generally cool, wet conditions of 2009 (Table 1) resulted in excellent root yields (Fig. 1), the generally warm, dry conditions of late 2010 promoted greater sugar concentrations (Fig. 2). Sugar concentrations averaged 169, 157, and 197 g kg^{-1} in 2008, 2009, and 2010, respectively. The greater sugar concentrations in 2010 increased sugar yields in 2010 relative to 2009 sugar yields, with the exception being at Hemingford.

Press wheels and stand establishment.

There was a significant site by population by press wheel treatment interaction for established plant population. At Gurley in 2009, plant densities were greater in the basket-type press wheel treatment than with the solid press wheel treatment, except at the lowest target population density, where there was no treatment difference. There were no significant population by press wheel treatment interactions at any of the other site-years. Plant densities were greater with the basket-type press wheel than the solid press wheel at all locations. Averaged across all site-years, varieties, and populations, plant densities were 3.94 and 4.74 plants m^{-2} for the solid and basket-type press wheels, respectively.

Of the 10 site-years in this study, surface soil conditions at planting were the wettest at Hemingford in 2009. We observed the greatest difference in plant density between the two press wheel treatments at this site. Averaged across variety and populations, plant densities were 2.4 and 4.4 plants m^{-2} for the solid and basket-type press wheels, respectively. The basket-type press wheel was designed to leave the soil surface loose and cloddy to resist soil surface crusting. Soil crusting can reduce seedling emergence (Durrant et al. 1988). In 2009 and 2010, all the sites had wet surface soil conditions at planting as a result of good spring rainfall and an excellent quantity of winter wheat residue. The basket-type press wheel design was superior to the solid press wheel design under these conditions.

DISCUSSION

Although soil water at planting can be ascertained, our ability to predict seasonal weather is limited. Therefore, we are unable to use individual sites to determine optimum plant population densities to recommend for any given site in some future year. Consequently, we feel that our best recommendations are developed from pooling the data from as many sites as possible.

The data from all 10 site-years were pooled and regression analysis used to estimate root yield response to changes in plant population density. The resulting regression equation: $y = 9.7 + 11.4x - 0.962x^2$ ($R^2 = 0.397$, $P < 0.001$, n = 477), where y = root yield in Mg ha^{-1} and x = plant population density in plants m^{-2}, was used to estimate a maximum root yield of 43.5 Mg ha^{-1} at a plant density of 5.93 plants m^{-2}. Using individual site-year data, the optimum plant density varied from a low of 2.55 plants m^{-2} at Sidney 1 in 2008 to a high of 6.66 plants m^{-2} at Sidney 1 in 2009.

Data from all 10 site-years sites were pooled and regression analysis used to estimate sugar concentration response to changes in plant population density. The relationship was best described by the linear regression equation: $y = 161 + 3.83x$ ($R^2 = 0.155$, $P < 0.001$, n = 477), where y = sugar concentration in g kg^{-1} and x = plant population density in plants m^{-2}. Within the range of plant population densities used in this study, sugar concentration can be expected to increase by about 3.9 g kg^{-1} for every increase in plant population density of 1 plant m^{-2}.

The response curve for the pooled sugar yield data is described by the equation: $y = 1.39 + 2.06x - 0.165x^2$ ($R^2 = 0.448$, $P < 0.001$, n = 477), where y = sugar yield in Mg ha^{-1} and x = plant population density in plants m^{-2}. Using this equation, the maximum sugar yield is estimated to be 7.82 Mg ha^{-1} at a plant density of 6.24 plants m^{-2}, which is 0.31 plants m^{-2} greater than the estimated plant density for maximum root yield of 5.93 plants m^{-2}. This is likely due to the linear increase in sugar concentration with increasing plant population density. In this study, sugar loss to molasses either decreased in a linear fashion or was not affected as plant density increased (data not shown). Using individual site-year data, the optimum plant density for sugar yield varied from a low of 2.52 plants m^{-2} at Sidney 1 in 2008 to a high of 7.41 plants m^{-2} at Sidney 1 in 2010.

