Response of Eight Sugarbeet Varieties to Increasing Nitrogen Application: I. Root, Sucrose, and Top Yield

W.B. Stevens[1], R.D. Violett[2], S.A. Skalsky[3], and A.O. Mesbah[2].

[1]USDA-ARS Northern Plains Agricultural
Laboratory, Sidney, MT 59270;
[2]University of Wyoming Powell Research and
Extension Center, Powell, WY 82435; and
[3]former graduate research assistant, Department of
Agricultural and Applied Economics,
University of Wyoming, Laramie, WY 82071.

ABSTRACT

Nitrogen (N) management affects the root and top biomass production of sugarbeet (*Beta vulgaris* L.). An interaction between genetic factors and the amount of N applied may influence variety selection for different N management and cropping practices. A three-year field study was conducted with the objective of comparing the relationship between applied N and root, sucrose and top yield for selected commercial sugarbeet varieties. Eight varieties were treated with five amounts of N (0, 90, 179, 269, and 358 kg N ha^{-1}) at a furrow-irrigated site in northwest Wyoming. Variety affected sucrose concentration and sugar loss to molasses (SLM) in all three years, root yield and sucrose yield in one of three years, and top dry matter (TDM) yield and sucrose:TDM ratio in two of three years. All yield parameters were affected by N application rate in all three years. The variety (V) × N interaction was significant for only the sucrose:TDM ratio in two of three years and was most prominent with 0 or 90 kg ha^{-1} applied N at which two varieties produced higher amounts of sucrose per unit TDM than the other six varieties. Results do not suggest that N fertilizer management should be variety-specific, but the significant interaction in sucrose:TDM ratio indicates there may be differences in N response among varieties based on how

they partition photosynthate between roots and tops, especially at low available N. These differences can help determine which varieties are best suited for different management objectives.

Additional key words: *Beta vulgaris*, variety × nitrogen interaction, sugar loss to molasses, sugar, nitrogen rate, nitrogen fertilizer.

INTRODUCTION

Sugarbeet has historically been an important crop in some areas because of its capacity to provide both cash income from the harvested root as well as livestock feed in the form of above-ground biomass (tops) and root processing byproducts such as pulp and molasses. This dual benefit was well-suited to the integrated farming systems common in the early 20th century; however, a shift away from integrated crop-livestock production systems has reduced the economic importance of the practice of grazing tops, virtually eliminating it in some production areas (M. Killen, personal communication, 2008; C. Millard, personal communication, 2008). However, an estimated 25 to 60% of sugarbeet growers in parts of Montana and Wyoming continue to utilize sugarbeet tops for livestock feed and consequently benefit from maximizing both sugar and top production (M. Killen, personal communication, 2008; K. Rassmussen, personal communication, 2008). This presents a contradiction in objectives in that the extra N fertilizer required to enhance top yield is detrimental to sugar yield due to its negative effects on root sucrose content and SLM, a measure of sucrose extraction efficiency (Carter and Traveller, 1981). Response of sugarbeet to N fertilizer application is influenced by factors such as residual soil NO_3-N, weather, irrigation, and fertilizer management. Genetically-controlled factors including root development, top growth characteristics, and root:top ratio also may be important. If sugarbeet varieties respond differently to the amount of available N (i.e., produce a significant V × N interaction), both farmers who specialize in sugar production and those with integrated livestock-sugarbeet systems may be better able to optimize production through variety selection.

Past research on V × N interactions has focused on root yield and quality characteristics with interactions occurring infrequently and inconsistently. In a three-year study, Draycott and Russell (1974) reported significant V × N interactions in individual years, but no interactions were observed from one year to the next and no significant interactions

were detected when individual years were pooled. James et al. (1978) compared the N response characteristics of a large number of varieties in a two-year study and reported significant V × N interactions for both yield and quality, but the consistency of these interactions from year to year could not be evaluated because the varieties and N treatments varied between the study years. Halvorson and Hartman (1980) evaluated the response of five commercial varieties using five N rates one year and three varieties using eight N rates the following year. A response to N application was reported, but the optimum amount of N applied was near the lower end of application range, possibly because the study was conducted on long-term N rate study plots where significant amounts of residual soil NO_3-N (up to 904 kg N ha^{-1}) had accumulated in the higher N rate treatments. The authors reported only a single instance (one year for clear juice purity) of a significant V × N interaction.

These studies present an inconsistent picture regarding variability in N response among sugarbeet varieties and no information is reported on the effect of N application and variety on sugarbeet top production and the relationship between sugarbeet top and sucrose production. Furthermore, it has been over twenty years since the most recent of these studies was conducted. Since that time, sugarbeet genetics have advanced and observations in the field suggest that there may be differences in N response among these newer varieties. Based on these observations, we hypothesize that sugarbeet varieties will differ in their response to applied N. The objectives of this field study were to evaluate commercially available sugarbeet varieties common to northern Wyoming and southern Montana and describe their root yield, root quality and top biomass production response to applied N.

