Nitrogen Fertilization of Sugarbeet and Fodder Beet for Alcohol Production*

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INTRODUCTION

Alcohol production potentials from feedstocks such as sugarbeet (*Beta vulgaris* L.) and fodder beet continue to stimulate research (5, 13). These root crops store large amounts of potentially fermentable sugars. The harvested root of sugarbeet has higher percent sucrose, thin juice purity and dry matter, and has lower root tonnage than fodder beet (1, 5). The total yield of fermentable sugars per hectare from each of these genetically diverse feedstocks is, however, the major evaluation criterion for alcohol production potential. Although this potential has been reported to be higher for fodder beet cultivated in New Zealand (8), work in the United States suggests no advantage of fodder beet compared to the better commercial sugarbeet cultivars (5).

Nitrogen fertilization of sugarbeets is one of the more manageable areas of sugarbeet production and one of extensive research. Reports of increased fresh root and top yields, decreased sucrose and purity contents as the N levels are increased are numerous (3, 7, 16, 18, 21). Yield-type, as compared to sugar-type sugarbeets, require more N for maximum gross sugar production (2, 10, 17). Although some of the literature suggests a higher N requirement of fodder beet, there is a dearth of information about the relative production level of fodder beet compared to sugarbeet in response to N fertilization. This research was conducted to evaluate the response of

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several sugarbeet and fodder beet-types, as potential feedstocks, to different N management regimes.

MATERIALS AND METHODS

Irrigated field experiments were conducted in 1980 and 1981 at the Colorado State University Research Center near Fort Collins, Colorado. The soil, a Nunn silty clay loam (Aridic Argiustolls; fine, beidellitic, mesic) sampled to a depth of 30 cm for fertility analyses, indicated no limiting nutrients other than N and P (19).

A split plot experimental design replicated four times was used with N application levels as main plots and cultivars as subplots. The N levels for each experiment were based upon the soil fertility analyses. The recommended rate for a 45 metric tons/ha crop of sugarbeet was 168 kg N/ha in 1980 and 140 kg N/ha in 1981. The preplant N application levels as ammonium nitrate were 0, 84, 168 and 252 kg N/ha in 1980 and 0, 140 and 280 kg N/ha in 1981. The equivalent of 50 kg P/ha in 1980 and 35 kg P/ha in 1981, as concentrated superphosphate, was broadcast and disked into the soil in the spring to ensure that P did not limit plant growth.

Four cultivars were planted in six row plots, 56 cm wide and 15.2 m long on April 29, 1980. Three different fodder beet cultivars and a sugarbeet hybrid were planted in six row plots, 56 cm wide and 12.2 m long, on April 14, 1981. The beets were hand-thinned to about 25 cm in-row spacings in mid-June and hand-weeded periodically throughout the season. The cultivars and their characteristics which were utilized in these studies are presented in Table 1. Root yield decreases and sucrose and dry matter percentage increases in a progression from fodder beet to fodder x sugar to sugar x fodder and finally to sugarbeet. Great Western Mono Hy D2 was used as the control in both years. The 1981 fodder beet entries differed from the 1980 entries because of a shortage of seed.

Nitrate-N concentration was determined from petiole samples from fifty of the most recently mature leaves randomly sampled from each plot on July 28 and September 8,

Table 1. Cultivar and beet-types for the feedstocks in the 1980 and 1981 experiments.

Year	Cultivar	Seed Source	Beet-Type*
1980	Mono Hy D2	U.S.	sugar x sugar (sugar type)
	Zwaanpoly	Germany	sugar x sugar (yield type)
	Netherlands A-71	Netherlands	sugar x fodder
	Labora II	Sweden	sugar x fodder
1981	Mono Hy D2	U.S.	sugar x sugar
	Monara	Germany	fodder
	Peroba	Germany	fodder
	Blanca	Netherlands	fodder x sugar

*Personal communication, Dr. G. A. Smith, Research Geneticist, USDA-SEA, Fort Collins, CO 80523.

1980 and August 4 and September 8, 1981. The petioles were cut into 4 cm segments, rinsed in deionized water, dried in a forced-draft oven at 65°C, and ground to pass a 40-mesh screen. The NO_3-N concentrations were determined using a nitrate specific ion electrode (12).

