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Effect of Time and Amount of Nitrogen Uptake on Sugarbeet Growth and Yield[1]

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ABSTRACT

Sugarbeet (*Beta vulgaris* L.) root quality has been steadily decreasing since the early 1950's with increased use of N fertilizer. Since the extent of these decreases may be associated with the time and amount of N uptake, the objective of this study was to evaluate the effects of several rates and times of N fertilizer applications and N uptake by sugarbeets on seasonal growth rates, sucrose percentage and accumulation, dry matter production, and partitioning of the photosynthate.

Sugarbeets were grown under field conditions on a Portneuf silt loam soil (Durixerollic Calciorthids, coarse-silty, mixed, mesic) near Twin Falls, Idaho, in 1977, using four N rates, each applied preplant, mid-June, mid-July, and mid-August. Root yields, sucrose concentration and yield, dry matter production, leaf area index, and plant N uptake were determined from samples taken throughout the season. Adding N fertilizer above that needed for optimum plant growth or delaying N application until midseason caused a greater proportion of the photosynthate to be used for increased top growth at the expense of dry matter and sucrose accumulation in the roots. Sucrose accumulation was maximum from late July until early September; therefore, during this period, addition of N and N uptake by the plant caused the greatest decrease in sucrose accumulation and production at harvest. Increasing N levels decreased sucrose concentrations during the season and at harvest because of 1) increased moisture level of roots, and 2) dry matter produced and accumulated in the roots having a decreased sucrose concentration. The rate of accumulation of stored sucrose was reduced by midseason N application, but stored sucrose was not used for increased growth of beet tops. Excess and late N applications also increased impurities in the beet root, decreasing extractability of stored sucrose, which further decreased refined sucrose production. Early application of N fertilizer at optimum levels should maximize refined sucrose production.

Additional index words: Leaf area index, Dry matter production, Photosynthate partitioning.

SUGARBEET (*Beta vulgaris* L.) yield and quality are dramatically influenced by the level of available N (4, 7, 10). Residual and fertilizer N levels that will allow adequate top growth and maximize the product of root growth and extractable sucrose concentration are desired. Soil tests have been developed that can assess the residual N and provide a basis for calculating needed levels of N fertilizer application (3, 15).

However, in experiments conducted throughout southern Idaho, large differences have been obtained in sucrose concentrations, even when the total available soil and fertilizer N has been similar (7). Some of these differences may be attributed to climatic factors (13). However, within seasons between adjacent fields, different sucrose concentrations have been measured. Some of these differences may be attributed to variations in early plant growth and N uptake by the sugarbeet plant (16).

The objective of this study was to evaluate the effect of several rates and times of N fertilizer applications and N uptake by sugarbeets on seasonal growth rates, sucrose percentage and accumulation, dry matter production, and partitioning of photosynthate.

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 1977. The field used was cropped to barley (straw burned) the previous year and required 56 kg P/ha (18) and 252 kg N/ha (3, 7) for an expected maximum yield of 63 metric tons/ha of beet roots.

The 1977 experiment involved three replications of a randomized block design, using four N-fertilizer rates (0 (three plots only, not included in analysis of variance), 112, 252 (recommended), and 392 kg N/ha), each applied preplant (6 April), mid-June (15 June), mid-July (14 July), and mid-August (11 August). Preplant and mid-June N applications were applied as ammonium nitrate and mid-July and mid-August applications as urea. Preplant N treatment was broadcasted with a uniform application of concentrated superphosphate (56 kg P/ha) and incorporated into the upper 10 cm of soil, whereas the mid-June application was sidedressed on the side and below the irrigation furrow. The mid-July and mid-August N applications were broadcasted and moved into the soil with sprinkler irrigation. All zero N (check) and preplant N treatment plots were 15.2 m × 15.2 m, and all seasonal N treatments were 7.6 m wide × 15.2 m long.

Sugarbeets (Amalgamated AH-10) were planted on 13 April in 56-cm rows and were thinned to a 23 to 30-cm spacing in early June.

Alternate furrow irrigation was used for the first four irrigations (15 April to 16 June), and sprinkler irrigation was used during the remainder of the season. Plots were adequately irrigated based on previous irrigation experiments. Irrigation dates were based on estimated soil moisture depletion (11) with a 1 or 2-day adjustment to accommodate plant sampling. Irrigation durations depended on the amount of water to be applied.

Root and top samples were manually harvested from three uniform, 3-m row sections from each check and preplant N treatment plots at weekly intervals from 14 June to 18 July and at biweekly intervals starting 18 July. Root and top samples were harvested from the seasonal N treatment plots at 3-week intervals starting immediately before their first fertilizer application. Enough plot area was provided so that the plant sampling did not influence subsequent yield measurements. Root samples were washed, root and crown tissue were separated at the lowest leaf scar, and all fresh tissue was weighed before and after drying. Duplicate root samples (12 to 14 roots per sample) were taken for sucrose and purity analysis.

