Potential Alcohol Production from Beta Vulgaris Genotypes as Affected by Nitrogen Level and Water Stress

J. N. Carter, D. L. Doney and J. C. Theurer

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INTRODUCTION

Present and future world shortages and increasing petroleum costs have stimulated the search for alternate renewable and nonrenewable energy sources. Sugarbeets (*Beta vulgaris* L.) and sugarcane (*Saccharum spp.*) have high potential as a feedstock for conversion to alcohol as a practical renewable energy source. Sugarbeets have many desirable characteristics such as: storage of 40 to 50% of their dry matter as fermentable sugars (6, 7, 15); a small nitrogen (N) requirement per unit of sugar produced (2, 5, 7); a range of related *Beta vulgaris* genotypes which may be used to increase yield potential (7, 8); use of by-products as a cattle feed or conversion to methane (6, 7); and wide adaptation within the U.S. (19). They can also be stored up to 6 months in cool areas, all of which make them a primary feedstock source for alcohol production.

In the development of new sugarbeet cultivars for sucrose production, high sucrose concentration with low levels of impurities including nonsucrose sugars in the harvested root has been emphasized to maximize extractable sucrose. Fodder beets, which in contrast have higher root yields, high impurities, and low sugar concentration, have been grown extensively in Europe as cattle feed. Many of the disadvantages to fodder beets as a refined sucrose source are not important if they are to be used for alcohol production. Although low in sugar concentration, the high root yielding fodder beet may have the potential to

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* Contribution from the U.S. Department of Agriculture, Agricultural Research Service; in cooperation with the University of Idaho College of Agriculture Research and Extension Center, Kimberly, Idaho. The authors are Soil Scientist, Snake River Conservation Research Center, Kimberly, ID 83341; and Research Geneticists, Crops Research Laboratory, Logan, UT 84332, respectively.

yield more fermentable sugars per hectare than can be obtained from commercial sugarbeet varieties.

Soil tests have been developed to assess the residual N and provide a basis for calculating N fertilizer application levels needed to maximize the product of root growth and extractable sucrose concentration of commercial sugarbeet hybrids (2, 5, 9, 10, 11). However, little is known concerning the N requirements of other genotypes for situations where total fermentable sugar production is of primary importance.

The sugarbeet water requirements have been studied extensively and reviewed by Jensen and Erie (12). Recent studies show that irrigation water level can be reduced below present day practices during the growing season with very little effect on sucrose yield (3, 4, 18, 22). The areas of the western U.S. where many beets could be grown for alcohol production may have limited irrigation water.

The objective of this study was to evaluate the fermentable sugar yield potential of several genetically diverse *Beta vulgaris* genotypes (sugarbeet and fodder beet types) grown under moderate and high N levels and normal and mid- to late-season soil water deficit and plant water stress and to determine their N and water requirements.

MATERIALS AND METHODS

An irrigated field experiment was conducted on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) near Twin Falls, Idaho in 1980. This soil has a weakly cemented hardpan at the 50- to 60-cm depth that has little effect on water movement when saturated but may restrict root penetration. The area used was cropped to barley (*Hordeum vulgare* L.) the previous year and was deficient in N (2) and phosphorus (P) (21).

Two adjacent experimental areas (irrigation treatments), each involving six replications of a split-plot design with two N rates as main plots and eight *Beta vulgaris* genotypes as sub plots, were used. The N treatments were broadcast preplant as ammonium nitrate at 196 and 392 kg N/ha on plots 17.9 m wide by 7.6 m long. Phosphorus was applied uniformly at 56 kg P/ha. The fertilizers were incorporated with the upper 10

cm of soil as the seedbed was prepared.

The N fertilizer rates used were established by the use of the sugarbeet N requirement equation developed by Carter et al. (2, 5).

$$N_f = \frac{Y_E\ (5.5 \pm 0.5) - (\alpha_n N_n + \alpha_m N_m - 5\ R_s)}{E_f} \qquad [1]$$

where N_f is the N fertilizer/ha needed, Y_E is the expected maximum yield, 5.5 $\pm$ 0.5 kg of N is the N required to produce a metric ton of crowned fresh roots (root minus crown), $\alpha_n N_n$ is the available NO_3-N in the soil depth sampled, $\alpha_m N_m$ is the available mineralizable N in the soil depth sampled, R_s is the straw in metric tons/ha, and E_f is the efficiency of applied N fertilizer.

Eight *Beta vulgaris* genotypes (Table 1) were planted in four row plots on 8 April 1980. All genotypes were planted in 56-cm rows that had previously been marked and treated with aldicarb at 2.24 kg of active ingredient per hectare to control insects. The genotypes were thinned to a 23- to 30-cm within-row spacing in early June.