The two center rows, each 15.2 m in length, were harvested per plot on October 24 and 25, 1980. All beets were hand-topped at the base of the actively growing leaf tissue. The crown area was not removed by this topping operation and total root weights were determined in the field. Ten consecutive randomly selected beets per plot were sent to the USDA Sugar Laboratory in Fort Collins, Colorado for the determination of sucrose (11), purity (4), and tare. A tare correction, by cultivar, was then made on the root weights obtained in the field. The tops from the ten-beet samples were weighed in the field for fresh top yield analysis. For root dry matter determination, a 1.5 cm thick slice parallel to the crown area was taken from five randomly selected beets per plot.

In 1981, harvest of 27.4 m of row began on October 24 and was completed on October 27. All beets were hand-topped at the base of the actively growing leaf tissue. Root weights were determined after high pressure mechanical washing. Ten randomly selected beets per treatment were analyzed for sucrose and purity as previously described. The fresh tops from all harvested beets were weighed in the field and subsamples were taken for dry matter determinations. Root dry matter analysis was determined using the brei samples.

Potential alcohol production was calculated from gross sugar, the product of root yield and percentage sucrose, by assuming 0.595 hl alcohol is produced by fermentation of one kg sucrose (5).

RESULTS AND DISCUSSION

Visual observations of cultivars were taken each year for relative disease readings and for the amount of above ground exposure of the root (Table 2). In 1980, Labora II

Table 2. Above ground exposure of the root at harvest and visual disease readings by cultivar for the 1980 and 1981 experiments.

Year	Cultivar	Aerial* Portion	Diseases+ Mildew	Curly Top	Cercospora
		(cm)			
1980	Mono Hy D2	2	low	low	none
	Zwaanpoly	6	low	medium	none
	Netherlands A-71	4	none	medium	none
	Labora II	14	none	low	none
1981	Mono Hy D2	4	medium	low	low
	Monara	11	medium	low	low
	Peroba	9	medium	low	low
	Blanca	10	medium	low	low

*Average measurement throughout the experimental area.
+Rated by visual observation from low (slight) to high (severe) incidence.

had a substantial amount of aerial exposure which led to mechanical problems during harvest and a small decrease in yield. Zwaanpoly and Netherlands A-71 were intermediate in exposure. In 1981, Monara, Peroba and Blanca had similar aerial characteristics which were higher than Mono Hy D2, the sugarbeet check. Field readings on the incidence of powdery mildew, curly top, and Cercospora showed no difference among beettypes. Although not a factor in this experiment, Zwaanpoly has a history of susceptibility to Cercospora, a curly top, Rhizoctonia, and the sugarbeet nematode (*Heterodera schachtii*) (15).

As expected, fresh root yields for the fodder beet cultivars and Zwaanpoly were all higher than the sugarbeet check (Table 3). Root yield included the crown and root since both contain potentially fermentable sugars. Although the main effect of N in 1980 and the N x cultivar interaction had no effect on root yields either year at the five percent probability level, the cultivar differences were substantial. Nitrogen fertilization significantly increased root yields in 1981 at the ten percent probability level. Mono Hy D2, both years, had the lowest root yield of all beet-types. The root yields for the fodder beet genotypes ranged from 84.9 to 122.4 metric tons/ha over the two-year period. Sucrose content in 1980 and 1981 for Mono Hy D2 was the highest of all entries. In 1981, the sucrose contents of Monara, Peroba and Blanca were only about one-half that of the sugarbeet check. Increasing N level generally reduced the sucrose concentration. This effect was greater in 1980 than in 1981. The N x cultivar interaction (Figure 1) in 1980 was caused

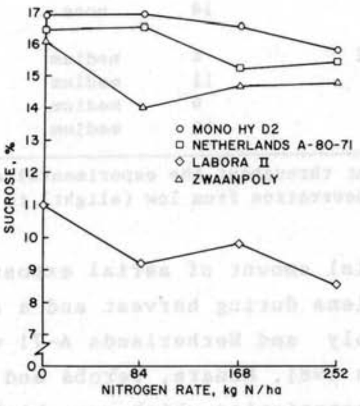

Figure 1. The effect of N rate and cultivar on sucrose content of the root, 1980.

primarily by a greater negative effect of N level on percentage sucrose for Labora II than for the other cultivars.

Potential alcohol yields were calculated from gross

Table 3. Root yield and sucrose percentage as influenced by N rate and cultivar for the 1980 and 1981 experiments.

