The effect of plant population and nitrogen level on sugar yield and juice purity of sugar beet (*Beta vulgaris*)

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Abstract

Sugar beet production has been examined previously in New Zealand and sugar yields have been high, with 10-12 t/ha commonly produced. However while commercial sucrose production depends on the percentage of the sucrose that can be extracted from the juice, this has not previously been examined in New Zealand. The objective of this research was to examine the effect of nitrogen level and plant population on sugar yield and juice purity of sugar beet in the Manawatu under dryland conditions.

Monogerm seed of sugar beet cv. Gala was grown at five levels of N (0, 90, 180, 270 and 360 kg N/ha) and 5 plant population densities (60,000, 80,000, 100,000, 120,000 and 140,000 plants/ha) in factorial combination. There were four replicates in a randomised complete block design. Root yield, sucrose yield and juice purity were measured, and juice purity was calculated from the concentration of Na, K and α-amino N.

Only the interaction between N level and population density significantly affected root yield. Maximum root fresh weight was at 360 kg N/ha and 60,000 plants/ha. Maximum sugar yield was at 180 kg N/ha and at 80,000 plants/ha. Juice purity ranged from 91% at 0 N/ha to 80% at 360 kg N/ha, and from 89% at 140,000 plants/ha to 82% at 60,000 plants/ha.

Maximum extractable sucrose yield was at 180 kg N/ha and at population densities from 80,000 to 140,000 plants/ha. That is, extractable sucrose yield was insensitive to population density from 80,000 plant/ha and greater, but decreased when N level exceeded 180 kg N/ha. These results illustrated the disparity between measurements of total and commercial extractable sucrose yield and suggested that extractable sucrose yield was relatively more sensitive to N level than population density.

Additional key words: Beta vulgaris *L., sucrose production, sucrose extraction, dryland, juice purity, root yield*

Introduction

Sugar beet (*Beta vulgaris* L.) is used worldwide for sugar production, but currently sugar is not produced in New Zealand. Nevertheless, there has been a history of sugar beet research in New Zealand that has examined sugar yields and the potential of sugar beet as a source of sugar for fermentation to ethanol for use as fuel (Greenwood, 1980; Martin, 1980). McCormick and Thomsen (1983) concluded that commercial yields of 10-11 t sucrose/ha were possible.

When sugar beet is grown for sucrose production, the percentage of the sucrose that can be extracted from the juice is important (Smith *et al.*, 1977), yet this appears not be have been examined in New Zealand. Sucrose extraction is affected by the presence of potassium, sodium, α-amino nitrogen and other non-sucrose substances in the juice. Alexander (1971) found that each kg of non-sucrose substance in sugar beet juice inhibited crystallisation of 1.4 to 1.8 kg of sucrose, which is then lost to molasses.

Apart from juice purity, the sucrose yield of sugar beet is influenced by root yield and the sucrose concentration of the roots. Both the level of nitrogen applied and plant population density are known to affect juice purity, sucrose concentration and root yield, and thereby sucrose yield (Draycott and Webb, 1971; Follett, 1991). The objective of this experiment was to examine the effect of nitrogen level and plant population density on the juice purity and sucrose yield of a dryland sugar beet crop in the Manawatu.

Materials and Methods

Sugar beet cv. Gala (monogerm, coated seed) was sown on 19 October 1990 and harvested on 12 April

1991 at Massey University. The soil was Te Arakura silt loam (pH 5.1, Olsen P 9, 12 μg S/g, 0.58 meq K/100 g, 6.3 meq Ca/100 g, 1.53 meq Mg/100 g 0.17 meq Na/100 g, CEC 18). Single superphosphate at 250 kg/ha and potassium chloride at 109 kg/ha were applied before sowing. The crop received 674 mm rainfall with December (50 mm) and March (30 mm) unusually dry. The minimum mean monthly temperature ranged from 8 to 13°C, and the maximum mean monthly temperature ranged from 17 to 22°C. Weed control was by chloridazon (Pyramin FL 43%) applied at 9 kg/ha as a pre-emergence and phenmediphan (Betanal E 12%) applied at 6 l/ha as a post-emergence herbicide.

The experiment consisted of a factorial combination of five nitrogen (N) levels and five plant population densities replicated four times in a randomised complete block design. The N levels, applied as urea, were 0, 90, 180, 270 and 360 kg N/ha. The plant densities were 60,000, 80,000, 100,000, 120,000 and 140,000 plants/ha.