Two irrigation levels, M_1 and M_3 (3), were used. The irrigation times and amounts are summarized in Figure 1 for the following treatments:

M_1 - Adequate irrigation based on previous experiments. Irrigation dates were based on estimated soil moisture depletion (13) and irrigation durations depended on the amount to be applied.

M_3 - No irrigation was applied after the soil profile was filled with water on 1 August: Irrigations were the same as M_1 before 1 August.

A light irrigation was applied to both irrigation levels about 10 days before harvest. Every other row irrigation was used throughout the season. The net amount of water applied was determined using an equation previously reported (3).

The soil water content in the 0- to 30-cm depth was determined gravimetrically at various times between 30 July to 6 October. One access tube located within the center rows of each of the genotypes on two replications (196 kg N/ha) near the upper and lower part of each irrigation treatment and a calibrated neutron probe were used to measure the soil moisture in

Table 1. Description of *Beta vulgaris* genotypes used in this experiment.

Common Name	Seed From	Curly top†	Germ	Description
GWD2	U.S.	XX	mono-	Commercial hybrid, Great Western Sugar Co.
AH10	U.S.	XXX	mono-	Commercial hybrid, Amalgamated Sugar Co.
LHY-1	U.S.	XXX	multi-	Logan high yield exp. hybrid.
LHS-1	U.S.	X	multi-	Logan high sucrose conc. exp. variety
Monorosa	Netherlands	X	mono-	Diploid high yield hybrid fodder beet‡
Monoblanc	Netherlands	X	mono-	Triploid high yield hybrid fodder beet§
Pajbjerg Korsroe	Denmark	X	multi-	Polyploid high yield fodder beet
Rota	Germany	X	multi-	Diploid open pollinated fodder beet

† X = highly susceptible, XX = partial resistance, XXX = highly resistant.
‡ 2n sugarbeet x 2n fodder beet.
§ 2n sugarbeet x 4n fodder beet.

Treatment	IRRIGATIONS AND RAINFALL† to 30 June	July	Aug.	Sept.	Oct.	Total
			mm			
Rainfall			2	13 30 1		46‡
M_1	211	70 70 70 180	70 70 70		79	890
M_3	211	70 70 70 180			79	680

† Arrows above quantity of water refers to application date. ‡ After 1 August.

Figure 1. Irrigation water applied and rainfall.

the 30- to 230-cm depth at the same time intervals as of those taken for the 0- to 30-cm depth between 30 July to 6 October.

Petiole samples consisting of 25 of the youngest fully-mature leaves were selected at random from each plot of the M_1 irrigation treatment on 21 August. The petioles were cut into 0.5-cm sections, dried at 65°C, ground to pass through a 40-mesh sieve, subsampled, and analyzed for NO_3-N, using a nitrate specific ion electrode (17).

Root and top samples were harvested manually from three uniform 3-m row sections from the center rows of each plot between 14 to 21 October. Root samples that included the crown were brushed free of soil, weighed, and triplicate root samples consisting of 10 to 12 roots were taken for total sugars, sucrose, purity, dry matter, and N analysis. A representative top sample was taken from a composite of the three row sections for dry matter and N analysis. All fresh tissue was weighed before and after drying. Extra root samples were taken from the genotypes AH10 and GWD2 to determine the yield of crowned roots (root minus crown).

Total sugars, reducing sugars, and sucrose were determined by the Sugarbeet Research Laboratory at Logan, Utah, using the following methods: sucrose concentration was determined by the Sach - le Docte cold digestion procedure as outlined by McGinnis (16), reducing sugars (glucose and fructose) were quantified colorimetrically in the filtrate obtained for sucrose analysis using dinitrosalicylic acid reagent. Total fermentable sugars are the sum of sucrose and reducing sugars. Dry matter in the beet roots was determined by drying brei samples collected at the

time of sugar and sucrose analyses.

Samples from the tops and roots (root plus crown) were dried at 65°C and dry weight determined. The dried samples were ground to pass a 40-mesh sieve and the total N was determined by the semimicro-Kjeldahl procedure modified to include nitrate (1). Nitrogen uptake was calculated by assuming that the N concentration was the same in both the fibrous and storage roots and that the weight of the unharvested fibrous roots was equal to 25% of the total harvested storage root weight (14).

