Relationships Among Components of Yield and Quality of Sugarbeets

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INTRODUCTION

Recoverable sucrose/ha and recoverable sucrose/ton are of prime economic importance to sugarbeet *(Beta vulgaris* L.) producers and processors, respectively. Understanding relationships among the components of these traits is necessary for maximizing progress in a breeding program or as a basis for recommending management practices. Recoverable sucrose/ton, a measure of sugarbeet quality, is determined by sucrose concentration and the concentration of various impurities that interfere with sucrose extraction; primarily potassium, sodium and amino-nitrogen (Carruthers & Oldfield, 1962). Root yield also influences recoverable sucrose/ha.

Alexander (1971) discussed the factors influencing sugarbeet quality and interactions that may occur among traits related to quality. Hills et al. (1954) pointed out that sugar storage occurs at the expense of root and top growth. A "high tonnage" cultivar consistently produced more sucrose/ha than did a "high sugar" cultivar at various yield levels. Powers et al. (1963) found that sucrose concentration and purity (the ratio of sucrose to total soluble solids) were negatively associated with those characters with which weight per root was postively associated and positively associated with characters with which weight per root was negatively associated. Powers and Payne (1964) found that total nitrogen and percent sucrose were negatively associated in

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a study of 20 sugarbeet hybrids. The association between nitrogen content and purity suggested that high purity levels were not possible without low total nitrogen concentration. Smith, Hecker, and Martin (1979) showed the predominate effect of root weight on recoverable sucrose yield. Sucrose concentration had a greater effect on recoverable sucrose than purity percent. Path-coefficient analysis suggested that one or more of the nitrogenous compounds; nitrate-nitrogen, amino-nitrogen, or betaine, strongly affected purity. The relative importance of the components of recoverable sucrose was not changed by ploidy level. In a study of the effect of nitrogen fertility level on yield and quality components of 28 genotypes, Smith and Hecker (1973) concluded that a compromise of maximum root weight probably would be necessary to achieve significant increases in recoverable sucrose/ton.

Campbell and Kern (1982) found minor differences among cultivars for recoverable sucrose/ton and recoverable sucrose/ha compared to the differences observed for the components of these traits. Smith, Martin, and Ash (1977) found rather narrow ranges in percent purity in contrast to the components that affected purity. They suggested that any model developed to explain variation in purity should include sodium, potassium, betaine, and possibly nitrate-nitrogen, amino-nitrogen, and sucrose. They pointed out that there is no universal model to explain purity over wide combinations of genotypes, soils, nitrogen fertility levels, and plant population densities. Smith and Martin (1977) observed a low incidence of significant interactions among cultivars, nitrogen fertility level, and plant densitites. Shore et al. (1982) found an inverse relationship between amino-nitrogen and sucrose percent. This relationship was similar in sugarbeets grown on two contrasting soil types. Dudley and Powers (1960) reported a strong positive association between sodium and potassium.

This study investigated relationships among the components of economically important traits of commercial sugarbeet hybrids grown in a major sugarbeet production region, the Red River Valley of North Dakota and Minnesota.

MATERIALS AND METHODS

All analyses were based upon commercial sugarbeet variety trials conducted by American Crystal Sugar Company** (Watkins, 1976) at Wahpeton, ND; Moorhead, MN; Hillsboro, ND; Crookston, MN; East Grand Forks, MN; and Drayton, ND, from 1975 through 1978. The following cultivars were included: HH 21, Bush Monofort, Bush Mono, GW Mono-Hy D2, GW Mono-Hy R1, Beta 1934, Beta 1345, Beta 932, Beta 1443, ACH 14, and ACH 17. All cultivars were replicated four times within each environment.

Plots were thinned to a population of 58,710 plants/ha. Row spacing was 56 cm. Harvested area was 8.5 m^2. Percent sucrose, sodium, potassium, and amino-nitrogen were determined by standard tare laboratory procedures used by American Crystal Sugar Company. Sodium, potassium, and amino-nitrogen were used to calculate the know sucrose loss (Caruthers & Oldfield, 1962). Recoverable sucrose/ton was total sucrose/ton minus the know sucrose loss/ton. Recoverable sucrose/ha equaled recoverable sucrose/ton times root yield. Calculations to determine recoverable sucrose/ton and recoverable sucrose/ha were based upon samples independent of those used to measure the individual components.

A combined analysis of variance, assuming fixed cultivar effects and random replicate and environmental effects, was used to determine the significance of cultivar and cultivar x environment effects (Tai, 1971). Path-coefficient analysis (Li, 1956; Dewey & Lu, 1959) was used to measure relationships of components to recoverable sucrose/ton and recoverable sucrose/ha. The components of recoverable sucrose/ton were sucrose, sodium,

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potassium, and amino-nitrogen concentration. Root yield as an additional component for recoverable sucrose/ha.

