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Replanting guidelines for sugar beet production in southern Minnesota

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A replanting guide for sugar beet production in southern Minnesota

by

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ABSTRACT

Establishing an adequate plant population is one of the first challenges of sugar beet production. Reduced sugar beet emergence results in a decision between a lower than desired plant population or replanting the field. The objective of this study was to determine the plant population that warrants replanting a field to maximize extractable sugar ha^{-1}. The study was conducted in three environments during the 2016 and 2017 growing seasons. Two planting dates and six plant populations were utilized in each environment. The two planting dates were separated by 19 or 20 days to simulate a replant situation. Sugar beets in each planting date were hand thinned to six populations of 44000, 58700, 73400, 88100, 102800, and 117400 plants ha^{-1}. Planting date and plant population did not significantly affect sugar concentration. However, planting date and plant population influenced yield and extractable sugar ha^{-1}. Extractable sugar yield was maximized with the first planting date and populations of 102800 and 117400 plants ha^{-1}. A population of 58700 plants ha^{-1} in the first planting date had similar extractable sugar yield to the second planting date populations of 88100, 102800, and 117400 plants ha^{-1}. Sugar beet populations above 58700 plants ha^{-1} should not be replanted based on the results from this study.

CHAPTER 1

INTRODUCTION:

Sugar beets (*Beta vulgaris* L.) are grown in the United States and other countries for the production of sugar. In 2018, sugar beets were planted on 451,548 hectares in the United States (NASS, 2018). In west central Minnesota, sugar beets have been grown since the 1950s. In 2018, 50990 hectares of sugar beets were grown in 17 counties surrounding the processing facility in Renville, MN (Todd Geselius, personal communication, 2018). Sugar beets in the southern Minnesota growing area are normally planted between mid-April and early May. Harvest of sugar beets occurs during September and October. The sugar beets harvested in October are piled in large outdoor storage piles and are processed into sugar throughout the winter months.

Sugar beet seed is very small with pelleted seed ranging in size from 3.8-5.5 mm in diameter (Khan et al., 2018). In addition, sugar beet emergence can be quite variable (Durrant et al., 1988). There are multiple factors that can affect the emergence or reduce the stand of seedling sugar beets (Jaggard et al., 2011). Factors that can affect emergence or reduce the stand of seedling sugar beets include seed bed conditions, soil crusting from heavy rains, damaging winds, freezing temperatures, seedling disease and insect feeding. Average emergence in the Red River Valley was reported to be 68% (Khan et al., 2018). In Michigan, average emergence was 60-75% (Michigan Sugar Company, 2018). Average sugar beet emergence in the Nebraska, Colorado, and Wyoming region was approximately 65% with over 80% considered very good (Yonts et al., 2013).

Low sugar beet emergence leads to the need to consider replanting. At Southern Minnesota Beet Sugar Cooperative during the period of 1984 – 2018, replanting was required to attain an adequate plant population on between 0 and 59% of the planted acreage each year. The average replanted acres for these years was 6.7%. (Linda Foss and Jody Steffel, personal communication, 2018).

Research trials have been conducted to establish the optimum plant population for sugar beet production. In Wyoming, recoverable sucrose yield was maximized at 7.8 Mg ha^{-1} with a plant population of 88,600 sugar beets ha^{-1}(Lauer, 1995). Trials in Nebraska found similar sugar yields for plant populations between 40,000 to 100,000 sugar beets ha^{-1}(Yonts and Smith, 1997). Plant populations of 102,800 to 117,400 sugar beets ha^{-1} were indicated to maximize yield in the Red River Valley of North Dakota and Minnesota (Khan and Haak, 2016).

Plant populations below optimum can result in lower yields for the grower; however, replanting a field does not guarantee an adequate stand. As S.R. Winter stated, “Replanting is expensive and there is no guarantee of improved stand” (Winter, 1980). The average cost of sugar beet seed and associated technology fee in the Red River Valley 2017 Report was $536 per hectare (MN and ND Farm Business Management and Education, 2017). Replanting can be expensive, with no guarantee of improved stands, leading to a need for research like the current study.

Low sugar beet plant populations can lead to increased late season weed pressure, which was of particular concern prior to introduction of Roundup Ready® sugar beets. These weed control concerns and limited weed control product options were a major consideration in the past when determining whether to keep a lower than desired original plant population or replant to attempt to attain a higher population. In the 2009 growing season, Roundup Ready® sugar beets were planted on 95% of the United States sugar beet acreage (APHIS, 2018). The level of weed control attained with the Roundup Ready® system has reduced concerns about late season weed control in fields with lower plant populations (Mesbah and Miller, 2004; Stachler and Luecke, 2008; Peters et al., 2017).

The decision to replant a field of sugar beets is often made based on the experience of the grower and consulting agronomist. To date there have been no research trials conducted in the southern Minnesota growing area to determine at what plant population a grower should replant. To answer this question for the southern Minnesota growing area, a research project was initiated in the spring of 2016.

CHAPTER 2

BACKGROUND

Establishing an adequate population of sugar beets is one of the challenges in sugar beet production. North Dakota State University recommends a plant population at harvest of 102,800 to 117,400 sugar beets ha^{-1} (Khan et al., 2018). Sugar beet emergence can be inconsistent between fields and years. To attain the recommended harvest population, sugar beets typically are overplanted due to the variability that can occur with emergence. In situations of poor emergence, growers must evaluate the plant population to determine if replanting the field is the best option.