RESULTS AND DISCUSSION

The growth patterns of the various genotypes were very similar throughout the growing season. The main differences were in early and late top growth and the position of the storage roots in relation to the soil surface. From field observations during mid-June to mid-July, the earliest and greatest top growth ws observed for Pajbjerg Korsroe, Monoblanc, and Rota; followed by GWD2 and Monorosa; and smallest by the AH10, LHY-1, and LHS-1. The genotypes established complete cover of the soils surface by the leaf canopy in the same order during early to mid-July. Plants at the higher N level had a larger leaf canoy at all growth stages on all genotypes as compared with the lower N treatment. The fodder beets (Pajbjerg Korsroe and Rota) started to turn yellow in mid-August on the lower N treatment indicating a N deficit. This was particularly noticeable on Rota where only the younger leaves were green at both N levels by the end of the season. Leaf canopy was reduced on both N levels and all genotypes by mid- to late-season moisture stress as compared with the normal irrigation. In sugarbeet types, only the crown of the storage root is above the soil surface. The genotypes Monoblanc, Pajbjerg Korsroe, and Rota had 40 to 60% of the storage root above the soil surface at harvest. This could have adverse effects on harvesting the whole storage root for alcohol production using present day farm equipment.

The genotypes varied widely in their root yield, and sucrose and total sugar concentration at both N levels (Table 2). The fodder beets (Pajbjerg Korsroe and Rota) gave significantly higher root yields, lower sucrose and total sugar concentrations as compared with the sugarbeets (GWD2, AH10, LHY-1, and LHS-

Table 2. Interaction means for each genotype at each N level and N level means for root yield, sucrose (% and yield), total sugar (% and yield), and potential alcohol yield; mt = metric tons, kl = kiloliters.

Beta vulgaris Genotype	Root Yield			Sucrose				Total Sugars				Alcohol†			
	196‡		392‡	196		392		196	392			196	392		
	mt/ha			%				mt/ha		%		mt/ha		kl/ha	
GWD2	79.5	*	85.2	18.2	*	16.9		14.5	14.4	18.4	*	17.1	14.6	14.5	8.72	8.67
AH10	74.3	*	80.3	18.2	*	16.6		13.5	13.4	18.3	*	16.8	13.6	13.5	8.13	8.05
LHY-1	83.1		86.1	18.5	*	17.2		15.4	14.8	18.6	*	17.4	15.5	15.0	9.23	8.92
LHS-1	67.7	*	74.5	20.3	*	18.6		13.8	13.8	20.5	*	18.8	13.9	14.0	8.27	8.33
Monorosa	88.4	*	100.9	15.2	*	14.1		13.5	14.2	15.4	*	14.2	13.6	* 14.4	8.10	* 8.56
Monoblanc	102.3	*	110.5	14.3	*	12.7		14.7	14.0	14.5	*	12.9	14.8	14.2	8.84	8.49
Pajbjerg Korsroe	121.5	*	134.9	11.6	*	10.9		14.1	14.7	11.9	*	11.3	14.4	* 15.3	8.60	* 9.10
Rota	116.4	*	138.2	10.2	*	9.1		11.9	12.5	10.5	*	9.4	12.2	* 13.0	7.29	* 7.77
LSD (0.05)	3.8		3.8	0.5		0.5		0.8	0.8	0.5		0.5	0.7	0.7	0.45	0.45
Interaction		*			NS				NS		*			*		*
N effect means	91.7	*	101.3	15.8	*	14.5		13.9	14.0	16.0	*	14.7	14.1	14.2	8.40	8.49

* Significant interaction at p = 0.05, between N level means = significant difference between means at p = 0.05.

† 1.68 kg sugar/liter alcohol (14 lbs/gal).

‡ kg N/ha.

1). The fodder x sugarbeet hybrids (Monorosa and Monoblanc) were intermediate in root yields, sucrose and total sugar concentrations. This negative correlation between root yield and sucrose or total sugar concentrations resulted in similar yields of total sugar and potential alcohol production at both N levels. The highest potential alcohol production came from the experimental sugarbeet hybrid LHY-1, followed by the fodder beet hybrid Pajbjerg Korsroe. The lowest potential alcohol production was the highest root yielding genotype Rota, an open-pollinated fodder beet.

The fodder beets had the highest reducing sugar concentration on a dry (Table 3) and fresh root basis, but in no case did they exceed 0.5% on a fresh root basis. Total sugar concentration on a dry weight basis and root dry matter concentration were highest on the sugarbeets and lowest on the higher root yielding fodder beets with intermediate levels on the fodder x sugarbeet hybrids. Total dry matter production was similar between the two divergent types (sugarbeets and fodder beet types) except for the nonhybrid fodder beet, Rota, which was significantly less. The proportions of the total dry matter in the tops and roots indicated that fodder beets partitioned less photosynthate to the tops and more to the roots than sugarbeets. These data also indicated that the fodder beets partitioned the photosynthate in the roots differently than sugarbeets with less going for sugar storage.