There were four rows of plants in each 2 m x 12.5 m plot. Plots were hand-thinned twice to ensure the plant populations were accurate. The first thinning was in the second week of November, after which half of the urea was applied. The final thinning was when the plants were at the six to eight leaf stage in the second week of December. Afterwards the other half of the urea was applied.

The middle area of the two centre rows of each plot (4 m^2) was harvested by carefully digging out each plant. Plants were stored at 5°C prior to sub-sampling and analysis. Roots were sub-sampled with an electric corer that removed approximately 800 g diagonally through the root. 500 g of root was dried at 80°C to estimate dry matter content and 200 g was ground to a pulp in a commercial Waring blender for two minutes and stored at -17°C.

Juice was extracted from the sugar beet pulp in boiling water and the sucrose concentration analyzed in a high pressure liquid chromatographic (HPLC) system (Mulcock *et al.*, 1985). Sodium and potassium concentrations in the water extracts were measured in an atomic emission spectrophotometer, and α-amino N concentration was determined in an autoanalyser system after reaction with ninhydrin reagent at 100°C (Khani, 1992).

Juice purity (JP) was calculated from the following formula (Carruthers and Oldfield, 1961):

$$JP\ \% = 97 - 0.0008*(2.5K + 3.5Na + 10\alpha\text{-amino N})$$

where the concentrations of K, Na and α-amino N are in mg/100 g sucrose.

The data were analyzed by analysis of variance using the General Linear Model (GLM) of the SAS programme.

Results

The interaction between N level and plant population density significantly affected root fresh weight (Table 1). The highest root fresh weight of 128 t/ha was at the highest N level and the lowest plant population density, whereas the lowest root fresh weight was when no N was applied at the highest plant density (Table 1).

The N level by plant density interaction was not significant for sucrose yield or sucrose percentage (Khani, 1992). The main effects of N level and plant density significantly affected both sucrose yield and percentage (Table 2). Sucrose percentage was lowest at the highest N level of 360 kg N/ha and was highest at 0, 90 and 180 kg N/ha (Table 2). Sucrose percentage was highest at the plant densities 100,000, 120,000 and 140,000 plants/ha and lowest at 60,000 plants/ha (Table 2).

The highest sucrose yields were 12.9 t/ha at 180 kg N/ha and 12.5 t/ha at 80,000 plants/ha (Table 2). Nevertheless, the sucrose yield did not differ significantly with different plant densities, except at 60,000 plants/ha (Table 2). The sucrose yield at 180 kg N/ha was not significantly greater than the sucrose yield of 11.7 t/ha at 90 kg N/ha (Table 2).

The effect of N level and plant population density on the concentration of Na, K and α-amino N in the juice of sugar beet roots is shown in Table 3. There was no significant interaction between N level and plant density, but the main effects were significant. The concentration of Na, K and α-amino N increased as the N level increased and decreased as the plant density increased

Table 1. The effect of nitrogen level and plant population density on the root fresh weight (t/ha) of sugar beet cv. Gala.

Plant density	N level (kg N/ha)				
(x 10^3/ha)	0	90	180	270	360
60	90	95	92	110	128
80	82	94	111	111	113
100	77	78	109	103	104
120	79	79	82	92	104
140	69	76	89	83	94
LSD 5%			14.0		

Table 2. The effect of nitrogen level and plant population density on the sucrose concentration, total sucrose yield, and extractable sucrose yield of sugar beet cv. Gala.

	Sucrose %	Sucrose yield (t/ha)	Extractable sucrose yield (t/ha)
N level (kg N/ha)			
0	14.4 a[1]	11.4 b	10.4 b
90	14.0 a	11.7 ab	10.4 b
180	13.3 a	12.9 a	11.3 a
270	11.4 b	11.3 b	9.5 c
360	10.1 c	10.8 b	8.6 d
LSD 5%	1.2	1.3	0.8
Plant density (x 10^3/ha)			
60	10.5 c	10.6 b	8.7 b
80	12.4 b	12.5 a	10.6 a
100	13.1 ab	12.2 a	10.7 a
120	13.3 ab	11.5 ab	10.1 a
140	13.8 a	11.2 ab	10.0 a
LSD 5%	1.2	1.3	0.8

[1] Data within columns followed by the same letter are not significantly different at P<0.05.