Early planting of sugar beets usually results in increased production versus delayed planting. In Nebraska, Yonts (1999) found that root yield decreased 0.57 Mg ha^{-1} for each day delay in planting of variety Monohikari and 0.36 Mg ha^{-1} for each day delay in planting of the variety

Beta 3778. In Idaho, yields decreased 6.3 Mg ha^{-1} for every 10 days planting was delayed in eastern Idaho and 7.3 Mg ha^{-1} for every 10 days planting was delayed in western Idaho (Elison et al. 2014).

In Wyoming, trials to compare planting date, harvest date, and genotype were performed in 1992 and 1993 (Lauer, 1997). Sugar beets were planted on a 2-week schedule providing five different planting dates beginning approximately April 1 and ending in early June. The recoverable sucrose yield decreased significantly at each of the later planting dates in comparison to the next earlier date in the 1992 trial. In 1993, the recoverable sucrose yield decreased significantly for each of the later planting dates with the exception of the second planting date (Lauer, 1997). Reduced sugar yields with later planting dates decrease the potential yield and revenue from a replanted field due to the reduced length of growing season.

The potential for increased yields with early planting encourages growers to plant their sugar beet crop as soon as soil conditions are favorable. Early planting often leads to planting into cooler soils. Cool soil temperatures slow the rate of sugar beet germination and emergence. The optimum temperature for sugar beet germination was reported at 25° C. Temperatures of 16-19° C. germinated sugar beet seed in 3.75 days while a temperature of 4° C. required 22 days for germination (Forbes and Watson, 1992). Slower germination and emergence of the sugar beet seeds leads to a longer period of time for stand establishment issues to occur. Historical average soil temperatures at the 5-cm depth at the Southwest Research and Outreach Center in Lamberton, MN range from 4 to 13ºC in April and between 9 to 19ºC in May (SWROC, 2014). The speed of emergence is a direct result of accumulated heat units during the emergence period. Information from Nebraska indicated 85 soil heat units were necessary to reach 50% emergence (Yonts et al., 2013). It is often 14 to 21 days after planting before a grower can be confident of final emergence in the field. When final emergence is known, decisions need to be made regarding the potential productivity of the emerged plant population and whether this population is adequate or should be replanted. These decisions are often based on the experience of company agronomists and growers.

CHAPTER 3:

RESEARCH RESULTS FROM OTHER SUGAR BEET GROWING AREAS

Trials have been conducted in sugar beet growing areas across the United States over the past 40 years to create replanting guidelines. These guidelines provided information for the various production areas where the trials were established. The approaches and results have varied depending on the location of the growing area where the trials were conducted.

In the High Plains of Texas, studies were conducted to establish a replanting guide for sugar beets in the area. The initial planting in the experiment was conducted at the same time growers would plant and the second planting was made when the original planted beets were at the two leaf stage. Population or stand density was not measured; however, the author used "unoccupied area" as a measurement to evaluate population density (Winter, 1980). Areas within the row that were blank for greater than 46 cm were considered unoccupied area. In this two-year study, replanted sugar beets had similar yield to the original planting when the replanted beets had 15% less unoccupied area than the original planting. Winter also discussed the issue of harvest losses increasing as the plant population decreased due to difficulties in defoliating and harvesting the sugar beets without knocking them out of the row. His conclusion was that growers in the Texas

High Plains should not replant an original stand of two-leaf sugar beets unless the unoccupied area exceeded 30% (Winter, 1980).

In the Klamath Falls production area of California and Oregon, planting date and population trials were conducted to develop a replant guide for sugar beets grown in the area. It was found that for every week delay in planting after May 1, sugar yield decreased by 673 kg ha^{-1} (Carlson et al., 1999). The studies also found sugar beet yields declined with reduced plant populations. A regression equation was developed using the data from these trials to produce a replant guide for the Klamath Basin:

Beet Yield (ton/A) = $14.7 + 0.708D + 1.11P - 0.00339D^2 - 0.0168P^2 - 0.00234DP$; $R^2 = 0.59$; where P is plant population in thousands of plants per acre and D is the planting date in days from January 1.

The Red River Valley of Minnesota and North Dakota is a large sugar beet production region. Giles and Cattanach (2003) conducted a two-year study near Glyndon, MN comparing planting dates and plant populations. They indicated that a minimum population of 100 sugar beets per 30.5 meters of row in 56-cm rows was necessary to maximize sugar production at either planting date (Giles and Cattanach, 2003).

In Crookston, MN, Smith (2002) conducted studies on the effects of planting date and population on yield and quality of sugar beets grown in 56 cm rows. He found that a population of 75 beets per 30.5 meters of row from an original planting would give equal or greater recoverable sugar yield than the replant timed planting with populations of 150-200 sugar beets per 30.5 meters of row (Smith, 2002). Trials conducted in row spacings other than 56 cm showed that sucrose concentration and recoverable sucrose concentration also can be influenced by plant population. In trials conducted in Sidney, MT, in 61 cm rows, sucrose decreased and impurities increased as seed spacing increased (Eckhoff et al., 1991). Seed spacings between 10-15 cm resulted in the highest sucrose and recoverable sucrose yields. Plant population trials conducted in sugar beet production areas of Turkey in 45 cm rows, showed decreased sugar concentration and purity with wider plant spacing (Çakmakçi et al., 1998).