The final fall samplings of the beet tops and roots were taken between 17 to 21 October as described previously, except six 3-m rows were harvested and triplicate root samples were taken from each plot (16 to 18 roots per sample) for sucrose and purity analysis. The sucrose concentration in beet roots was determined by methods previously described for the 1976 (6) and 1977 (5) experiments.

The leaf area index (LAI) was determined by measuring the area of a weighed subsample of green blades from a 3-m row with a Lamda model LI-3100 area meter.[3] Discolored blades

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[3] Mention of trade names or companies is for the benefit of the reader and does not imply endorsement by the U.S. Department of Agriculture.

were considered photosynthetically inactive and their area was not included in the LAI.

Beet tops, roots, and crowns were dried at 65 C and their dry weights determined. The dried samples were ground to pass through a 40-mesh sieve and the total N was determined by the semimicro-Kjeldahl procedure modified to include nitrate (2). Nitrogen uptake was calculated by assuming that the N concentration was the same in both the fibrous and storage roots, and the weight of the unharvested fibrous roots was equal to 25% of the total harvested storage root weight (12).

A field experiment which had a similar experimental design, sampling procedure, and objectives as those of the 1977 study was completed in 1976 (6). Hail defoliated 75% of this sugarbeet crop on 3 August which affected both root and sucrose yields. However, there was no indication that sucrose concentrations in the beet roots were affected. Sucrose concentrations and corrected N uptake data (measured plant N loss from defoliation was added to measured N uptake at each sampling date following hail damage) from this experiment were used in Table 2 to support the results found in 1977.

RESULTS AND DISCUSSION

Leaf area index (LAI) increased from the earliest sampling date until mid to late-August and then decreased as top growth rate decreased with a dying of the older leaves (Fig. 1A and B). The LAI at any particular time depended upon the level of available soil and fertilizer N (Table 1). Increasing the N levels increased the rate of development of leaves at all stages of plant growth. Leaf area development was delayed when mid to late-season N fertilizer was applied and LAI was lower near final harvest on the higher N levels applied in mid-August as compared with similar N treatments applied earlier.

Root yields increased from the first sampling in early June until harvest for all treatments with growth rates greatest from mid-July until late August (Fig. 1C and D). Preplant N application, that caused a more rapid early development of leaf area, increased the rate of root development and maintained a higher yield throughout the season as compared with that for the check and seasonal N treatments (Table 1). For mid-June N applications, yields resembled those for preplant at the 112 kg N/ha treatment, but at higher N rates, root yields were reduced as compared with those for preplant. Mid-July and mid-August N treatments generally increased yields above those for

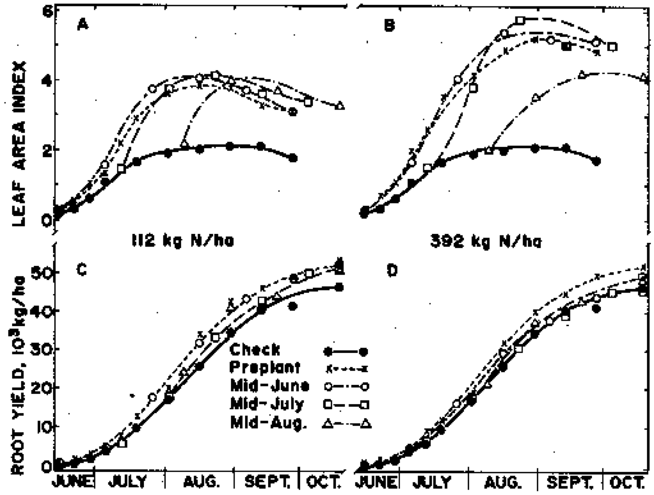

Fig. 1. Leaf area index (A, B) and root yield (C, D) as affected by time of sampling, N fertilizer level, and time of N application in 1977.

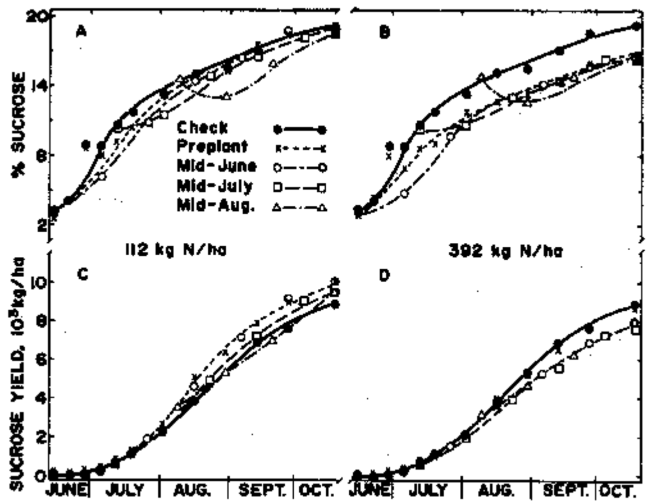

Fig. 2. Sucrose percentage (A, B) and sucrose yield (C, D) as affected by time of sampling, N fertilizer level, and time of N application in 1977.