MATERIALS AND METHODS

Field studies were conducted from 2003 to 2005 at the University of Wyoming Research and Extension Center at Powell, WY (44º45'45" N, 108º45'17" W; 1326 m elevation) where conditions and cultural practices are representative of sugarbeet producing areas within the Yellowstone River drainage of northern Wyoming and south central Montana and similar to other regional sugarbeet producing areas in Colorado, Idaho, Nebraska, and eastern Montana. The site is located in the Bighorn Basin of NW Wyoming and has a 30-yr mean annual precipitation and temperature of 185 mm and 7ºC, respectively. The soil belongs to the Garland series (fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Haplargids) typified locally by 0.5 to 1.0 m of moderately fine textured soil underlain by basalt sand, gravel,

and cobbles. In each of the three study years, the plot area was moved to a new location where barley (*Hordeum vulgare* L.) was the preceding crop. Barley straw was removed from the study area by burning in 2003, but was incorporated into the soil by tillage in 2004 and 2005 to better represent grower practices. Selected soil chemical properties of the three study locations are shown in Table 1.

Plots were organized into a split-plot arrangement of a randomized complete block design with three (2003) or four (2004 and 2005) replications. Individual plots were 3.4 m wide (six 56-cm rows) by 10.7 m long. The main plot factor was variety and the subplot factor was amount of N applied. Sugarbeet varieties (Table 2) were selected in con-

Table 1. Chemical characteristics[†] of three study sites at Powell, WY. Sample depth was 15 cm for all properties except for NO_3-N, which determined using a 30-cm sample.

Year	OM	pH	EC	NO_3-N	P	K
	g kg^{-1}		dS m^{-1}	----------- mg kg^{-1} -----------		
2003	12	8.1	1.14	19.0	11	257
2004	10	8.0	1.00	10.2	17	277
2005	15	8.1	1.04	10.0	14	263

[†]   Walkley-Black OM; 1:1 pH; saturated paste EC; KCl-extractable NO_3-N; bicarbonate-extractable P; NH_4OAc-extractable K.

Table 2. Relative root yield and root sucrose of eight sugarbeet varieties evaluated for response to N fertilization at Powell, WY from 2003 to 2005.

Variety	Root yield	Root sucrose
BETA 4546	low	high
BETA 8749	high	low
ACH 9104	high	low
ACH 9902	high	low
HM 9155	high	medium
HM Treasure	high	high
SX Ranger	medium	high
SX Blazer	medium	medium

[†]   Relative to other commercial varieties on the 2003 Western Sugar Approved Varieties list for western Wyoming (Western Sugar Company, 2003).

sultation with local seed company representatives and were commercially available varieties commonly being grown at the time in northern Wyoming and southern Montana. The eight varieties were ranked from low to high in both root yield and root sucrose content based their performance relative to other entries in regional variety performance evaluations (Western Sugar Cooperative, 2003). Sugarbeet seed was planted in late April at a depth of 20 mm into preformed beds (ridges) with a row spacing of 56 cm. After planting, unused seed was placed in a cool, dry storage area so that the same seed lots could be used for all three years of the study. Nitrogen treatments (Table 3) consisted of a control (0 kg N ha^{-1}) and four application rates (90, 179, 269, and 358 kg N ha^{-1}) applied either as a single preplant (PP) application (90 and 179 kg-ha^{-1} treatments) or a split application with 179 kg N ha^{-1} applied PP and the remainder post-emergence at the 8-leaf growth stage (269 and 358 kg-ha^{-1} treatments). As suggested by Stevens et al. (2007), adequate N availability during early growth stages influences sugarbeet yield. Consequently, a single PP application was used for lower N treatments to avoid N deficiency during the critical early growth stages. A split application was used for higher N treatments to reduce the risk of seedling injury due to excessive salinity in the germination zone. Preplant applications were accomplished by broadcasting NH_4NO_3 prilled fertilizer using a drop spreader. The fertilizer was immediately incorporated into the soil to a depth of approximately 5 cm using a harrow. Post-emergence N applications were accomplished by injecting urea-NH_4NO_3 liquid fertilizer (32% N) into the soil using a knife applicator set to place a continuous band of fertilizer approximately 8 cm below the soil surface and 18 cm to the side of the seed row.

Table 3. Amounts of N applied for each fertilizer treatment at Powell, WY from 2003 to 2005. For the lower amounts (90 and 179 kg N ha^{-1}) all N was applied preplant (PP) while for the higher amounts (269 and 358 kg N ha^{-1}) a portion was applied preplant (PP) and the remainder was applied post-emergence (POST) at the 8-leaf growth stage.

Total N applied	N applied PP	N applied POST
----------------	kg ha^{-1}	----------------
0	0	0
90	90	0
179	179	0
269	179	90
358	179	179

Primary tillage was accomplished by moldboard plow in the fall. Secondary tillage consisted of two passes with a seedbed-preparation implement known locally as a roller-harrow, and two passes with a leveling blade to ensure proper water flow in irrigation furrows. Triple-super phosphate fertilizer was broadcast to supply 116 kg P_2O_5 ha^{-1}. Soil test levels of other nutrients were sufficient according to University of Wyoming guidelines (Blaylock et al., 1996).