The review of previous research indicates there has been plant population and planting date studies in several of the sugar beet growing areas of the United States and replanting guidelines were developed based on these studies. There are only limited results published recently on this topic, and there have been no results from replicated studies published from the southern Minnesota growing area on this topic. Data developed within the southern Minnesota growing area will be a useful tool for growers, sugar company agricultural staff, and agribusiness personnel to use when facing potential replant decisions. Consequently, a multi-year study was initiated in southern Minnesota to determine the influence of planting date × stand density on sugar beet yield and quality.

CHAPTER 4

MATERIALS AND METHODS

A field study was established in three environments over 2016 and 2017. Sites were located near the towns of Murdock, MN (N45.11138295°, W-95.42909560°) and Lake Lillian, MN (N44.90615123°, W-94.82280956°) in 2016 and near the town of Renville, MN (N44.69488342°, W-95.19643961°) in 2017. The soil at the Murdock site was mapped as a mixture of Bearden silty clay loam (fine, silty, mixed, superactive, frigid Aeric Calciaquoll) and Quam silty clay loam (fine, silty, mixed, superactive, frigid Cumulic Endoaquoll) in a depressional complex with 0-2% slope. The soil at Lake Lillian was mapped as a Canisteo clay loam, 0-2% slope (fine, loamy, mixed, superactive, calcareous, mesic, Typic Endoaquoll). The soil at Renville was Chetomba silty clay loam, 0-2% slope (fine, silty, mixed, superactive, mesic Typic Endoaquoll). The previous crop at Murdock was sweet corn (*Zea mays* L.). At Lake Lillian the previous crop was soybean (*Glycine max* L.) and at Renville sugar beet followed field corn.

Precipitation and temperature data are from Willmar, MN (45.1901° N, -95.0586° W. (NCEI, 2018). The Willmar, MN weather station is approximately 23 km from the Murdock trial, 34 km from the Lake Lillian trial, 48 km from the Renville trial.

Soil samples were taken in the late fall of 2015 for the 2016 trial sites at Murdock and Lake Lillian and in the late fall of 2016 for the 2017 site at Renville. Nitrate-N soil sample depths were: 0-15 cm, 15-61 cm, and 61-122 cm. All other soil sample parameters were measured on a 0-15 cm depth sample. Sample analysis was conducted by Agvise Laboratories, Benson, MN following the recommended chemical soil test procedures for the North Central Region (Nathan and Gelderman, 2012). Nitrate-N was determined colorimetrically following extraction with KCl (Gelderman and Beegle, 2012). Phosphorus was determined by the Olsen sodium bicarbonate method (Frank et al., 2012). Potassium was determined using the ammonium acetate extractant (Warnke and Brown, 2012). Organic matter concentration was determined by the loss on ignition method (Combs and Nathan, 2012). The pH was determined with a 1:1 soil water mixture (Peters et al., 2012). Soil test results are summarized in Table 1. Fertilizer recommendations were based on University of Minnesota sugar beet fertility recommendations (Lamb and Sims, 2011). No additional fertilizer was applied to the Murdock site. Fertilizers applied at the Lake Lillian site were 168 kg N ha^{-1}, 39 kg P_2O_5 ha^{-1}, and 140 kg K_2O ha^{-1}.

Fertilizer applied at Renville was 28 kg N ha^{-1}, 6 kg P_2O_5 ha^{-1}, and 6 kg K_2O ha^{-1}. Fertilizer sources applied were blends of urea, diammonium phosphate, and potassium chloride fertilizers.

Table 1. Fall soil nitrate-N content, concentrations of Olsen-P, K, organic matter, and pH for three environments in western Minnesota. 2016 and 2017.

Parameter	**Murdock**	**Lake Lillian**	**Renville**
Nitrate-N (0-15cm) kg ha^{-1}	37	9	24
Nitrate-N (15-61cm) kg ha^{-1}	54	13	44
Nitrate-N (61-122cm) kg ha^{-1}	18	7	30
Total nitrate-N (0-122cm) kg ha^{-1}	109	29	98
Phosphorus (Olsen) (0-15cm) mg kg^{-1}	5	25	21
Potassium (0-15cm) mg kg^{-1}	170	194	193
Organic matter g kg^{-1}	46	48	45
pH (0-15cm)	8.3	7.6	6.9

The experimental design at each location was a randomized complete block in a split plot arrangement with six replications. The whole plot treatment was planting date; plant population was the sub plot treatment. The first planting date for each trial location was in early May. The second planting date was 19 or 20 days following the first planting date at each location. The subplots were populations of 44000, 58700, 73400, 88100, 102800, and 117400 plants ha^{-1}. Row spacing was 56 cm. Individual subplot size was 12.2 m long and 2.25 meters wide comprising four rows. Each of the environments was planted with ‘Beta 92RR30’ (Betaseed Inc., Shakopee, MN) at 206,300 seeds ha^{-1}. Seeds were planted with a John Deere 7300 MaxEmerge row crop planter (Deere and Company, Moline, IL). The plots were hand-thinned to the desired plant population at 21 to 30 days after the planting date. Azoxystrobin (Quadris®, Syngenta, Greensboro, NC) was applied at the 4-8 leaf stage to suppress Rhizoctonia root and crown rot (*Rhizoctonia solani*) (Stump et al., 2004). Weed control was accomplished with glyphosate (Roundup PowerMAX®, Monsanto, St. Louis MO). Cercospora leafspot (*Cercospora beticola*) was managed during the months of July through September with six fungicide applications.