The results of this 10 site-year study have established that sugarbeet root yields of over 40 Mg ha^{-1} and sugar yields of greater than 7.5 Mg ha^{-1} are achievable without irrigation, i.e., dryland, in the semiarid environment of western Nebraska, using no-till practices and glyphosate-tolerant sugarbeet varieties. Optimum plant densities for root and sugar yield were 5.93 and 6.24 plants m^{-2}, respectively, which is lower than the density of 7.4 to 9.9 plants m^{-2} recommended for irrigated production (Wilson et al., 2001). In water-short environments such as semiarid western Nebraska, low plant densities are frequently

used to maximize the water available to each plant (Loomis and Conner 1992). Yonts and Smith (1997) reported that root yield, sucrose content, and sugar yields for irrigated sugarbeet peaked at 4, 10, and between 4 and 10 plants m^{-2}, respectively.

There is significant risk to making recommendations for dryland production based on just three years of field research — the result of highly variable year-to-year and within year rainfall in the semi-arid High Plains. In this study, 2009 was unusual in the amount of precipitation received, particularly in June, and the below normal temperatures, which resulted in relatively low crop stress levels throughout the growing season. We were surprised by the excellent root yields achieved in 2009. Although 2009 may bias our results upward for yield and optimum plant population recommendations, it should be noted that 2008 was a relatively warm and dry year that started with a very dry soil profile below 0.6 m. Planting in 2008 would not have been advised given the dry soil conditions at planting. We feel our 10 site-years provide us with a reasonable estimate of yield potential for dryland sugarbeet in semi-arid western Nebraska. A plant density recommendation between 5 and 6 plants m^{-2} seems reasonable.

Maximum yields require deep, well drained soils, with high water holding capacity and adequate stored water at planting to a depth of at least 1.2 m. Having adequate soil water throughout the top 1.2 m of soil at planting helps to ensure good emergence and root development. Brown et al. (1987) reported that early drought severely affected fibrous root development in sugarbeet and significantly reduced root yields compared to late drought, which was imposed when the fibrous root system was already extensive. In 2010, weather conditions turned dry and hot in July, yet root yields were only slightly reduced compared to 2009 and sugar yield was actually increased at some locations compared to 2009.

Planting into heavy crop residues helps to reduce evaporation from the soil surface and reduces weed competition. The condition of the previous crop residue, and the planter design are essential ingredients for stand establishment in dryland conditions. The combine used to harvest the previous year's wheat crop must be equipped with effective straw and chaff spreaders to avoid residue windrows and bunching. The sugarbeet planter should have a residue cutting coulter followed by residue managers ahead of the planter furrow openers. The coulter should be either a flat or narrow ripple design to cut and not punch residue. Floating residue managers are more effective than fixed or solid disk designs for moving only residue and not creating a soil depression. Plant emergence can be increased with the use of a basket-type press wheel on the planter rather than the standard solid press wheel design. The basket-type press wheel reduced soil surface crusting compared to the solid press wheel.

Row spacing of 76 cm is recommended over narrower row spacings for dryland sugarbeets. Wider row spacing will allow movement of the

residue loosened by the planter row cleaners without plugging within the planter and will limit the amount of loose residue that moves back over the row area behind the planter. The wider row spacing will also limit how fast the sugarbeet crop uses the soil water between rows, moderating plant stress during long periods between summer rains.

Very good to excellent weed control was achieved at all sites with two applications of glyphosate at 1.12 kg ha⁻¹. Up to three applications at this rate are allowed per season, but were not needed in this study.