Dry soil conditions in 2003 and 2004 required that plots be irrigated immediately after planting to initiate seed germination and to fill the soil profile with moisture, but unusually abundant spring moisture eliminated the need for this pre-emergence irrigation in 2005. Post-emergence irrigations were performed in all years to ensure that soil moisture was not limiting. Water was applied using a constant-flow furrow-irrigation system with every other furrow receiving water. Weed and insect control measures were performed in accordance with industry recommendations.

Root samples were collected in late September or early October by manually digging 1.5 m of row from two different rows in the center of each plot for a total of 3 m per plot. Samples were washed, weighed to determine root yield, and analyzed for sucrose content and brei impurities by the Western Sugar Cooperative tare laboratory. Sugar loss to molasses (SLM) was calculated using an empirical formula based on brei Na^+ and K^+ concentrations. Sucrose yield was calculated by multiplying the fresh-weight root yield (Mg ha^{-1}) by the fresh-weight root sucrose concentration (g kg^{-1}) adjusted for SLM (g kg^{-1}). A single sample of eight roots representing all varieties was collected and analyzed for moisture content by weighing before and after drying at 60ºC. Tops (leaves + petioles + crown) were collected from each plot at the same time and from the same 3 m of row as the root samples then placed into plastic tubs and immediately weighed using a basket suspended from a load cell. A sub-sample from each tub was also weighed immediately, dried for 72 hours at 60ºC then weighed again so that top dry matter (TDM) and moisture content of the fresh top tissue could be calculated. Finally, sub-samples were ground using a Wiley mill fitted with a 1 mm sieve, then analyzed for total N using the Dumas combustion technique (Edeling, 1968).

Statistical analysis of data was performed using a procedure for mixed models (SAS Institute, 2003). Year, variety and N rate were considered fixed effects, while block and block interactions were considered random. Year was considered fixed rather than random due to notable differences among the three study years. Moreover, most response variables exhibited year interactions and where thus analyzed within

years. Least squares means with probability differences were estimated
to determine significant differences among treatment means. Mention
of statistical significance refers to a probability level of 0.05 unless
otherwise stated. Quadratic, quadratic-plus-plateau, and linear models
were fit to root yield, sucrose content, and sucrose yield means using the
SAS regression and nonlinear models procedures (SAS Institute, 2003)
and the model with the best fit was selected using R^2 and P values as
selection criteria.

RESULTS AND DISCUSSION

Weather conditions varied markedly over the three years of the
study resulting in significant year (Y) × variety (V) and Y × N effects in
all but two cases (Table 4). Because Y × V and Y × N interactions were
significant, data were not pooled over years. The 2003 average growing
season (April through September) temperature and precipitation were
1.3°C greater than and 85.1 mm less than their respective 21-year aver-
age values of 12.7°C and 136.4 mm. The average temperature during the
2004 and 2005 growing seasons was within 0.3°C of the 21-year aver-

Table 4. Probability values from the multi-year (2003 to 2005) analysis of
variance for a field study evaluating the effects of variety and amount of N
applied (N rate) on sugarbeet yield and quality parameters in Powell, WY.

Source	df	Root yield	Root sucrose	SLM[†]	Sucrose yield	TDM[‡] yield	Sucrose: TDM[¶]
Year (Y)	2	<0.002	<0.001	<0.001	0.317	<0.001	<0.001
Variety (V)	7	0.112	<0.001	<0.001	0.063	<0.001	<0.001
Y × V	14	0.035	0.042	0.955	0.033	0.004	0.027
N rate (N)	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Y × N	8	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V × N	28	0.414	0.255	0.710	0.659	0.967	0.074
V × N × Y	56	0.803	0.960	0.256	0.902	0.392	0.007
N Linear	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N Quadratic	1	<0.001	<0.001	<0.001	<0.001	<0.001	0.792

[†]   SLM is sugar loss to molasses.
[‡]   TDM is top dry matter where top refers to the crown above the lowest leaf
     scar, petioles, and leaves.
[¶]   Sucrose:TDM is the ratio of sucrose yield (kg ha⁻¹) to TDM (kg ha⁻¹).

age, but the precipitation was 40.4 mm less than average in 2004 and 71.1 mm greater than average in 2005. Differences between 2004 and 2005 precipitation amounts occurred mainly during the early growing season (April and May) when rainfall was 24.7 mm below and 67.1 mm above average in 2004 and 2005, respectively. Despite the annual differences, weather conditions were generally favorable for irrigated sugarbeet production, as indicated by average sucrose yields that exceeded 10.5 Mg ha^{-1} in all 3 years (Fig. 1).