Cultivar	Root Yield					Sucrose				
	0†	84	168	252	Mean	0	84	168	252	Mean
	metric tons/ha					%				
1980 Experiment										
Mono Hy D2	55.5	62.3	64.4	62.7	61.3	16.0	16.9	16.5	15.8	16.6
Zwaanpoly	84.0	82.9	79.8	85.7	83.1	16.1	14.0	14.7	14.8	14.9
Netherlands A-71	79.9	92.3	87.2	80.0	84.9	16.4	16.5	15.2	15.4	15.9
Labora II	110.9	123.1	122.2	133.3	122.4	10.0	9.2	9.8	8.5	9.6
Mean	82.6	90.2	88.4	90.4		15.1	14.2	14.0	13.6	
N rate LSD*			NS					0.6		
Cultivar LSD#			8.6					0.6		
1981 Experiment										
	0	140	280	Mean		0	140	280	Mean	
Mono Hy D2	50.3	55.5	61.1	55.6		14.3	15.5	14.7	14.8	
Monara	73.6	106.6	104.4	94.8		7.9	7.7	6.2	7.2	
Peroba	70.3	88.3	99.0	85.8		8.6	7.8	7.2	7.8	
Blanca	83.2	83.1	96.9	87.7		9.2	9.4	7.9	8.8	
Mean	69.3	83.4	90.3			10.0	10.1	9.0		
N rate LSD*		NS					0.8			
Cultivar LSD#		13.2					0.9			

*Fisher's protected LSD, P = 0.05 (20); NS = not significant at P = 0.05
#The N x cultivar interaction for percentage sucrose in 1980 was the only interaction significant at the 0.05 probability level. kg N/ha.
†kg N/ha.

sugar, assuming 0.595 hl produced per kg sugar (5). Reducing sugars, an additional source of potentially fermentable sugars which would have increased potential alcohol yields by about 2% (5), were not measured in these experiments. Nitrogen fertilizer recommendations for both sugar-type and fodder-type beets appear to be similar for alcohol production (Table 4). The potential alcohol yields in 1980 for Zwaanpoly, Netherlands A-71 and Labora II were significantly higher than Mono Hy D2. Higher root yields more than compensated for lower sucrose contents to give higher alcohol yields. In 1981, only Blanca compared favorably to Mono Hy D2, with Monara and Peroba both lower in potential alcohol yields. The N x cultivar interaction was not significant at the five percent probability level for either experiment.

The total amount of raw sucrose is the major consideration in sucrose production for potential alcohol. Ideally, a beet crop could be produced for two markets: the alcohol market and the commercial sugar market. The primary evaluation factor for the commercial sugar market is recoverable sucrose which is dependent upon thin juice purity (data not presented) and sucrose content (6, 18). Percentage recoverable sucrose for this study was determined from tables generated from a Great Western Sugar Company formula (9). Recoverable sucrose production per hectare, calculated from percentage recoverable sucrose and root yield, is shown in Table 4. Under the conditions of these test, only Mono Hy D2, Netherlands A-71 and Zwaanpoly would have been suitable for a dual-purpose type cropping system. The N x cultivar interaction for the 1980 experiment was caused largely by the greater negative effect of increasing N level on recoverable sucrose for Labora II than for the other cultivars.

Beet cultivars can be classified according to root color, root shape, yield, sucrose concentration and percentage root dry matter (1, 14). These parameters further delineate the differences between the entries in these studies. In addition, cellulosic crop residues are also

Table 4. Potential alcohol and recoverable sucrose yield as influenced by N rate and cultivar for the 1980 and 1981 experiments.

Cultivar	Potential Alcohol†					Recoverable Sucrose				
	0‡	84	168	252	Mean	0	84	168	224	Mean
	hectoliters/ha					metric tons/ha				
1980 Experiment										
Mono Hy D2	55.8	62.7	63.4	59.0	60.2	7.3	8.1	8.2	7.2	7.7
Zwaanpoly	80.6	69.1	70.1	75.8	73.9	10.5	8.6	8.4	9.2	8.9
Netherlands A-71	78.2	91.1	78.5	73.6	80.3	9.6	11.5	9.2	9.0	9.8
Labora II	72.6	67.4	70.5	67.7	69.5	7.2	5.5	6.0	5.1	6.0
Mean	71.8	72.6	70.6	69.0		8.6	8.2	8.0	7.6	
N rate LSD*			NS					NS		
Cultivar LSD#			6.8					1.0		
1981 Experiment	0	140	280	Mean		0	140	280	Mean	
Mono Hy D2	43.1	51.3	53.4	49.3		5.6	6.6	6.6	6.3	
Monara	34.7	48.8	38.3	40.6		3.1	3.8	2.1	3.0	
Peroba	36.8	40.8	42.3	40.0		3.7	3.5	3.2	3.5	
Blanca	45.4	46.5	46.4	46.1		4.1	4.4	3.9	4.2	
Mean	40.0	46.9	45.1			4.1	4.6	4.0		
N rate LSD*		NS					NS			
Cultivar LSD#		7.1					0.7			

*Fisher's protected LSD, P = 0.05 (20); NS = not significant at P = 0.05.