The parameters that make up total sugar yield for the various genotypes were compared in a regression analysis at both N and water levels in Table 4. There was an inverse linear relationship between root yield and dry matter or total sugar concentration in the roots at both irrigation levels within each N level. The total sugar concentration in the fresh roots was primarily dependent upon the dry matter concentration within the roots with a lesser but still important total sugar concentration within the dry matter. Increased N level reduced the total sugar concentration in the fresh roots by reducing the percent dry matter and the total sugar concentration of the dry matter. There was no effect of irrigation level on the total sugar concentrations in the fresh and dry roots or the dry mat-

Table 3. Interaction means for each genotype at each N level and N level means for reducing sugar and total sugars as a percent of dry matter, root percent dry matters, and top, root, and total plant dry matter yields; DM = dry matter.

Beta vulgaris genotype	Reducing Sugars % of DM			Total Sugars % of DM			Root Dry Matter			Dry Matter Yield: Tops			Dry Matter Yield: Roots			Dry Matter Yield: Total		
	196†		392†	196		392	196		392	196		392	196		392	196		392
	%			%			%			metric tons/ha								
GWD2	0.57	*	0.68	75.7		74.7	24.3	*	22.8	5.0	*	7.4	19.3		19.5	24.3	*	26.9
AH10	0.64		0.70	74.1		72.1	24.7	*	23.3	5.7	*	7.8	18.4		18.7	24.1	*	26.5
LHY-1	0.60		0.67	75.2		74.6	24.8	*	23.3	4.8	*	6.8	20.6		20.0	25.4	*	26.9
LHS-1	0.61	*	0.76	75.2		73.3	27.3	*	25.6	4.9	*	6.9	18.5		19.0	23.4	*	26.0
Monorosa	0.67	*	0.83	75.1		73.4	20.5	*	19.4	4.1	*	6.1	18.1	*	19.6	22.2	*	25.7
Monoblanc	0.85	*	1.31	74.9		73.0	19.3	*	17.7	4.2	*	6.2	19.8		19.5	23.9	*	25.6
Pajbjerg Korsroe	2.44		2.63	73.2	*	70.6	16.2		16.0	3.5	*	4.5	19.7	*	21.6	23.2	*	26.1
Rota	2.22	*	2.81	73.0	*	70.3	14.4	*	13.4	3.0	*	4.0	16.7	*	18.5	19.7	*	22.6
LSD (0.05)	0.11		0.11	2.4		2.4	0.5		0.5	0.3		0.3	1.1		1.1	1.2		1.2
Interaction		*			NS			*			NS			*			NS	
N effect means	1.07	*	1.30	74.6	*	72.8	21.4	*	20.2	4.4	*	6.2	18.9	*	19.6	23.3	*	25.8

* Significant interaction at p = 0.05, between N levels means = significant difference between means at p = 0.05.

† kg N/ha.

ter concentration of the various genotypes. Therefore, total sugar yield was primarily dependent upon the dry matter yield at the different irrigation and N levels.

Table 4. Effect of root yield on percent dry matter and percent total sugars, percent root dry matter on percent total sugars, and dry matter yield of roots on total sugar yield as affected by N fertilizer level, and mid- to late-season moisture stress.

N	M_1		M_3	
Fertilizer	Regression equation	r	Regression equation	r
kg/ha	Root yield (yd) on % Dry Matter†			
196	$\hat{y}$ = 41.1 - 0.210 yd	0.92	$\hat{y}$ = 39.1 - 0.197 yd	0.91
392	$\hat{y}$ = 36.3 - 0.154 yd	0.95	$\hat{y}$ = 36.2 - 0.163 yd	0.93
	Root yield (yd) on % Total Sugar‡			
196	$\hat{y}$ = 31.1 - 0.160 yd	0.91	$\hat{y}$ = 29.7 - 0.154 yd	0.90
392	$\hat{y}$ = 27.8 - 0.123 yd	0.94	$\hat{y}$ = 26.6 - 0.123 yd	0.93
	% Root Dry Matter (DM) on % Total Sugar§			
196	$\hat{y}$ =-0.41 + 0.770 DM	0.99	$\hat{y}$ =-0.65 + 0.773 DM	0.98
392	$\hat{y}$ =-1.12 + 0.794 DM	0.98	y =-0.31 + 0.736 DM	0.98
	Dry Matter Yield, Roots (YDM) on Total Sugar Yield¶			
196	$\hat{y}$ =-1.47 + 0.826 YDM	0.96	$\hat{y}$ = 0.30 + 0.725 YDM	0.89
392	$\hat{y}$ = 1.20 + 0.676 YDM	0.85	$\hat{y}$ = 0.69 + 0.683 YDM	0.82

†S_b (Common standard error of the slopes) = 0.011, ‡S_b = 0.009, §S_b = 0.021, ¶Sb = 0.055.