Sugar beets were harvested in late September to mid-October. Harvest date was dependent upon the trial site and field conditions. Plots were defoliated just prior to harvest with a four-row Alloway 622 sugar beet defoliator (Alloway Standard Industries, Fargo, ND) equipped with scalper knives. The center two rows of each four row plot were harvested with a two row custom fabricated research plot harvester. All beets harvested in each plot were weighed on the harvester utilizing RL35023-N5-1K load cells (Rice Lake Weighing Systems, Rice Lake, WI) to determine yield.

A 10 kg sub-sample was collected from each plot for quality analysis. Samples were analyzed for quality attributes by the Southern Minnesota Beet Sugar Cooperative tare lab. Quality attributes determined included tare percent, sugar content, and purity. Tare percent was calculated by the formula:

Tare percent = ((SDW – SCW)/SCW) ×100 where SDW = sample dirty weight (kg) and SCW = sample clean weight (kg).

Sugar concentration and purity were analyzed with an Autopol 880 polarimeter (Rudolph Research Analytical, Hackettstown, NJ). Sugar concentration and purity analysis were conducted utilizing industry standard analysis (ICUMSA method GS6-3) (Bartens, 2009).

The percent extractable sugar was calculated by:

Percent extractable sugar = (10000×(BP – MP) + (MP×CE×(100-BP)×(S-TL/S).

Where S = percent sugar (tare lab result), TL = percent total losses expected in factory on beets (except molasses) (0.89), MP = expected molasses purity percent (60), CE = expected factory carbonation elimination (30), BP = beet purity (tare lab result).

Extractable sugar per Mg (ES Mg^{-1}) = % extractable sugar × 10

Extractable sugar per ha (kg $ha^{-1)}$ = ES Mg^{-1} × Mg ha^{-1}

Data were analyzed using PC-SAS v9.4 procedures PROC MIXED and PROC REG (SAS Institute, Cary, NC). Year and location were combined into one factor, environment. Fixed effects consisted of planting date, plant population, and the planting date × plant population interaction. Random effects consisted of environment, replicate, and the replicate × environment interaction. Mean separation was done by the least square means test. Differences between means were reported as significant at $P \leq 0.05$. The effect of plant population on yield (Mg ha^{-1}) and extractable sugar ha^{-1} (kg ha^{-1}) for each planting date were fitted to quadratic regressions using PROC REG.

CHAPTER 5

RESULTS AND DISCUSSION

Precipitation for the April through September period was above the 30-year mean in the 2016 and 2017 growing seasons (Table 2). Average monthly temperatures for this same period were near normal (Table 2). Average temperature and precipitation data were from the 30-year period 1981 to 2010.

Table 2. Mean precipitation and temperature data (Willmar, MN)

Month	Mean Precipitation (cm)			Mean Temperature ºC		
	2016	2017	30-Year Mean	2016	2017	30-Year Mean
May	10.7	9.6	7.9	14.0	13.1	14.5
June	10.9	12.9	12.6	19.7	19.2	19.8
July	16.0	5.3	9.7	21.1	21.9	22.2
August	24.7	24.6	10.4	20.8	18.6	20.7
September	11.0	7.6	8.5	16.7	17.2	15.7
Total	73.3	60.0	49.1			

Type 3 tests of fixed effects showed significant differences in planting date and plant population for extractable sugar percent, yield, extractable sugar per Mg, and extractable sugar yield. A significant interaction occurred with percent purity, but all other planting date × population interactions were not significant (Table 3).

Table 3. Results of Type 3 analysis of variance utilizing PROC MIXED. For sugar beet with two planting dates and six populations over three environments.

Parameter	Fixed Effect		
	Planting Date	Population	Date × Population
Tare %	NS	NS	NS
Sugar %	NS	NS	NS
Extractable sugar %	*	**	NS
Yield (Mg ha^{-1})	***	***	NS
Purity %	***	***	*
Extractable sugar (kg Mg^{-1})	**	**	NS
Extractable sugar (kg ha^{-1})	***	***	NS

NS = not significant, $P > 0.05$
* Significant at $P \leq 0.05$
** Significant at $P \leq 0.01$
*** Significant at $P \leq 0.0001$

Planting Date

The effect of planting date was not significant for tare percent and sugar percent (Table 4). The effect of planting date on sugar percent has been inconsistent in previous trials. Decreasing sugar percent with delayed planting date was documented in studies from Wyoming (Lauer,

1997) and Nebraska (Yonts et al., 1999). In studies conducted in Idaho the response of sugar percent to planting date was not significant at most trial sites (Elison et al., 2014). In trials conducted in Minnesota in 2002 and 2003 the influence of planting date on sugar content was not significant in either year (Giles and Cattanach, 2003). In the current study, sugar content was not significantly different between the two planting dates. In the southern Minnesota growing area, the soils are high in organic matter and rainfall events during the fall season can mineralize nitrogen from the organic matter and limit sugar accumulation.