N Effect on Root Yield and Quality

The amount of N applied significantly affected all yield components in all years (Table 5). The root yield response in 2003, though statistically significant, was small (Fig. 1a). In 2003, weather conditions favorable for N mineralization along with residual N in the top 30 cm that was approximately twice that of the other two years (Table 1) resulted in atypically high non-fertilizer N availability. Consequently, root yield with no applied N was 63.5 Mg ha^{-1} in 2003 (Fig. 1a) while the same treatment produced more typical values of 41.9 and 46.6 Mg ha^{-1} in 2004 and 2005, respectively (Fig. 1b,c). The more favorable conditions in 2003 led to greater production with lower amounts of applied N than in the other two years. A maximum root yield of 70.4 Mg ha^{-1} was predicted to occur with 206 kg N ha^{-1} in 2003, which is 22% less N fertilizer than to obtain a predicted maximum root yield of 66.4 Mg ha^{-1} in 2004 and 30% less than to obtain a predicted maximum yield of 65.5 Mg ha^{-1} in 2005.

Root quality, as indicated by root sucrose content and SLM, declined as the amount of N applied increased (Figs. 1 and 2). There was a greater detrimental effect of increasing N application on sucrose concentration and SLM in 2003 than in 2004 and 2005, probably due to higher levels of soil-derived N in 2003. Sucrose content decreased 14.4 g kg^{-1} as N application increased from 0 to 358 kg ha^{-1} in 2003 (Fig. 1a) while in 2004 and 2005, decreases of 7.6 and 7.5 g kg^{-1}, respectively, were observed over the same range of N treatments (Fig. 1b, c). Furthermore, the relationship between sucrose concentration and N applied was quadratic in 2004 and 2005 with little or no decrease at low N rates and greater rates of decline at higher levels of applied N. In contrast, the relationship in 2003 was linear with sucrose concentration being reduced by 0.40 g kg^{-1} for every 10 kg N ha^{-1} applied. Similar negative effects of N application on root quality were observed by Carter et al. (1976), who reported negative linear relationships with the slopes ranging from about -0.10 to -0.80 g kg^{-1} for each 10 kg N ha^{-1}, and Carter and

Table 5. Probability values from the multi-year (2003 to 2005) analysis of variance for a field study evaluating the effects of variety and amount of N applied (N rate) on sugarbeet yield and quality parameters in Powell, WY.

	Source	df	Root yield	Root sucrose	SLM[†]	Sucrose yield	TDM[‡] yield	Sucrose:TDM[¶]
2003	Variety (V)	7	0.284	<0.001	0.064	0.099	0.076	0.061
	N rate (N)	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	V × N	28	0.278	0.8718	0.522	0.353	0.918	0.510
	N linear	1	0.034	<0.001	<0.001	0.008	<0.001	<0.001
	N Quadratic	1	<0.001	0.601	<0.001	<0.001	0.003	0.176
2004	Variety (V)	7	0.005	<0.001	<0.001	0.007	<0.001	<0.001
	N rate (N)	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	V × N	28	0.444	0.729	0.093	0.415	0.595	0.002
	N linear	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	N Quadratic	1	<0.001	<0.001	0.271	<0.001	<0.001	0.001
2005	Variety (V)	7	0.277	<0.001	<0.001	0.397	<0.001	<0.001
	N rate (N)	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	V × N	28	0.928	0.569	0.812	0.992	0.262	0.015
	N linear	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	N Quadratic	1	<0.001	<0.001	0.815	<0.001	0.908	0.437

[†] SLM is sugar loss to molasses.

[‡] TDM is top dry matter where top refers to the crown above the lowest leaf scar, petioles, and leaves.

[¶] Sucrose:TDM is the ratio of sucrose yield (kg ha^{-1}) to TDM (kg ha^{-1}).
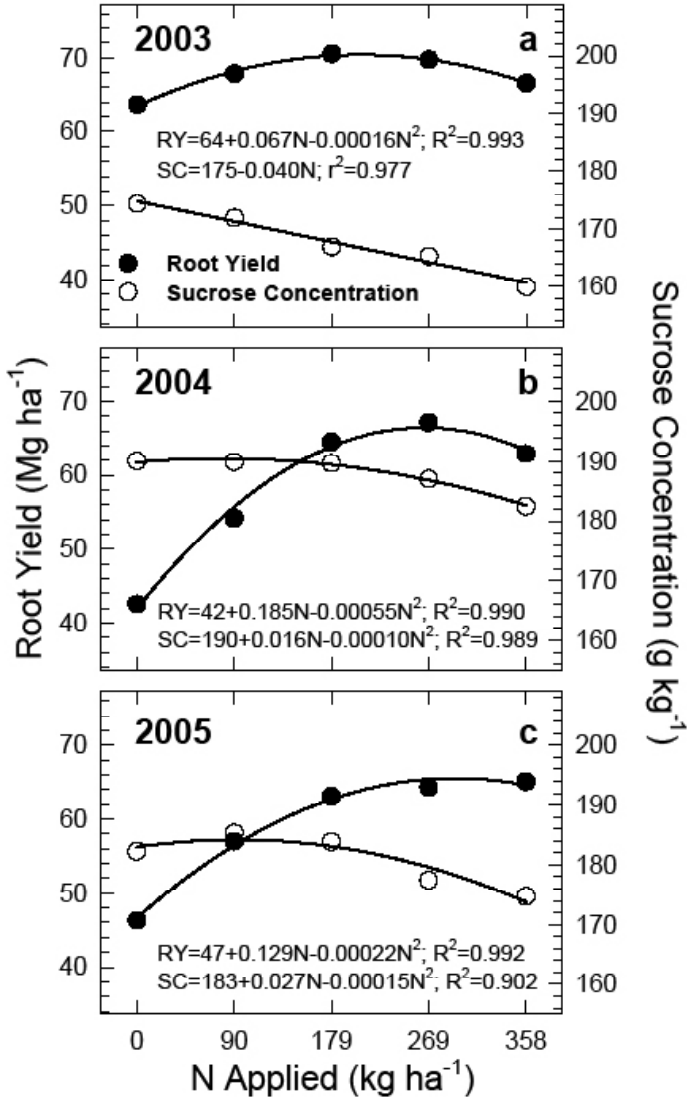
Fig. 1: Root yield (●) and root sucrose concentration (○) as affected by the amount of N applied in each of the three study years. Each data point is the mean of eight varieties and four replications (N=32) for 2004 (b) and 2005 (c). For 2003 (a) there were three replications and eight varieties (N=24).