Nearly all the measured factors were affected by increasing the N level on all genotypes (Tables 2, 3). High N levels increased root yield and reducing sugars but decreased the concentrations of sucrose, total sugar and dry matter. This resulted in little difference in total sugars and potential alcohol production between the two N levels except for the fodder beet types.

Genotype x N interactions were largely due to the difference in N treatment effects on the fodder and sugarbeet types. The fodder beets (Pajbjerg Korsroe and Rota) showed a much greater root yield increase and a smaller decrease in total sugar concentration at the higher N level than sugarbeets. This resulted in significant increases in total sugar and potential alcohol production for the fodder beets at the high N level; whereas the sugarbeets showed no difference at the two N levels.

The genotypes produced more dry matter under the high N level with the tops generally showing the greatest increase. The fodder beets yielded significantly more root dry matter at the high N level; whereas the sugarbeets produced essentially the same root dry matter at the two N levels. There was very little difference between the sugarbeet hybrids for total dry matter production at the high N level. The increased dry matter production caused by the higher N levels was mainly partitioned to top growth in the sugarbeet types; whereas in the fodder beet types the extra dry matter and growth was equally divided between the tops and roots.

The N requirement for maximum fermentable sugars and potential alcohol production for the various genotypes, using data from the optimum irrigation level (M_1), were evaluated in Table 5. Previous experiments (5) have shown, because of the linear decrease in sucrose concentration with increasing total available N (N_T), that maximum sucrose yield was obtained at a N_T value that was slightly less than required for maximum root yield. The same criteria should apply for total sugar yield on the various genotypes. The large increase in root yields that occurred for most genotypes with increased N rate indicated that maximum sugar yields would probably occur somewhere between the two application rates of 196 and 392 kg N/ha.

The two N application levels were calculated using a measured $\alpha_n N_n + \alpha_m N_m$ value of 146 kg N/ha and the upper limit of 6 kg N/metric ton in Equation [1] as the optimum N rates for a yield of 57 metric tons (mt) of crowned roots (root minus crown) per hectare for the genotype AH10 if a N fertilizer efficiency (E_f) of 100 and 50% was obtained for the 196 and 392 kg N/ha rates, respectively. From past experiments (2, 5), an average E_f of 65% has been determined and used. However, in this experiment E_f for AH10 was found to be 75% at both N rates. The maximum root yield for the crowned AH10 roots of 71 metric tons/ha was found to be considerably above that used to determine N application rates. If the measured root yield for 392 kg N/ha level is used to determine the N requirements per metric ton of roots, the required kg N/metric ton would be 4.8, 5.6, 6.2, and 7.6 for the 50, 65, 75, and 100% E_f, respectively. Past

experimental work has shown the 5.5 ± 0.5 kg N/metric ton is the optimum N rate for maximum sucrose yield. However, the average N requirement using the actual root yield of the 196 and 392 kg N/ha fertilizer levels for AH10 (roots minus crown) at 75% E_f would be near 5.3 kg N/metric ton (Table 5).

The total N uptake for the various genotypes was quite similar and averaged 258, 274, and 260 kg N/ha on the 196 kg N/ha rate and 400, 429, and 411 kg N/ha on the 392 kg N/ha rate for the sugarbeet, fodder x sugarbeet, and fodder beet types, respectively. Although total N uptakes were similar, a greater proportion of the N was found in the roots of the fodder x sugarbeet and fodder beet types as compared with sugarbeet types (Table 5). The N uptake used to produce a metric ton of sugar was significantly greater at the 392 kg N/ha level than at the 192 kg N/ha level. However, there were no significant differences between genotypes in N uptake per metric ton of sugar produced except for Rota at the 192 kg N/ha level. Similarity between the total N uptake by the various genotypes indicated that the N necessary for maximum total sugar yield would also be similar. This is further verified by the petiole NO_3-N in late August (Table 6). The critical low range for NO_3-N has been established at 1000 ppm (20) and experience in this area indicates that petiole NO_3-N should be near 1000 ppm by late August to maximize yields, sucrose concentration and purity of sugarbeets. In the present work, the petiole NO_3-N concentration in late August was found to be quite similar between the various genotypes at each N level. Based on past experience, the 196 kg N/ha rate was found too low in petiole NO_3-N and 392 kg N/ha rate in slight excess for maximum sucrose and total sugar yields. This would indicate that the same criteria used for determining N needs of sugarbeets may be applicable to fodder x sugarbeet and fodder beet types.