Extractable sugar percent was 0.2% higher and extractable sugar per Mg was 2.4 kg Mg^{-1} greater for the first planting. Beet yield was 9.6 Mg ha^{-1} greater for the first planting date. The difference in yield and extractable sugar per Mg for the first planting over the second planting produced 1425 kg ha^{-1} greater extractable sugar for the first planting (Table 4). The finding of decreased root yield (Mg ha^{-1}) and extractable sugar per hectare with delayed planting in the current study is consistent with the results of other planting date studies conducted at other locations (Lauer, 1997; Yonts et al., 1999; Elison et al., 2014). The reduction in extractable sugar yield with later planting is another cost in the decision to replant a field.

Table 4. Planting date effect on tare, sugar concentration, yield, and extractable sugar concentration and yield over three environments. Southern Minnesota, 2016-2017.

Planting date	**Tare**	**Sugar**	**Yield**	**Extractable sugar**		
	%	%	Mg ha^{-1}	%	kg Mg^{-1}	kg ha^{-1}
1	3.4	15.8	65.9 a	13.4 a	134.1 a	8839 a
2	3.2	15.6	56.3 b	13.2 b	131.7 b	7414 b

† Means in the same column followed by different lower case letter are significantly different at $P \leq 0.05$ using the least square means test.

‡ Means in the same column without lower case letters are not significantly different at $P \leq 0.05$ using the least square means test.

§ Each value shown represents the mean of 108 observations.

Plant Population

The effect of plant population was non-significant for tare percent. Decreasing plant population did not influence sugar percent in the current study (Table 5). In previous research, sugar percent was shown to decrease with reduced plant population (Eckhoff, 1991; Yonts and Smith, 1997; Çakmakçi, 1998). In the current study the lack of a difference in sugar content could be the consequence of the high organic matter content of the soils mineralizing nitrogen late in the growing season. Extractable sugar percent did increase as plant population increased until the 117400 plants per hectare population. The same trend was found for extractable sugar per Mg. Yield increased from 49.0 Mg ha^{-1} at the 44000 plant population to 68.4 Mg ha^{-1} at the 117400 plant population. Extractable sugar yield increased from 6421 kg ha^{-1} at the 44000 plant population to 9077 kg ha^{-1} at the 117400 plant population in the current study (Table 5). These results differed from experiments conducted in Wyoming and Nebraska. In Wyoming, Lauer (1995) found that yield did not significantly increase as population increased between 42770 and 105400 beets ha^{-1} and extractable sugar per hectare only increased 390 kg ha^{-1} when population increased from 42,700 to 88,600 beets ha^{-1}. Plant population trials in Nebraska did not find a significant increase in extractable sugar per hectare as population increased from 40000 to 100000 beets ha^{-1} (Yonts and Smith, 1997). The yield potential of the varieties has increased over the twenty-year period between these two studies and the current study, which may be an explanation for the yield differences with increasing plant population found in the current study.

Table 5. Plant population effect on tare, sugar concentration, yield, and extractable sugar concentration and yield over three environments. Southern Minnesota, 2016-2017.

Plant population	**Tare** %	**Sugar** %	**Yield** Mg ha^{-1}	**Extractable Sugar** %	kg Mg^{-1}	kg ha^{-1}
44000	3.2	15.6	49.0 d	13.1 c	130.9 c	6421 e
58700	3.0	15.7	55.5 c	13.2 bc	132.2 bc	7334 d
73400	3.2	15.7	62.5 b	13.3 bc	132.5 bc	8287 c
88100	3.5	15.8	64.5 b	13.4 ab	133.7 ab	8621 b
102800	3.5	15.9	66.8 a	13.5 a	135.1 a	9019 a
117400	3.5	15.7	68.4 a	13.3 bc	132.8 bc	9077 a

† Means in the same column followed by different lower case letter are significantly different at $P \leq 0.05$ using the least square means test.