Traveller (1981), who reported linear declines from -0.40 and -0.67g kg⁻¹ for each 10 kg N ha⁻¹ applied.

Nitrogen-induced SLM is caused primarily by late season accumulation of α-amino N, which interferes with sucrose extraction during factory processing (Harvey and Dutton, 1993). The positive linear relationship between applied N and SLM observed in 2004 and 2005 was expected. Sugar loss to molasses increased 0.022 and 0.026 g kg⁻¹ in 2004 and 2005, respectively, for each 10 kg ha⁻¹ increase in N applied. The unusual results in 2003 revealed that SLM decreased from 12.1 to 9.0 g kg⁻¹ as the amount of N applied increased from 0 to 90 kg ha⁻¹ and then increased sharply as the N applied increased beyond 90 kg ha⁻¹ (Fig. 2). There is no obvious explanation for this unexpected pattern, which was consistent across all eight varieties as indicated by the lack of a significant V x N interaction (Table 5).

N Effect on Sucrose and Top Yield

The response of sucrose yield to added N (Fig. 3) was similar to that of root yield except the rate of decline at higher N levels was greater for sucrose yield due to the compounding effects of decreasing
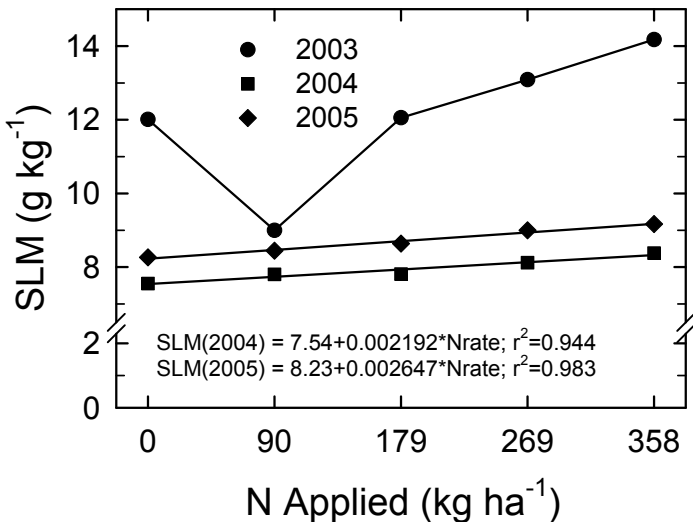
Fig. 2: Sugar loss to molasses (SLM) as affected by the amount of N applied in each of the three study years. Each data point is the mean of eight varieties and four replications (N=32) for 2004 and 2005. For 2003 there were three replications and eight varieties (N=24).
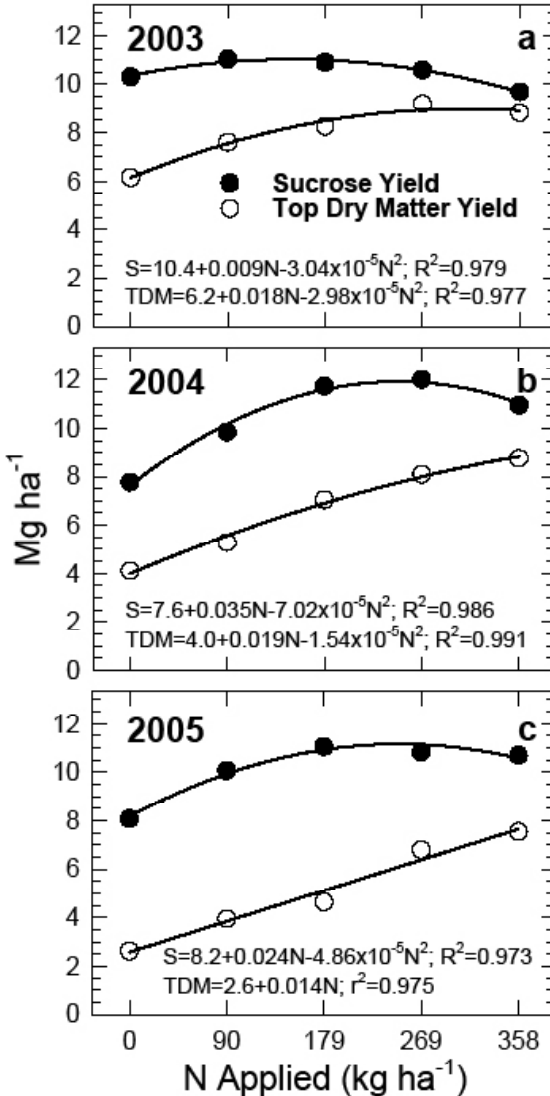
Fig. 3: Sucrose yield (●) and top dry matter (TDM) yield (○) as affected by the amount of N applied in each of the three study years. Each data point is the mean of eight varieties and four replications (N=32) for 2004 (b) and 2005 (c). For 2003 (a) there were three replications and eight varieties (N=24).