#The N x cultivar interation for recoverable sucrose in 1980 was the only interaction significant at the 0.05 probability level.

†Assumes 0.595 hectoliters alcohol per kg gross sucrose production.

‡kg N/ha

potential feedstocks for alcohol production. Percentage root dry matter decreased with increased N levels only in the 1980 experiment (Table 5). Mono Hy D2 was the highest in root dry matter content each year. The lower root dry matter percentages were compensated for by the higher fresh root yields of Zwaanpoly, Netherlands A-71 and Labora II to give higher root dry matter yields compared to Mono Hy D2. The higher fresh root yields of the fodder beet-types in 1981, but lower percentage dry matter, did not affect root dry matter yields. Top growth provides an additional material for hydrolytic saccharification processes followed by fermentation and alcohol production. Fresh top yield increased with each increment of fertilizer N (Table 6). Maximum top production occurred at the highest N level in both years. Nitrogen fertilization generally increased top dry matter yield with Mono Hy D2

Table 6. Fresh top yield as influenced by N rate and cultivar for the 1980 and 1981 experiments.

	Fresh Top Yield				
Cultivar	0‡	84	168	252	Mean
	------------ metric tons/ha ------------				
1980 Experiment					
Mono Hy D2	25.0	26.6	29.9	35.0	29.1
Zwaanpoly	20.1	27.5	28.9	29.2	26.4
Netherlands A-71	27.0	25.6	34.4	35.7	30.7
Labora II	16.2	23.0	21.9	23.1	21.1
Mean	22.1	25.7	28.8	30.8	
N Rate LSD*			3.9		
Cultivar LSD#			4.6		
1981					
	0	140	280	Mean	
Mono Hy D2	17.9	22.6	26.2	22.2	
Monara	12.1	17.4	19.4	16.3	
Peroba	12.3	13.2	17.3	14.2	
Blanca	14.8	14.9	16.9	15.5	
Mean	14.3	17.0	20.0		
N rate LSD*		3.4			
Cultivar LSD#		2.6			

*Fisher's protected LSD, P = 0.05 (20).

#N x cultivar interactions not significant at the 0.05 probability level.

‡kg N/ha

Table 5. Root dry matter percentage and root dry matter yield as influenced by N rate and cultivar for the 1980 and 1981 experiments.

Cultivar	Root Dry Matter					Root Dry Matter Yield				
	0†	84	168	252	Mean	0	84	168	252	Mean
	%					metric tons/ha				
1980 Experiment										
Mono Hy D2	24.5	24.1	24.2	23.1	24.0	13.6	15.0	15.6	14.5	14.7
Zwaanpoly	23.4	21.6	21.1	21.3	21.8	19.7	17.9	16.8	18.2	18.2
Netherlands A-71	23.1	22.9	22.9	21.6	22.6	18.5	21.2	20.0	17.3	19.2
Labora II	15.7	14.2	14.0	14.5	14.6	17.3	17.5	17.0	19.3	17.8
Mean	21.7	20.7	20.6	20.1		17.2	17.9	17.4	17.3	
N rate LSD*			1.0					NS		
Cultivar LSD#			0.7					1.7		
1981 Experiment										
	0	140	280	Mean		0	140	280	Mean	
Mono Hy D2	20.1	20.9	21.0	20.7		10.2	11.6	12.9	11.6	
Monara	12.7	12.2	11.3	12.0		9.3	13.0	11.9	11.4	
Peroba	13.0	12.4	11.9	12.4		9.2	11.0	11.6	10.6	
Blanca	14.1	14.4	13.3	13.9		11.7	12.0	13.0	12.2	
Mean	15.0	15.0	14.4			10.1	11.9	12.3		
N Rate LSD*		NS					NS			
Cultivar#		0.9					NS			

*Fisher's protected LSD, P = 0.05 (20); NS = not significant at P = 0.05.
#N x cultivar interactions, not significant at the 0.05 probability level.
†kg N/ha

producing the most top dry matter in 1981 (Table 7). The positive response of both top and root yield to increased N fertilization was evidenced by the increased total dry matter yields in 1981. Top dry matter yield was not determined in the 1980 experiment.