Table 1. Effect of N fertilizer level and time of N application on final sampling (17–21 Oct.) parameters in 1977.

Treatment	Root yield†	Sucrose†		Extractable		Dry matter			N uptake			Leaf area index§
		%	Total			Tops	Roots‡	Total	Tops	Roots‡	Total	
Amount kg N/ha	kg/ha	%	kg/ha	%	kg/ha							
					Mean N effects							
0	46,100	19.3	8,900	89.6	8,000	4,000	12,700	16,700	54	76	130	1.7
112	51,700	18.8	9,700	88.7	8,600	6,500	14,300	20,800	105	122	227	3.3
252	49,400	17.3	8,600	86.4	7,400	8,200	13,400	21,600	183	152	335	4.2
392	48,700	16.4	8,000	84.2	6,700	9,200	12,900	22,100	238	181	419	4.8
Time					Mean application date effects							
Preplant	52,600	17.9	9,400	87.5	8,200	8,200	14,600	22,800	161	158	319	3.9
Mid-June	50,000	17.7	8,900	87.2	7,700	8,700	13,700	22,400	182	153	335	4.1
Mid-July	47,600	17.5	8,300	86.1	7,200	8,000	12,900	20,900	188	150	338	4.2
Mid-Aug.	49,500	17.0	8,400	85.0	7,200	7,100	12,800	19,900	170	147	317	4.1
$S_{\bar{x}}$ (24 df)¶	671	0.20	438	0.39	372	419	204	267	7.5	7.7	12.3	0.25

† Harvested root (root minus crown). ‡ Values include crown tissue. § Final LAI was measured in late September or early October.
¶ Zero-N treatment was not included in analysis of variance. $S_{\bar{x}}$ for mean N effects and mean application date effects.

the check, but yields were below those for the preplant applications. Midseason application of N to correct deficiencies did not replace the yield lost during the earlier plant growth stages. Root yields were highest when 252 kg N/ha was applied preplant with a maximum LAI of 5.5 (graph not shown).

Sucrose concentration increased most rapidly during June and July for the check and for all preplant N treatments (Fig. 2A and B). From late July until harvest, the rate of increase in sucrose concentration was rather uniform when no N was applied during that time. The sucrose concentration during the season depended upon the level of soil N. Increasing the N available to the sugarbeet plant by applying N fertilizer preplant reduced the sucrose concentration of the beet roots during the early plant growth stages. When 252 and 392 kg N/ha were applied preplant, the sucrose concentration remained below that for the check during the remainder of the season. However, when 112 kg N/ha was applied preplant, the sucrose concentration was at least equal to that of the check by the end of the season. Applying N fertilizer mid-July or mid-August reduced the sucrose concentration in the best roots for the remainder of the season. Sucrose concentration was also decreased for each increase in N fertilizer applied midseason. Sucrose concentration in the beet root was decreased by each increase in N application rate and by each delay in its application time (Table 1). Similar results were obtained in 1976 (6). During these experiments we found no indication of the commonly expected large increase in sucrose concentration during the latter part of the growing season when temperatures reduce the growth and respiration processes (13, 17). Sucrose concentrations for the remainder of the season were determined at an early plant growth stage provided that the N supply to the sugarbeet plant was not changed. Sucrose concentration increased steadily from early August until the end of the season so delaying harvest as long as weather conditions permitted should improve both sucrose yields and concentrations.

Total sucrose accumulation in the roots followed a rather consistent pattern for the different N treatments (Fig. 2C and D). The rates of increase in sucrose accumulation were highest from late July until early September. Sucrose yields were increased over that of the check for all application times for the 112 kg N/ha treatment and by the preplant 252 kg N/ha treatment. The preplant 392 kg N/ha treatment gave sucrose yields equal to that of the check, but at all other application times this high level of N as well as the 252 kg N/ha rate reduced sucrose yields below that of the check. In these latter cases, root yield increases were not sufficient to compensate for the decrease in sucrose concentration caused by the increased N treatment. In general, the earlier the N was applied at all N levels, the greater the sucrose yield (Table 1). However, either preplant or mid-June 112 kg N/ha treatments gave the highest and practically the same sucrose yield with a maximum LAI near 4 (Fig. 1A), which was similar to values found by Follett et al. (8).