sucrose concentration (Fig. 1) and increasing SLM (Fig. 2).

Top dry matter yield increased linearly throughout the range of N applied in 2005, but quadratic responses were observed in 2003 and 2004. Maximum TDM production was predicted to occur at 308 kg ha^{-1} applied N in 2003. Conversely, the N rate at which TDM was maximized could not be estimated for 2004 because the quadratic relationship did not reach a maximum within the range of N applied. That TDM yield reached a maximum only in 2003 is likely the result of the relatively high residual soil NO_3-N carried over from the previous crop and unusually high N mineralization that likely was the result of warmer-than-average weather conditions during that year. The response of TDM to added N was strongly linear in 2005 (Fig. 3c) when there were more typical levels of spring soil NO_3-N while the response in 2004 was intermediate, exhibiting a predominantly linear pattern with only a weak quadratic component (Fig. 3b). It is noteworthy that TDM yield continued to increase in all three years beyond the point that sucrose yield reached a maximum, causing the sucrose:TDM ratio to narrow when the agronomic optimum N application rate with respect to sucrose yield was exceeded.

Variety Effect on Root Yield and Quality

Root yield was affected by variety only in 2004. In 2003, the plant population in one of three replications was reduced by sugarbeet root maggot (*Tetanops myopaeformis* (Röder)) damage. The severity of damage varied among the eight varieties with HM Treasure and BETA 8749 being affected noticeably less than the other six varieties. Despite the insect damage, no differences in root or sucrose yield were observed among varieties in 2003. In 2005, a late spring frost reduced the plant population of BETA 4546 and BETA 8749, which had plant populations of 72% and 83% respectively, of the mean population of the remaining six varieties. Root yield of the two affected varieties were not significantly lower than for the other varieties.

Root quality was affected by variety in all three years (Table 5). Sucrose concentration of roots grown from BETA 4546 and HM Treasure seed were consistently among the highest observed while sucrose concentrations for ACH 9902 and BETA 8749 were typically the lowest (Table 6), consistent with the descriptions in Table 2. The effect of variety on sugar extractability as measured by SLM was consistent across years with ACH 9104 and SX Blazer among varieties with the lowest SLM and BETA 4546, HM 9155 and HM Treasure among those with the highest SLM (Table 6).

Table 6. Yield and quality parameters for eight sugarbeet varieties averaged over five N treatments. Means followed by the same letter within a column and year are not significantly different (*p*<0.05).