RESULTS AND DISCUSSION

Means for recoverable sucrose/ha and recoverable sucrose/ton are presented in Table 1. Cultivar means for recoverable sucrose/ha ranged from 6262 kg/ha for ACH-14 to 6954 kg/ha for Bush Monofort. ACH-14 exhibited the highest recoverable sucrose/ton with 141 kg/metric ton compared to the low of 125 kg/metric ton for Beta 1934.

An analysis of variance indicated significant (P 0.05) cultivar effects for all characters studied. Significant cultivar x environment interactions indicated that cultivars responded differently to the varied environmental conditions for all traits except amino-nitrogen. Environmental means for recoverable sucrose/ha ranged from 3661 kg/ha at Drayton in 1975 to 9202 kg/ha at Crookston in 1978. Cultivar x environment means ranged from 3260 kg/ha for ACH 17 at Drayton in 1975 to 10334 for Bush Monofort at Hillsboro in 1977. Recoverable sucrose/ton environment means ranged from 98 kg/metric ton at Wahpeton in 1977 to 174 kg/metric ton at Wahpeton and Hillsboro in 1975. ACH-14 had the highest cultivar x environment mean for recoverable sucrose/ton with 184 kg/metric ton at Wahpeton and Hillsboro in 1975 and 1976, respectively, compared to 91 kg/metric ton for Beta 1934 in 1978 at Moorhead.

Simple correlations among the component traits are shown in Table 2. Root yield was positively associated with amino-nitrogen, sodium, and potassium, whereas

Table 2. Correlation coefficients for yield and quality components of 11 sugarbeet cultivars.

	Sucrose	Amino-nitrogen	Potassium	Sodium
Root yield	-0.54 **	0.55 **	0.15 *	0.31 **
Sucrose	---	-0.57 **	-0.19 **	-0.65 **
Amino-nitrogen	---	---	0.30 **	0.48 **
Potassium	---	---	---	0.24 **

*, ** Significant at P 0.05 and 0.01, respectively.

Table 1. Cultivar means for recoverable sucrose/ha, recoverable sucrose/ton, and their components.

Cultivar	Recoverable sucrose		Root yield	Sucrose	Amino-nitrogen	Potassium	Sodium
	kg/ha	kg/metric ton	metric tons/ha	%	ppm	ppm	ppm
Bush Monofort	6954	136	51	15.8	688	2283	687
GW Mono-Hy R1	6851	132	52	15.3	716	2143	505
Beta 1934	6817	125	55	15.0	757	2465	731
Beta 1443	6724	131	54	15.4	747	2433	665
Beta 932	6722	129	53	15.3	760	2375	669
Bush Mono	6718	131	53	15.3	701	2341	732
HH21	6709	129	52	15.3	715	2377	593
Beta 1345	6707	135	50	15.8	732	2360	629
GW Mono-Hy D2	6651	131	52	15.2	749	2246	495
ACH-17	6642	130	52	15.1	690	2160	627
ACH-14	6262	141	45	16.3	708	2159	597
Mean	6706	132	52	15.4	724	2304	629
LSD_{05}	232	2	2	0.2	29	56	38

sucrose percent was negatively associated with all three. Amino-nitrogen appeared to be closely associated with both

Table 3. Correlations and path-coefficients showing direct and indirect effects of yield components on recoverable sucrose/ha ($R^2 = 0.64$).

Character analyzed	Coefficient
Root yield vs. recoverable sucrose/ha	
direct effect	0.96
indirect effect via sucrose %	-0.22
indirect effect via amino-nitrogen	0.05
indirect effect via potassium	0.01
indirect effect sodium	0.02
Total correlation	0.79**
Sucrose % vs. recoverable sucrose/ha	
direct effect	0.38
indirect effect via root yield	-0.53
indirect effect via amino-nitrogen	0.06
indirect effect via potassium	0.01
indirect effect via sodium	0.04
Total correlation	-0.04
Amino-nitrogen vs. recoverable sucrose/ha	
direct effect	-0.10
indirect effect via root yield	0.54
indirect effect via sucrose %	-0.22
indirect effect via potassium	-0.02
indirect effect via sodium	-0.03
Total correlation	-0.15**
Potassium vs. recoverable sucrose/ha	
direct effect	-0.06
indirect effect via root yield	0.15
indirect effect via sucrose %	-0.07
indirect effect via amino-nitrogen	-0.03
indirect effect via sodium	-0.02
Total correlation	-0.03
Sodium vs. recoverable sucrose/ha	
direct effect	-0.07
indirect effect via root yield	0.30
indirect effect via sucrose %	-0.25
indirect effect via amino-nitrogen	-0.04
indirect effect via potassium	-0.02
Total correlation	-0.11

** Indicates correlation coefficient is significant at $P < 0.01$.

root yield and sucrose percent. Amino-nitrogen, sodium, and potassium were all positively correlated with each other. The negative correlation between root yield and sucrose percent indicated difficulty in simultaneously improving both recoverable sucrose/ha and recoverable sucrose/ton.