If the sugarbeet N requirements are applicable to fodder x sugarbeet and fodder beet types as they appear to be, the average kg N/metric ton value at 75% N fertilizer efficency for the two fertilizer rates (196 and 392 kg N/ha) in Table 5 should be used in Equation [1] to determine the N needs to maximize sugar production for the various genotypes. The E_f value in

Table 5. Nitrogen available per metric ton of beet roots, percentage of the total N uptake in the tops and roots, plant N uptake per metric ton of roots, and plant N uptake per metric ton of sugar as affected by N fertilizer level and efficiency, and genotype on the M_1 irrigation level; mt = metric tons, R = roots, S = sugar.

Beta vulgaris genotype	Soil† & Fertilizer N					Plant N Uptake							
	100%‡		75%‡			Tops		Roots		Tops & Roots			
	196§	392§	196	392	Avg.	196	392	196	392	196	392	196	392
	kg N/mtR					%				kgN/mtR		kg N/mtS	
GWD2	4.1	6.1	3.5	5.0	4.3	33	38	67	62	3.0	4.8	16.5	27.5
GWD2¶	4.6	6.8	3.9	5.5	4.7					3.4	5.3		
AH10	4.5	6.4	3.9	5.3	4.6	36	41	64	59	3.4	4.9	18.3	29.0
AH10¶	5.2	7.6	4.4	6.2	5.3					3.9	5.7		
LHY-1	4.0	6.1	3.5	5.0	4.3	32	41	68	59	3.2	4.2	17.2	23.9
LHS-1	5.0	7.0	4.3	5.7	5.0	31	37	69	63	3.7	5.1	17.7	26.7
Monorosa	3.7	5.2	3.2	4.2	3.7	22	27	78	73	3.0	4.2	19.6	30.4
Monoblanc	3.2	4.7	2.7	3.8	3.3	27	31	73	69	2.5	3.6	17.2	27.8
Pajbjerg Korsroe	2.8	3.8	2.4	3.1	2.8	23	22	77	78	2.2	3.2	18.6	28.1
Rota	2.9	3.8	2.5	3.1	2.8	17	20	83	80	2.2	2.6	21.4	28.0

† Residual NO_3-N and mineralizable N = 146 kg N/ha. ‡N fertilizer efficiency. §kg N/ha.
¶ Crowns removed for yield determinations.

Table 6. Petiole NO_3-N as affected by N fertilizer level and genotype.

Beta vulgaris genotype	Petiole NO_3-N (21 August)†		*Beta vulgaris* genotype	Petiole NO_3-N (21 August)†	
	196 kg N/ha	392 kg N/ha		196 kg N/ha	392 kg N/ha
	ppm			ppm	
GWD2	110	2180	Monorosa	100	1680
AH10	210‡	2070	Monoblanc	110	2360
LHY-1	280	1960	Pajbjerg Korsroe	250	2560
LHS-1	360	2100	Rota	110	1570

† M_1 irrigation level. ‡Check plots=100 ppm.

Equation [1] can be expected to range from 50 to 75% depending on management practices (2) and it was found to average 65% in previous studies. The main difficulty would be that fodder x sugarbeet and fodder beet types have not been grown in the U.S. for a sufficient number of years to establish the root yield potential for the individual climatic zones. Until the root yield potentials are established, it would be preferable to use the N test for sugarbeets where the root yield potentials are generally known. However, there may be yield benefits to a slightly higher N_T level for fodder beets.

Sugarbeet water requirements have been studied extensively (12) and the general concensus for irrigated areas is that early light irrigations are needed to assure seed germination to establish and maintain a good stand with vigorous early growth. Soil water for the remainder of the season should be maintained at a favorable level to allow sufficient top growth and maintain leaf turgidity so as not to restrict the photosynthetic process. The top growth of the fodder x sugarbeet and fodder beet types was similar to that of the sugarbeets throughout the season so it can be concluded that the water requirements of various genotypes would also be similar. However, the increased top growth early in the season and the late season loss in active leaf area by the fodder beet types, may vary slightly their evapotranspiration rates during that part of the season as compared with sugarbeet types.