Table 3. The effect of nitrogen level and plant population density on the concentration of sodium, potassium and α-amino nitrogen, and on the juice purity from the roots of sugar beet cv. Gala.

	Na	K	α-amino N	Juice purity
	(mg/100 g sucrose)			(%)
N level (kg N/ha)				
0	140 d[1]	989 c	432 e	91.2 a
90	179 cd	1080 c	657 d	89.1 b
180	211 c	1092 c	866 c	87.3 b
270	271 b	1416 b	1191 b	83.9 c
360	360 a	1693 a	1599 a	79.3 d
LSD 5%	56	212	175	1.8
Plant density (x 10^3/ha)				
60	340 a	1888 a	1272 a	82.1 c
80	269 b	1380 b	1071 b	84.9 b
100	198 c	1084 c	874 c	87.3 a
120	186 c	1002 c	814 c	88.0 a
140	160 c	917 c	713 c	89.0 a
LSD 5%	56	212	175	1.7

[1] Data within columns followed by the same letter are not significantly different at P<0.05.

(Table 3). As a consequence, the juice purity percentage was greatest at 0 kg N/ha and at 140,000 plants/ha respectively (Table 3). However, the juice purity percentage was similar at 100,000 and 120,000 plants/ha to that at 140,000 plants/ha (Table 3).

The extractable sucrose yield is dependent on the juice purity percentage, sucrose percentage and root fresh weight. Juice purity percentage and sucrose percentage were highest when root fresh weight was lowest (Tables 1, 2 and 3). As a consequence the maximum extractable sucrose yield was at 180 kg N/ha and at all plant population densities except 60,000 plants/ha, which had the lowest extractable sucrose yield and the highest root fresh weight (Tables 1 and 2).

Discussion

The components of the sucrose yield of sugar beet cv. Gala exhibited different responses to N level and plant population density. The highest sucrose yields were at the medium levels of N and plant density, but juice purity was relatively low for these treatments. Sucrose percentage of the roots was highest when the root fresh weight was the lowest. Overall, the results suggest the greatest yield of commercially extractable sucrose for this crop would have been at 180 kg N/ha and 100,000 plants/ha. The maximum extractable sucrose yield of 11.3 t/ha was comparable to the better yields obtained in New Zealand and elsewhere (Draycott and Webb, 1971; Greenwood, 1980).

The response of juice purity to N level and plant density was consistent with the findings of Follett (1991). The disparity between the conditions required for maximum juice purity and maximum sucrose yield demonstrated that the manner in which a sugar beet crop is to be processed affects the husbandry requirements for maximum production. In New Zealand the emphasis has been to determine the husbandry requirements of sugar beet for either maximum root yield or maximum sucrose yield because of its potential as an alternative energy source (Greenwood, 1980; Martin, 1980). If commercial sucrose extraction was to develop in New Zealand then the balance between maximum sucrose yield and extractable sucrose yield would need to be considered when developing crop husbandry requirements. The greater sensitivity of extractable sucrose yield to N level than plant density suggests that it would be better to tend towards too high a plant density than to use N fertiliser to try and compensate for a poor plant density. Additionally, plant densities such as 100,000 plants/ha or greater produce similar extractable sucrose yields to lower densities but in a crop with a lower root fresh weight. Transport of the fresh roots to processing plants is costly due to the weight involved.

The highest sucrose percentage was in the lowest root yields. Doney *et al.* (1981) showed there was a negative relationship between root fresh weight/ha and sucrose percentage. Increased root fresh weight, whether due to increased N level or decreased plant density, is largely a consequence of increased cell size and is due less to an increased number of cells in the roots (Doney *et al.*, 1981). The sucrose concentration of root cells is relatively insensitive to cell size so large roots have larger cells but a lower sucrose percentage than small roots. Presumably in Gala sugar beet an increase in N level increases cell size more than does a decrease in plant density over the range of values examined in this trial.

Overall, the results demonstrate that to maximise the yield of commercially extractable sucrose by sugar beet requires a balance between root yield, sucrose percentage and juice purity, rather than using N level or plant population density to maximise any one of these yield components, and that the extractable sucrose yield is more tolerant of changes in plant density than in N level.

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