Variety	Root yield	Root Sucrose	SLM[†]	Sucrose Yield	TDM[‡] yield	Sucrose:TDM[¶]
	Mg ha^{-1}	g kg^{-1}	g kg^{-1}	Mg ha^{-1}	Mg ha^{-1}	
2003						
ACH 9104	68.0 a	167.6 c	11.48 a	10.63 a	7.64 a	1.48 a
ACH 9902	60.4 a	162.0 d	12.13 a	9.02 a	8.42 a	1.10 a
BETA 4546	70.8 a	172.6 ab	12.75 a	11.27 a	8.37 a	1.50 a
BETA 8749	70.1 a	160.6 d	11.99 a	10.43 a	8.79 a	1.21 a
HM 9155	72.5 a	168.2 bc	12.51 a	11.22 a	9.02 a	1.26 a
HM Treasure	67.8 a	173.3 a	12.10 a	10.93 a	6.81 a	1.73 a
SX Blazer	64.4 a	169.5 abc	11.65 a	10.15 a	7.98 a	1.36 a
SX Ranger	67.4 a	167.7 c	11.93 a	10.47 a	7.04 a	1.70 a
2004						
ACH 9104	60.6 ab	186.4 b	7.60 d	10.83 ab	6.40 cd	1.78 ab
ACH 9902	58.5 abc	186.1 cd	7.82 cd	10.42 abc	7.69 a	1.45 c
BETA 4546	57.7 bc	193.4 a	8.57 a	10.68 ab	6.08 d	1.80 ab
BETA 8749	63.8 a	183.3 e	7.86 bcd	11.18 a	7.08 b	1.69 b
HM 9155	53.1 c	187.6 bcd	8.20 b	9.49 c	6.66 bc	1.50 c
HM Treasure	62.2 ab	188.9 bc	8.12 bc	11.20 a	5.97 d	1.92 a
SX Blazer	53.3 c	189.9 b	7.56 d	9.71 c	6.90 bc	1.46 c
SX Ranger	56.9 bc	186.9 cd	7.75 d	10.16 bc	6.47 bcd	1.66 b
2005						
ACH 9104	61.1 a	180.3 bcd	7.98 c	10.52 a	4.72 d	2.60 a
ACH 9902	62.1 a	177.2 de	8.68 bc	10.43 a	6.06 a	2.05 de
BETA 4546	53.4 a	189.4 a	9.46 a	9.49 a	3.93 e	2.61 a
BETA 8749	60.5 a	175.6 e	8.36 c	10.08 a	4.87 cd	2.31 bc
HM 9155	55.7 a	179.0 cde	9.03 ab	9.44 a	5.63 abc	1.91 de
HM Treasure	61.5 a	183.2 b	8.82 bc	10.79 a	5.12 bcd	2.46 ab
SX Blazer	60.3 a	179.9 bcd	8.52 bc	10.31 a	5.74 ab	2.02 de
SX Ranger	58.7 a	181.3 bc	8.77 bc	10.11 a	4.97 cd	2.21 cd

[†] SLM is sugar loss to molasses.

[‡] TDM is top dry matter where top refers to the crown above the lowest leaf scar, petioles, and leaves.

[¶] Sucrose:TDM is the ratio of sucrose yield (kg ha^{-1}) to TDM (kg ha^{-1}).

Variety Effect on Sucrose and Top Dry Matter Yield

As with root yield, sucrose yield varied among varieties only in 2004 (Table 5). The reduction in plant population due to the 2005 spring frost did not affect root or sucrose yield, but it did reduce top production for BETA 4546 and BETA 8749, which produced the lowest and third-lowest TDM yields in 2005 (Table 6). HM Treasure was typically among the varieties with the lowest TDM yield, despite consistently producing among the highest plant populations. This combined with this variety's tendency to produce among the highest root and sucrose yields (Table 6) suggests a genetic characteristic favoring root growth over top growth. ACH 9104 was also consistently among the lowest TDM producers while ACH 9902 was among the highest. In 2003 and 2004, BETA 8749 produced the second highest TDM yield. The eight varieties differed in their TDM yield and sucrose:TDM ratio in all years, with varietal differences in TDM and sucrose:TDM ratio significant in 2003 at a 90% confidence level (Table 5).

Variety × N Interaction

The V × N interaction was not significant for sucrose yield, its components or TDM yield in any of the three years (Table 5), contradicting the hypothesis that sugarbeet varieties respond differently to applied N. Much of the previous research reporting N response of multiple sugarbeet varieties reported similar results (Draycott and Russell, 1974; Halvorson and Hartman, 1980; Krantz and McKenzie, 1954). Other studies reported either inconsistent interactions (Bauer et al., 1974) or interactions for only one characteristic (Follett et al., 1964; Doxtator et al., 1965).