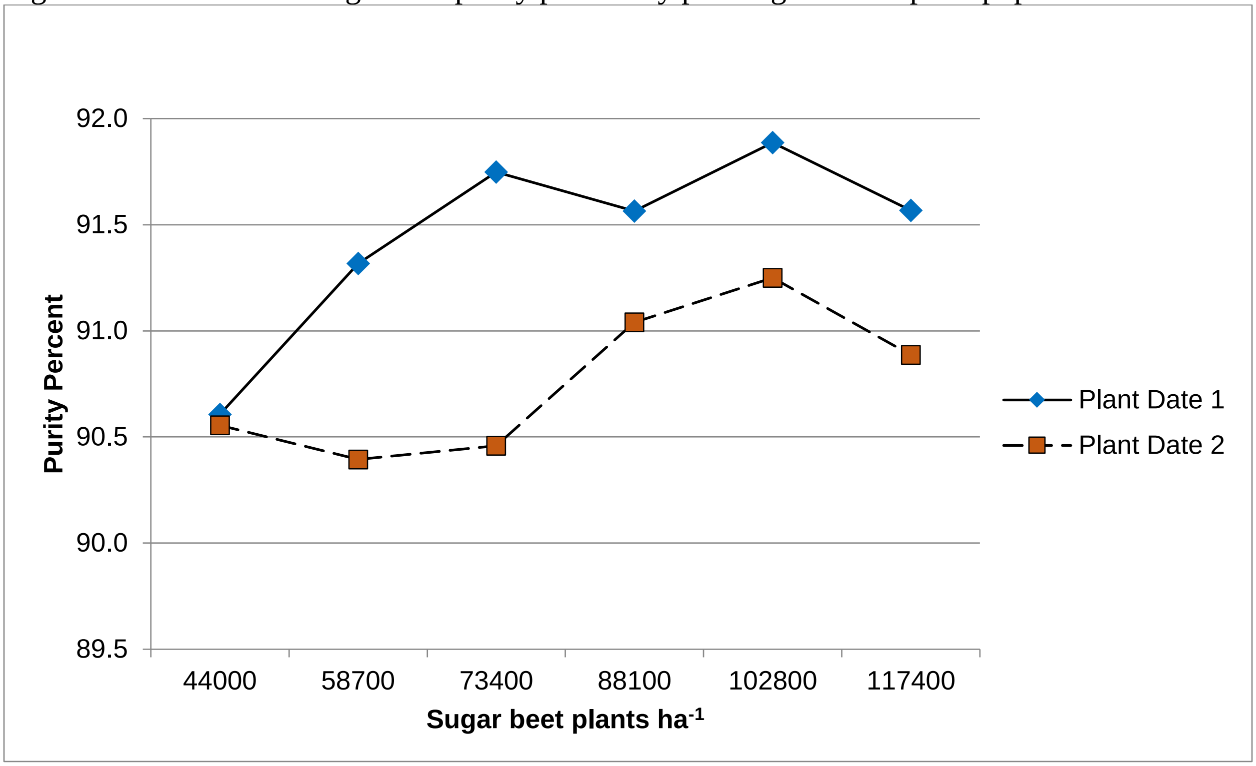
‡ Means in the same column without lower case letters are not significantly different at $P \leq 0.05$ using the least square means test.

§ Each value shown represents the mean of 36 observations.

Sugar Beet Purity Interaction

A significant interaction occurred with planting date by plant population for sugar beet purity percent (Table 3). The purity for the two planting dates at the 44000 plant population was 90.6%, however for the remaining plant populations the purity was consistently higher for planting date one (Fig. 1). The interaction occurred for two reasons. For planting date one, the purity increased from 90.6% at the 44000 plant population to 91.7% at the 73400 plant population. For planting date two, the purity was similar between the 44000 and the 73400 plant populations. The purity for planting date two then increased from 90.5% at the 73400 plant population to 91% at the 88100 plant population, while the purity for planting date one decreased slightly between these two plant populations.

Figure 1. Interaction of sugar beet purity percent by planting date and plant population.



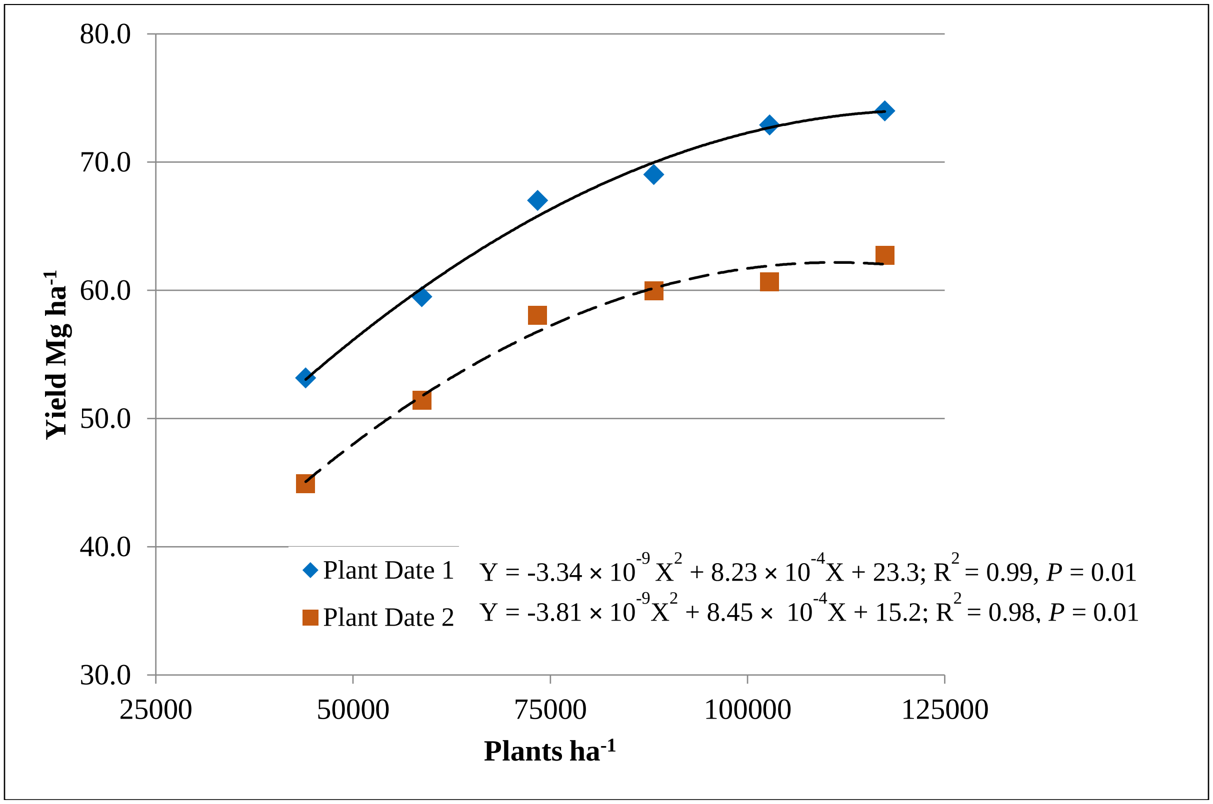
† Each symbol represents the mean of 18 observations.