Petiole NO_3-N analysis (22) may also be useful as a N fertilizer management guide with fodder beet for potential alcohol. Petiole NO_3-N increased as the N level increased and decreased as the season progressed (Table 8). The effects of N application, as petiole NO_3-N, were reflected in several final harvest characteristics. In 1980, root yield and potential alcohol were not affected by N treatments, but sucrose and purity contents decreased as petiole NO_3-N increased. As petiole NO_3-N levels increased with increased amounts of N, root yield increased, sucrose decreased and purity decreased for each cultivar. There was no observable relationship between petiole NO_3-N and potential alcohol production. The critical nutrient concentration of 1000 ppm four to six weeks before harvest (22) was not obtained in either 1980 or 1981, even for the zero N rate.

In addition to the agronomic characteristics of the beet-types presented in this study, several important points remain. The higher root yields of the fodder beet cultivars, due to large amounts of water, would increase costs associated with harvesting, transporting and fermenting operations. The greater above ground growth of the roots of several beet-types would require modification of existing commercial sugarbeet harvest equipment. The disease resistance of newly introduced genotypes and detailed economic evaluations of the production costs should be studied before an attempt to cultivate any beet-types as potential feedstocks.

SUMMARY

The response of several sugarbeet and fodder beet-types to different N levels as potential feedstocks was evaluated in field studies in 1980 and 1981 on a Nunn silty clay loam. The sugar-type and yield-type sugarbeets

Table 7. Top dry matter and total dry matter yields as influenced by N rate and cultivar for the 1981 experiment.

Cultivar	Top Dry Matter Yield 0‡	140	280	Mean	Total Dry Matter Yield 0	140	280	Mean
	metric tons/ha							
Mono Hy D2	3.4	3.9	3.8	3.7	13.5	15.5	16.7	15.2
Monara	2.4	3.2	3.2	2.9	11.7	16.2	15.1	14.3
Peroba	2.3	2.4	3.1	2.6	11.6	13.4	14.7	13.2
Blanca	2.6	2.7	2.9	2.7	14.3	14.7	15.8	15.0
Mean	2.7	3.0	3.2		12.8	14.9	15.6	
N Rate LSD*		0.4				2.2		
Cultivar LSD#		0.4				NS		

*Fisher's protected LSD, P = 0.05 (20); NS = not significant at P = 0.05.
#N x cultivar interactions not significant at the 0.05 probability level.
‡kg N/ha

Table 8. Petiole NO3-N as influenced by N rate, sampling date and cultivar for the 1980 and 1981 experiments.

Cultivar	Rate of N					Sampling Date		
	0‡	84	168	252	Mean	July 28		September 8
	ppm							
1980 Experiment								
Mono Hy D2	1550	2230	3060	3600	2610	2850		2360
Zwaanpoly	1540	2700	2890	3730	2710	2930		2500
Netherlands A-71	2060	2050	2830	3590	2630	2750		2510
Labora II	1640	3600	3700	4710	3410	3520		3310
Mean	1700	2640	3120	3910		3010		2670
N Rate LSD*			670				---	
Cultivar LSD#			470				---	
Date LSD			---				240	
1981 Experiment								
	0	140	280	Mean		August 4		September 8
Mono Hy D2	1690	2430	4180	2760		3920		1610
Monara	1050	1800	3550	2130		2950		1310
Peroba	950	1960	3860	2260		3210		1300
Blanca	1330	2410	4100	2610		3810		1410
Mean	1230	2150	3950			3470		1410
N Rate LSD*		880					---	
Cultivar LSD#		410					---	
Date LSD		---					380	

*Fisher's protected LSD, P = 0.05 (20).

#N x cultivar interactions not significant at the 0.05 probability level.

‡kg N/ha

and the sugar x fodder beet-type produced the largest amounts of potential alcohol. The other fodder and fodder x sugar beet-types did not produce competitive levels of potential alcohol. Potential alcohol yields were not affected by N treatment nor was there a significant N rate x beet-type interaction. The favorable recoverable sucrose levels produced from the sugarbeets and the sugar x fodder beet-types show potential for developing a dual-purpose, either sucrose or alcohol, marketing system. In 1980, the optimum N fertilizer rate for potential alcohol was the zero N rate for all genotypes. In 1980 recoverable sucrose was maximized at the 0 kg N/ha or 84 kg N/ha rate, depending upon the cultivar, due to the significant N x cultivar interaction. No difference in potential alcohol and recoverable sucrose was observed with N application in 1981. Nitrogen fertilization had no effect on root yield in 1980, but root yields increased with applied N in 1981. Sucrose and purity contents decreased with higher N fertilization rates for both years, but percentage dry matter decreased only in 1980. Application of N fertilizer generally stimulated top growth to a greater extent than root growth.

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