While there was no V × N interaction for sucrose yield or TDM yield individually, the interaction was significant in 2004 and 2005 for the sucrose:TDM ratio (Table 5), which is useful for identifying which varieties are best suited for sucrose production alone and which may be more effective if TDM production is also a production goal. The eight varieties were combined into three groups based on the similarities in their response patterns over the range of N treatments. Group 1 (ACH 9104, BETA 4546 and HM Treasure) produced a relatively high amount of sucrose per unit TDM; Group 2 (HM 9155 and SX Blazer) consistently produced a more balanced ratio than Group 1; and Group 3 (ACH 9902 and BETA 8749) produced the lowest ratios in 2003, ratios similar to Group 2 in 2003 and ratios similar to Group 1 in 2005 (Fig. 4). The sucrose:TDM ratio generally decreased for all varieties as the amount of N applied increased. This was expected since TDM typically responds to applied N beyond the point where sucrose response reaches a maximum (Fig. 3; Carter and Traveller, 1981). In 2004, all varieties produced simi-
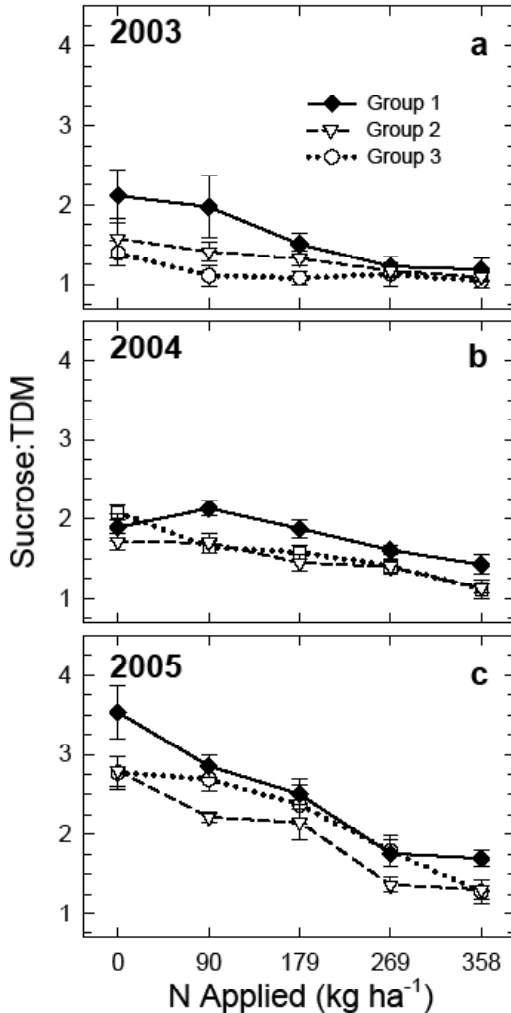
Fig. 4: The ratio of sucrose yield to top dry matter yield (TDM) as affected by the amount of N applied for eight sugarbeet varieties in each of the three study years. Group 1 includes four varieties (ACH 9104, BETA 4546 and HM Treasure) while Group 2 (HM 9155 and SX Blazer) and Group 3 (ACH 9902 and BETA 8749) each consist of two varieties. Treatments were replicated four times in 2004 (b) and 2005 (c), and three times in 2003 (a). Error bars represent the standard errors of the mean.

lar sucrose:TDM ratios when no N was applied, but the ratio widened for Group 1 as the N applied increased to 90 kg ha^{-1} while remaining constant or narrowed slightly for the remaining two groups (Fig. 4b). Beyond 90 kg N ha^{-1}, the ratios for all three groups declined at approximately equal rates. In 2005, the sucrose:TDM ratio was substantially higher for Group 1 than for Group 2 and Group 3 when no N was applied (Fig. 4c). The ratio declined for all three groups as N applied increased to 90 kg ha^{-1}. There were no clear interactions observed as the N rate increased from 90 to 269 kg ha^{-1}, but between 269 to 358 kg ha^{-1} N applied, the sucrose:TDM ratio changed very little for Group 1 and Group 3 while it continued to decline for Group 2 approaching 1 at the highest N rate. One of the varieties in this group, ACH-9902, consistently exhibited the lowest sucrose:TDM ratio of all eight varieties at 358 kg ha^{-1} N applied (data not shown) while producing a relatively high sucrose yield in 2004 (Table 6) suggesting it may be beneficial where both sucrose and TDM production are desired. Similarly, the other Group 2 variety (BETA 8749) produced a high sucrose yield while yielding relatively high TDM (Table 6). Conversely, ACH 9104 and HM Treasure from Group 1 produced high sucrose yields with low TDM (Table 6) resulting in high sucrose:TDM ratios, indicating they may be preferable varieties when sucrose yield is the sole production objective. The varieties in Group 1 appear to be especially effective at producing sucrose at suboptimum levels of available N as evidenced by their high sucrose:TDM ratios at 0 and 90 kg N ha^{-1} applied (Fig. 4). There is no clear indication which varieties might be preferred where available N is excessive. HM Treasure and BETA 4546 produced the highest amount of sucrose per unit of TDM in 2004 (Fig. 4b) along with relatively high sucrose yields (data not shown), but the pattern was not consistent in other years.

Generally, these results do not support the hypothesis that sugarbeet varieties respond differently to N fertilization and do not justify adjustment to N fertilizer recommendations for individual varieties. Conversely, the work of James et al. (1978) provides evidence that sugarbeet varieties respond differently to the amount of N applied. One possible reason for the disagreement is that the range of genetic diversity represented by the 20 varieties evaluated by James et al. (1978) was wider than in most other studies, including the one reported herein. Varieties included in our study and that of Halvorson and Hartman (1980) were limited to commercially available varieties which are probably more genetically similar than the 16 noncommercial lines and four commercial varieties evaluated by James et al. These researchers' approach is beneficial for determining the potential in parental lines for developing varieties that will perform under specific N availability situations; however, our objective was to

determine if there is justification to vary N fertilizer management depending on which commercial variety is grown. While our results generally support those of Halvorson and Hartman (1980) in indicating that the amount of N fertilizer need not be varied for different sugarbeet varieties, the significant interaction in sucrose:TDM ratio suggests that there may be small differences in N response among varieties based on how they partition photosynthate between roots and tops, especially at low levels of available N. Further research on this topic may be justified, especially in light of recent dramatic increases in the cost of N fertilizer and a recent transition from conventional sugarbeet varieties to transgenic herbicide-resistant varieties.

ACKNOWLEDGMENTS

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