Estimates of direct and indirect effects of the components on recoverable sucrose/ha (Table 3) revealed a relatively large positive direct effect of root yield on recoverable sucrose/ha. Sucrose percent had a positive direct effect accompanied by a large negative indirect effect of root yield, resulting from the negative association between sucrose percent and root yield. This resulted in a near zero correlation between sucrose percent and recoverable sucrose/ha. These results and the narrow range of sucrose percent, relative to root yield, imply that root yield should be given prime consideration in increasing recoverable sucrose/ha. Increasing sucrose percent would have a lesser effect because of the negative association with root yield. Amino-nitrogen appeared to be the most important impurity component with only a minimal effect on recoverable sucrose/ha.

Path-coefficient analysis of recoverable sucrose/ton (Table 4) emphasized the importance of sucrose percent. A major direct effect and a high correlation between recoverable sucrose/ton and sucrose percent were observed. Amino-nitrogen had a greater direct effect on recoverable sucrose/ton than sodium or potassium. All three impurities were negatively correlated with recoverable sucrose/ton. The association between sucrose percent and the three impurities again is apparent in the negative indirect effects for sucrose percent on the correlation between the three impurity components.

While the above analysis would indicate that concern for root yield and sucrose must be predominant in a breeding or management program, other quality components should not be completely disregarded. The correlation between recoverable sucrose/ha and recoverable sucrose/ton

Table 4. Correlations and path-coefficients showing direct and indirect effects of quality components on recoverable sucrose/ton ($R^2 = 0.88$).

Character analyzed	Coefficient
Sucrose % vs. recoverable sucrose/ton	
direct effect	0.75
indirect effect via amino-nitrogen	0.13
indirect effect via potassium	0.02
indirect effect via sodium	0.01
Total correlation	0.91**
Amino-nitrogen vs. recoverable sucrose/ton	
direct effect	-0.23
indirect effect via sucrose %	-0.42
indirect effect via potassium	-0.03
indirect effect via sodium	-0.01
Total correlation	-0.69**
Potassium vs. recoverable sucrose/ton	
direct effect	-0.09
indirect effect via sucrose %	-0.14
indirect effect via amino-nitrogen	-0.07
indirect effect via sodium	-0.01
Total correlation	-0.31**
Sodium vs. recoverable sucrose/ton	
direct effect	-0.02
indirect effect via sucrose %	-0.49
indirect effect via amino-nitrogen	-0.11
indirect effect via potassium	-0.02
Total correlation	-0.64**

** Indicates correlation coefficient is significant at P 0.01.

was near zero, indicating that relatively high per hectare yields of quality sugarbeets are possible with proper management and choice of cultivar. Bush Monofort, GW Mono-Hy R1, Beta 1934, Beta 1443, and Beta 932 were not significantly different for recoverable sucrose/ha, but ranged from 125 kg/metric ton to 136 kg/metric ton for recoverable sucrose/ton. Bush Monofort had a high sucrose percent and low amino-nitrogen concentration. GW Mono-Hy R1 had low levels of the three impurities and near average root yield and sucrose. Beta 1934 achieved its high recoverable sucrose/ha by producing high root yields.

The extent the observed relationships would apply to other production areas and cultivars is not known. However, the results are in general agreement with those involving other regions and genotypes. The predominant effect of root yield upon recoverable sucrose/ha and the negative association between root yield and sucrose percent have been observed under diverse conditions with numberous genotypes (Hills et al., 1954; Powers et al., 1963; Smith & Hecker, 1973). The relative importance of nitrogen containing compounds (including amino-nitrogen) as impurities has been documented under varied conditions (Powers & Payne, 1964; Smith & Martin, 1977; Shore et al. 1982). The role of nitrogen in determining sugarbeet quality emphasizes the need for proper nitrogen fertilizer management.

The results indicate that processors seriously wanting high quality beets must be willing to compensate producers for the decrease in recoverable sucrose/ha usually associated with improved quality. The data also indicate that proper management and cultivar choice can influence quality at a given level of scurose/ha. The negative association between sucrose and root yield probably will complicate breeding for high quality and yield. However, the differing levels of the various components in relatively high yielding cultivars indicates the possibility of some improvement.

SUMMARY

Recoverable sucrose/ton and recoverable sucrose/ha are economically important to sugarbeet (*Beta vulgaris* L.) processors and producers, respectively. Recoverable sucrose/ton is a function of sucrose percent and the concentration of various impurities (e.g. sodium, potassium, and amino-nitrogen) that interfere with sucrose extraction. Root yield is an additional factor in determining recoverable sucrose/ha. Data from 23 environments and 11 sugarbeet cultivars were used as a basis for examining relationships among these traits. Path coefficient analysis indicated that variability in sucrose

concentration had a major effect on recoverable sucrose/ton. The major factor influencing recoverable sucrose/ha was root yield, followed by sucrose concentration. Sodium, potassium, and amino-nitrogen were positively correlated with each other and with root yield and negatively correlated with sucrose concentration. The consistency of relative amino-nitrogen concentration over environments and its relatively large influence on recoverable sucrose/ton suggest that it should be given prime consideration in any attempt to lower impurity levels.

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