There were no N-by-water or genotype-by-water interactions in this experiment. All of the genotypes were affected similarly by water stress at each of the N levels (Table 7). The major effect on each genotype-by-water stress was to reduce the root yield by an average 7%, maintain the sucrose, total sugars, and dry matter concentrations at the M_1 irrigation level, and reduce root and total dry matter yields by an average 5%. Consequently, the total sugar and potential alcohol yields were reduced by water stress an average 7%. This reduction in total sugar yield compares well with the 2% sucrose yield reductions in 1977 (3), 6% in 1978 (3), and 5% in 1979 (4) caused by the irrigation cutoff on 1 August. However, it becomes apparent from comparing sugarbeet yields and yield reductions between

Table 7. Interaction means for each genotype at each moisture (M) level and moisture level means for root yield, total sugar (% and yield), potential alcohol yield, root percent dry matter, and total plant dry matter yields; DM = dry matter, Yd = Yield, mt = metric tons, kl = kiloliters.

Beta vulgaris genotype	Root Yield			Total Sugars				Alcohol			Root DM			DM Yd, Total		
	M_1		M_3	M_1	M_3	M_1		M_3	M_1		M_3	M_1	M_3	M_1		M_3
	mt/ha			%		mt/ha			kl/ha			%		mt/ha		
GWD2	86.0	*	78.7	17.9	17.5	15.4	*	13.8	9.16	*	8.22	23.7	23.4	27.0	*	24.2
AH10	79.8	*	74.8	17.6	17.5	14.0	*	13.1	8.37	*	7.81	24.1	24.0	26.3	*	24.4
LHY-1	87.0	*	82.3	18.1	17.9	15.8	*	14.7	9.40	*	8.76	24.1	24.0	26.9	*	25.3
LHS-1	73.0		69.1	19.9	19.4	14.5	*	13.4	8.62	*	7.98	26.1	26.8	25.0		24.4
Monorosa	98.5	*	90.8	14.7	15.0	14.4		13.6	8.58		8.08	19.7	20.1	24.7	*	23.3
Monoblanc	112.0	*	100.8	13.7	13.6	15.3	*	13.7	9.14	*	8.18	18.3	18.7	25.7	*	23.8
Pajbjerg Korsroe	131.8	*	124.5	11.6	11.6	15.2		14.5	9.06		8.63	15.9	16.4	24.9		24.4
Rota	130.2	*	124.4	9.9	10.1	12.8		12.5	7.63		7.43	13.7	14.1	21.3		21.0
LSD (0.05)	4.7		4.7	0.5	0.5	0.9		0.9	0.53		0.53	0.5	0.5	1.3		1.3
Interaction	NS			NS		NS			NS			NS		NS		
M effect means	99.8	*	93.2	15.4	15.3	14.7	*	13.6	8.74	*	8.14	20.7	20.9	25.2	*	23.8

* Significance interaction at p = 0.05; between M level means = significant difference means at p = 0.05.

years caused by water stress, that yield reductions increase as root and sucrose yields increase. Significant yield reductions caused by water stress only occurred during years or on fields where the root and sucrose yields were higher than average.

Water use by the sugarbeet fodder x sugarbeet, and fodder beet types was quite similar under each irrigation treatment (Figure 2A). When adequate soil water was present, evapotranspiration (ET), estimated from water depletion of the profile

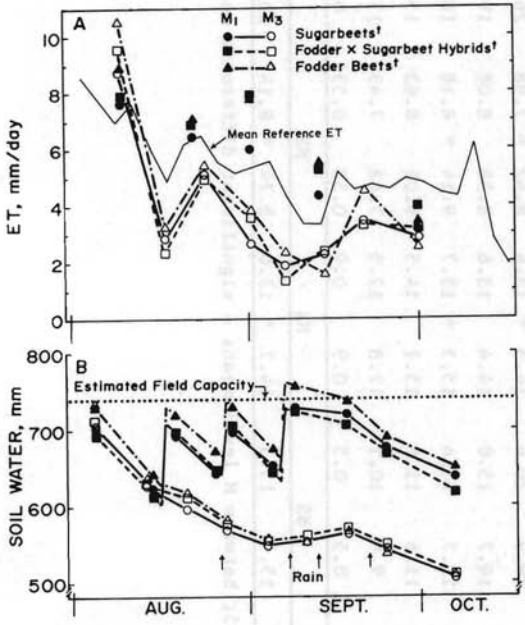

Figure 2. Measured soil water content and evapotranspiration, mean reference ET, and estimated field capacity for 1980 [Estimated field capacity determined at 0.33 bar. Mean (3-day) reference ET (alfalfa) determined by methods of Wright (23)]. †Sugarbeets =GWD2, AH10, LHY-1, and LHS-1; Fodder x Sugarbeet hybrids= Monorosa and Monoblanc; Fodder beets=Pajbjerg Korsroe and Rota.