Regression Analysis of Plant Population

A regression analysis was performed on plant populations with the means for yield (Mg ha^{-1}) and extractable sugar yield (kg ha^{-1}) for each planting date. From the regression analysis for yield (Mg ha^{-1}), the quadratic terms were significant for both planting dates. Figure 2 contains a graph of the yield (Mg ha^{-1}), regression equations, R^2, and probability values for the regression analyses of both planting dates. The maximum yield for planting date two was 62.7 Mg ha^{-1} and was obtained with a plant population of 117400 beets ha^{-1}. This yield was between the yield obtained from planting date one at 58700 beets ha^{-1} (59.5 Mg ha^{-1}) and the yield obtained at 73400 beets ha^{-1} (67.0 Mg ha^{-1}). This would indicate that plant populations above 73400 beets

ha^{-1} will have greater yield than the Mg ha^{-1} produced from any replanted populations used in this study.

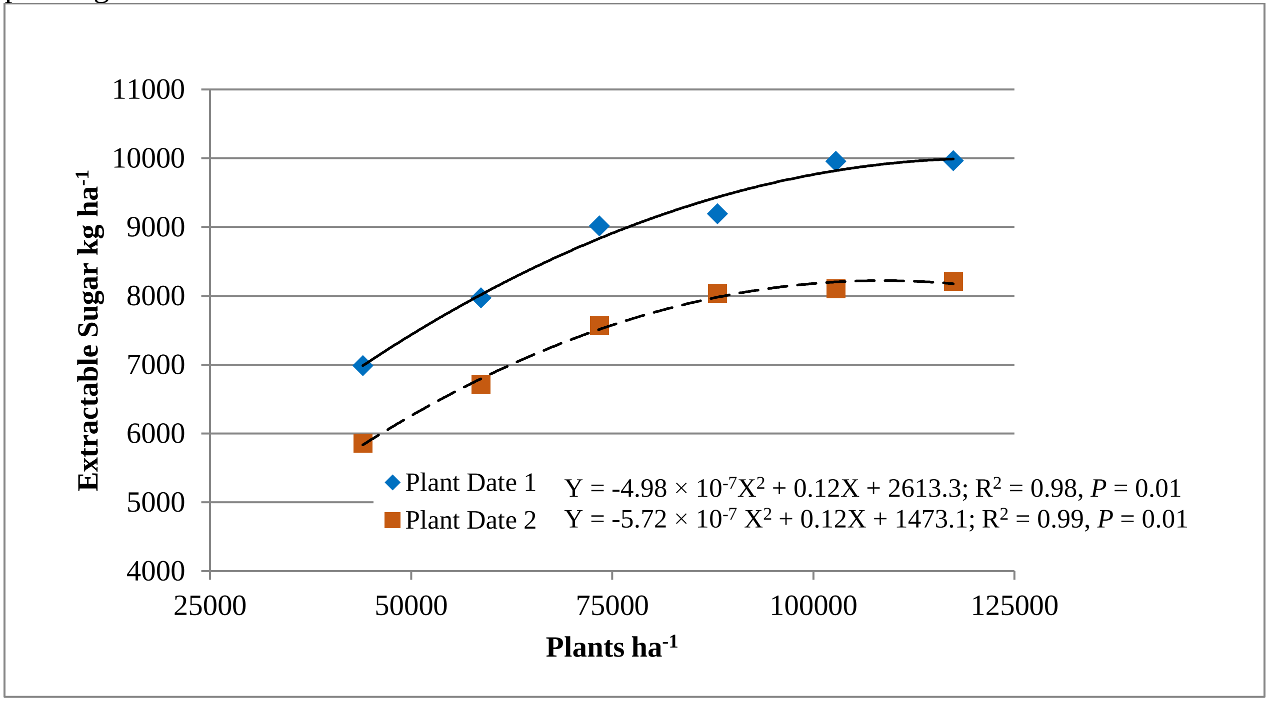
Figure 2. Sugar beet yield (Mg ha^{-1}) by plant population for planting date one and planting date two.



† Each symbol represents the mean of 18 observations.

The second regression analysis was conducted on extractable sugar yield (kg ha^{-1}). In the regression analysis for extractable sugar yield (kg ha^{-1}) the quadratic terms were significant for both planting dates. Figure 3 contains a graph of the extractable sugar yield (kg ha^{-1}), regression equations, R^2, and probability values for the regression analyses of both planting dates. The extractable sugar yield obtained of 7973 kg ha^{-1} from the 58700 beet ha^{-1} population of the first planting date was similar to (within 240 kg ha^{-1}) or greater than the extractable sugar yield obtained from any of the plant populations second planting dates of the study. This would indicate that an established plant population of 58700 sugar beets ha^{-1} or greater would not warrant replanting as the yield potential of extractable sugar per hectare of the initial planting would be not be surpassed by a replanted plant population. Initial plant populations below 58700 sugar beets per hectare may benefit from replanting if greater plant populations can be obtained from replanting the field.