Several potential management problems were identified in this study, including the difficulty of lifting roots when the soil at harvest time is very dry and hard. Good variety selection and plant population will minimize harvesting issues. If row finders are used for harvester guidance, use varieties with moderate crown height to register the row finder guides. Select varieties with good resistance to Aphanomyces root rot (*Aphanomyces cochlioides* Drechsler) to avoid losing diseased roots during defoliation and scalping. Strive for a plant population and seed spacing accuracy that will avoid small roots. Small roots will be much harder to lift in very dry soil, and will be harder to correctly defoliate and scalp. Lifting roots in very dry soil conditions might require closer lifter wheel spacing, and maintaining roots in the harvester tank for additional weight or transferring weight from the tractor via the harvester hitch arrangement. Certain varieties have root shapes that will have less tap root breakage when lifting in dry soil. Tractor RTK level autosteer systems, coupled to RTK level implement guidance systems will enable excellent harvester guidance in fields with no soil furrows or ridges.

Another potential management problem identified in this study was the lack of surface residue cover after harvest, which leaves the soil susceptible to wind and water erosion. Although further research is needed before no-till, dryland sugarbeet production becomes a recommended practice, this study suggests that it could play a role in future sugarbeet production in semi-arid western Nebraska. Economic analyses need to be done and management practices need to be refined, including variety selection for dryland production. The impact of sugarbeet on subsequent crops in the rotation also needs to be determined. Additionally, the sugar industry needs to consider the pros and cons of dryland production and federal crop insurance programs need to be established.

ACKNOWLEDGMENTS

Brown, K. F., A. B. Messem, R. J. Dunham, and P. V. Biscoe. 1987. Effect of drought on growth and water use of sugar beet. J. Agric. Sci. Camb. 109:421-435. http://dx.doi.org/10.1017/S0021859600081636

Dickey, E. C., C. R. Fenster, J. M. Laflen, and R. H. Mickelson. 1983. Effects of tillage on soil erosion in a wheat-fallow rotation. Trans.ASAE. 26:814-820.

Durrant, M. J., R. A. Dunning, K. W. Jaggard, R. B. Bugg, and R. K. Scott. 1988. A census of seedling establishment in sugar beet crops. Ann. Appl. Biol. 113:327-345. http://dx.doi.org/10.1111/j.1744-7348.1988.tb03310.x

Fryrear, D. W. 1995. Soil losses by wind erosion. Soil Sci. Soc. Am. J. 59:668-672. http://dx.doi.org/10.2136/sssaj1995.03615995005900030005x

Littell, R. C., W. W. Stroup, and R. J. Freund. 2002. SAS for linear models. 4th ed. SAS Institute Inc. Cary, NC.

Loomis, R. S., and D. J. Conner. 1992. Strategies and tactics for rainfed agriculture. p. 349-377. In Crop Ecology: Productivity and management in agricultural systems. Cambridge University Press, Cambridge, UK.

Lyon, D. J., and G. A. Peterson. 2005. Continuous dryland cropping in the Great Plains: What are the limits? Agron. J. 97:347-348. http://dx.doi.org/10.2134/agronj2005.0347

Nielsen, D. C., and M. F. Vigil. 2010. Precipitation storage efficiency during fallow in wheat-fallow systems. Agron. J. 102:537-543. http://dx.doi.org/10.2134/agronj2009.0348

Parashar, K. S., and N. G. Dastane. 1973. Studies on the effect of soil moisture regimes, plant population and nitrogen fertilization on yield and quality of sugarbeets. Indian J. Agron. 18:349-353.

Peterson, G.A., and D. G. Westfall. 2004. Managing precipitation use in sustainable dryland agroecosystems. Ann. Appl. Biol. 144:127-138. http://dx.doi.org/10.1111/j.1744-7348.2004.tb00326.x

Robinson, F. E., and G. F. Worker, Jr. 1969. Plant density and yield of sugar beets in an arid environment. Agron. J. 61:441-443. http://dx.doi.org/10.2134/agronj1969.00021962006100030032x

Wilson, R. G., J. A. Smith, and S. D. Miller (ed.) 2001. Sugarbeet Production Guide. Cooperative Extension EC01-156, University of Nebraska. Lincoln, NE.

Yonts, C. D., and J. A. Smith. 1997. Effects of plant population and row width on yield of sugarbeet. J. Sugar Beet Res. 34:21-30. http://dx.doi.org/10.5274/jsbr.34.1.21