using average neutron probe measurements for the upper and lower parts of the field on each genotype, followed a rather consistent pattern and was similar to those found in 1977 and 1978 (3), and 1979 (4), as compared with the potential or reference ET (alfalfa, *Medicago sativa* L.) as determined by J. L. Wright using described procedures (23). Evapotranspiration generally decreased after water cutoff on all genotypes as the soil water was depleted and as the potential ET decreased because of lower solar radiation and air temperatures. Evapotranspiration increased after significant effective rainfall on the water cutoff treatment because of the increased surface water. Compared with

the normal irrigation treatment, the water stress treatment reduced total ET by 134 mm when all genotypes were averaged.

The available water in the profile on the water cutoff treatment decreased steadily on all sugarbeet and fodder beet types during August and September without either irrigation or significant rainfall (Figure 2B). The water used for ET came mainly from above the hard layer when irrigation water was adequate. However, as the surface soil dried and approached the wilting range on the irrigation water cutoff treatment as much as 70 to 80% of the water used for ET came from the hard layer and below (60 to 230 cm). The total available water in these silt loam soils between the estimated field capacity (0.33 bar) and the maximum extraction (about 10 bar) is about 260 mm (3). The average total water used by the genotypes between the estimated field capacity and maximum extraction in this experiment was 230 mm of water on the irrigation water cutoff treatment. This demonstrated that 230 mm of available water was present in this soil and that an additional 30 mm of water may become available. Past research with sugarbeets has shown that very little reduction in sucrose yield can be expected by 1 August water cutoff if soil profile is filled with water about 1 August on soils where the usable soil water reservoir is at least 200 mm.

This experiment showed that the different genotypes act similarly under mid- to late-season moisture stress. All genotypes were able to use effectively the soil water below the hard layer probably by root penetration of the hard layer through small cracks or holes made by roots from previous crops having a stronger rooting system such as alfalfa. Mid- to late-season water stress reduced the irrigation water use by all genotypes an average of 24% as compared with the normally irrigated areas with very little total sugar yield reduction. The drought tolerance of the genotypes would allow their growth for alcohol production on land areas of marginal value for most food crops due to limited water for irrigation.

The results of this experiment showed clearly that the higher root yielding fodder beet types had no fermentable sugar yield or other advantages over the higher yielding commercial

or experimental sugarbeet types for alcohol production. In addition, fodder beet types have many disadvantages such as: 1) lower sugar concentration in the root that is due mainly to increased water content; 2) increased weight and volume per unit of sugar that increases the cost of harvesting, hauling to the factory, storage in piles, and processing; 3) increased moisture content decreases the time the roots can be stored in piles; 4) difficulty in defoliation and harvesting using present day equipment because a major part of the storage root is above the soil surface; 5) lack of resistance to curly top; 6) the multigerm seed would prevent mechanical thinning and add to the cost of proper plant spacing.

Using alcohol as a renewable energy source will depend upon the cost in relation to other renewable and nonrenewable energy sources and its priority in relation to food products for land use for biomass production. If alcohol is used to supply part of U. S. energy needs, using the higher yielding sugarbeet varieties presently grown or those developed in breeding programs, could make this crop a primary feedstock source for alcohol production.

SUMMARY

Several genetically diverse *Beta vulgaris* genotypes were grown in a field experiment on a Portneuf silt loam soil to evaluate their fermentable sugar yield potential under moderate and high N levels, and normal and mid- to late-season soil water deficit and plant water stress. The genotypes varied widely in their root yield, sucrose and total sugar concentrations with both N and irrigation water levels. There was an inverse linear relationship between root yield and total sugar concentration, resulting in similar total sugar yields and potential alcohol production among most genotypes. The N requirements for maximum sugar yields were slightly higher for fodder beets as compared with sugarbeets. This resulted from the extra dry matter production with increased N level being mainly partitioned to the sugarbeet tops; whereas with fodder beet types, the extra dry matter and growth were equally divided between the tops and roots. All genotypes were similarly affected by mid- to

late-season water stress and showed an average 7% total sugar yield reduction. The results showed that despite the higher root yields, fodder beet types had no sugar yield or other advantage over the better sugarbeets. Current high yielding sugarbeet hybrids are recommended as feedstock source for alcohol production.

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