Figure 3. Extractable sugar yield (kg ha^{-1}) by plant population for planting date one and planting date two.



† Each symbol represents the mean of 18 observations.

CHAPTER 6

CONCLUSIONS

Establishing an adequate plant population is one of the first challenges of sugar beet production. If the plant population that emerges is less than desired, replanting is an option to try and establish an adequate plant population. In this study we report that plant populations of 58700 sugar beets per hectare or more from an original planting produce as much extractable sugar per hectare as the potential of replanting the field. Fields with plant populations below 58700 sugar beets per hectare may benefit from replanting if the replanted population is greater than the original plant population. Based on this study, fields in the southern Minnesota growing area with sugar beet populations above 58700 sugar beets per hectare would not warrant replanting and would produce as much or more extractable sugar per hectare than the production possible by replanting the field.

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APPENDIX A

FIXED EFFECT MEANS

Table 6. Type 3 fixed effect means.

Planting date	Population	Tare	Sugar	Purity	Yield	Extractable sugar		
	plants ha^{-1}	%	%	%	Mg ha^{-1}	%	kg Mg^{-1}	kg ha^{-1}
1	44000	3.1	15.6	90.6	53.2	13.1	131.4	6983.9
1	58700	3.1	15.8	91.3	59.5	13.4	134.0	7972.5
1	73400	3.5	15.8	91.8	67.0	13.4	134.5	9015.0
1	88100	3.4	15.6	91.6	69.0	13.3	133.2	9193.2
1	102800	3.7	16.0	91.9	72.9	13.7	136.6	9956.8
1	117400	3.5	15.8	91.6	74.0	13.5	134.7	9962.2
2	44000	3.2	15.6	90.6	44.9	13.1	130.5	5860.8
2	58700	2.9	15.6	90.4	51.4	13.0	130.5	6709.5
2	73400	2.9	15.6	90.5	58.0	13.1	130.5	7577.2
2	88100	3.6	15.9	91.0	60.0	13.4	134.1	8042.1
2	102800	3.3	15.7	91.3	60.6	13.4	133.6	8100.2
2	117400	3.6	15.5	90.9	62.7	13.1	130.9	8212.8

APPENDIX B

SAS REGRESSION OUTPUT PLANTING DATE 1

Planting date 1 Sugar Beet Yield Mg ha^{-1}

The REG Procedure
Model: MODEL1
Dependent Variable: y

Number of Observations Read	6
Number of Observations Used	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	324.77939	162.38970	168.34	0.0008
Error	3	2.89394	0.96465		
Corrected Total	5	327.67333			

Root MSE	0.98216	**R-Square**	0.9912
Dependent Mean	65.93333	**Adj R-Sq**	0.9853
Coeff Var	1.48963		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	23.32883	4.59378	5.08	0.0147
x	**1**	0.00082313	0.00012149	6.78	0.0066
xsq	**1**	-3.33706E-9	7.4614E-10	-4.47	0.0208

Planting Date 1 Extractable sugar ha^{-1}

The REG Procedure
Model: MODEL1
Dependent Variable: y

Number of Observations Read	6
Number of Observations Used	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	6746689	3373344	89.87	0.0021
Error	3	112608	37536		
Corrected Total	5	6859297			

Root MSE	193.74237	**R-Square**	0.9836
Dependent Mean	8847.26667	**Adj R-Sq**	0.9726
Coeff Var	2.18986		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	2613.26943	906.17126	2.88	0.0633
x	**1**	0.12132	0.02397	5.06	0.0149
xsq	**1**	-4.98142E-7	1.471841E-7	-3.38	0.0429

APPENDIX C

SAS REGRESSION OUTPUT PLANTING DATE 2

Planting Date 2 Yield Mg ha^{-1}

The REG Procedure
Model: MODEL1
Dependent Variable: y

Number of Observations Read	6
Number of Observations Used	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	226.13959	113.06980	88.02	0.0022
Error	3	3.85374	1.28458		
Corrected Total	5	229.99333			

Root MSE	1.13339	**R-Square**	0.9832
Dependent Mean	56.26667	**Adj R-Sq**	0.9721
Coeff Var	2.01432		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	15.23683	5.30110	2.87	0.0638
x	**1**	0.00084517	0.00014020	6.03	0.0092
xsq	**1**	-3.8063E-9	8.61027E-10	-4.42	0.0215

Planting Date 2 Extractable sugar ha^{-1}

The REG Procedure
Model: MODEL1
Dependent Variable: y

Number of Observations Read	6
Number of Observations Used	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	4410849	2205424	236.80	0.0005
Error	3	27940	9313.31699		
Corrected Total	5	4438789			

Root MSE	96.50553	**R-Square**	0.9937
Dependent Mean	7417.10000	**Adj R-Sq**	0.9895
Coeff Var	1.30112		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	1473.10754	451.37538	3.26	0.0470
x	**1**	0.12429	0.01194	10.41	0.0019
xsq	**1**	-5.72333E-7	7.331427E-8	-7.81	0.0044