Total N uptake for the check, preplant, and mid-June N applications followed a rather typical pattern throughout the season (Fig. 3A and B). Rates of N uptake were maximum from late June until early August during the period of maximum leaf area increase. Increasing the N available to the sugarbeet plant by N fertilizer application at any stage of plant growth increased for the remainder of the season the N content of plant parts and the rates and amounts of N uptake (Table 1). Seasonal N application generally increased the efficiency and amount of N uptake by the plant as compared with similar amounts applied preplant. This was probably a result of minimizing the time between N application and N uptake by the sugarbeets which allowed less opportunity for N to be leached out of the root zone, denitrified, or incorporated into the soil microorganisms and their byproducts. Applying N fertilizer preplant or during the season increased N uptake and N concentration in both tops and roots (Fig. 4A and B). A greater portion of the N taken up by the plant was used for top growth.

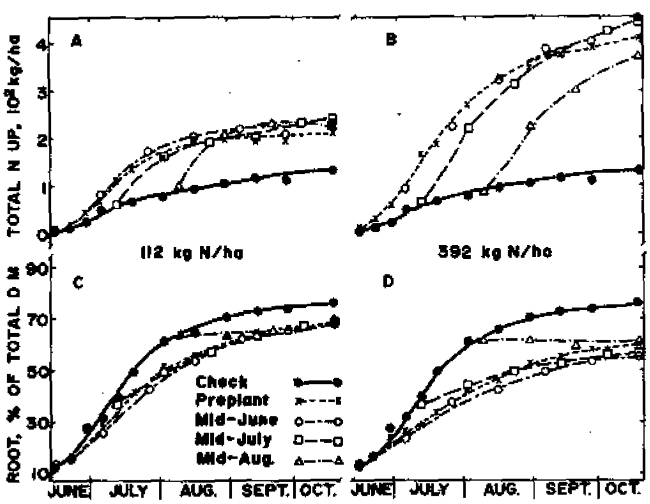

Fig. 3. Total N uptake (N_{up}) (A, B) and percent of the total dry matter (DM) in the roots (C, D) as affected by time of sampling, N fertilizer level, and time of N application in 1977.

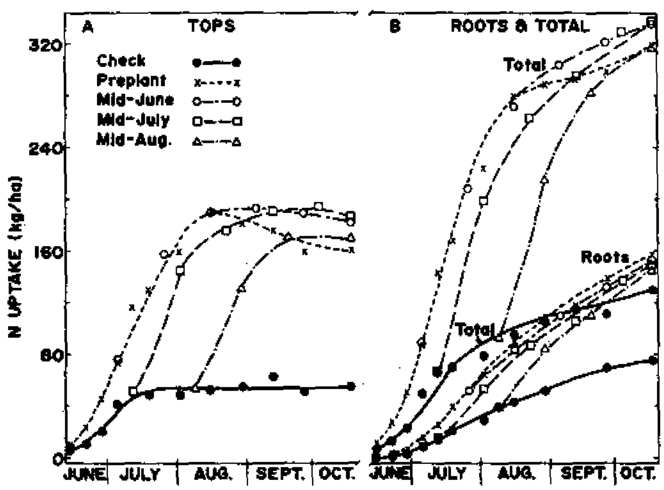

Fig. 4. Nitrogen uptake by the tops (A), roots (B), and total (B) as affected by time of sampling and time of N application (Avg. of 112, 252, 392 kg N/ha) in 1977.

Total dry matter production was increased by applying N fertilizer either preplant or seasonal (Table 1) with the extent of this increase depending upon the level of applied N. In general, the greater the N application the higher the dry matter production. Total dry matter production was about the same for preplant and mid-June applications, but was less for mid-July and mid-August applications. Using average values for three N rates, dry matter accumulation in the tops was increased over 100% by N fertilizer application. Preplant and mid-June N applications increased dry root weight at harvest by 15 and 8%, respectively, but mid-July and mid-August applications resulted in no difference in final root weight.

The percentage of the dry matter in the tops and roots for two levels of N applied preplant and seasonal are given in Fig. 3C and D. The percentages of the root dry matter for the preplant and mid-June N treatments increased from the first sampling in June until harvest with the rate of increase greatest from late June until early August. Preplant and mid-June applications decreased the percentage of dry matter in the roots, the extent depending upon the amount of N applied, and increased that in the tops throughout the season as compared with that for the check. Mid-July and mid-August N treatments increased top growth in relation to root growth which decreased the percentage dry matter in the roots. Proportions of root to top dry matter were similar for most treatment times. Lower percentage dry matter in the roots was obtained with each increase in N level at any plant growth stage.

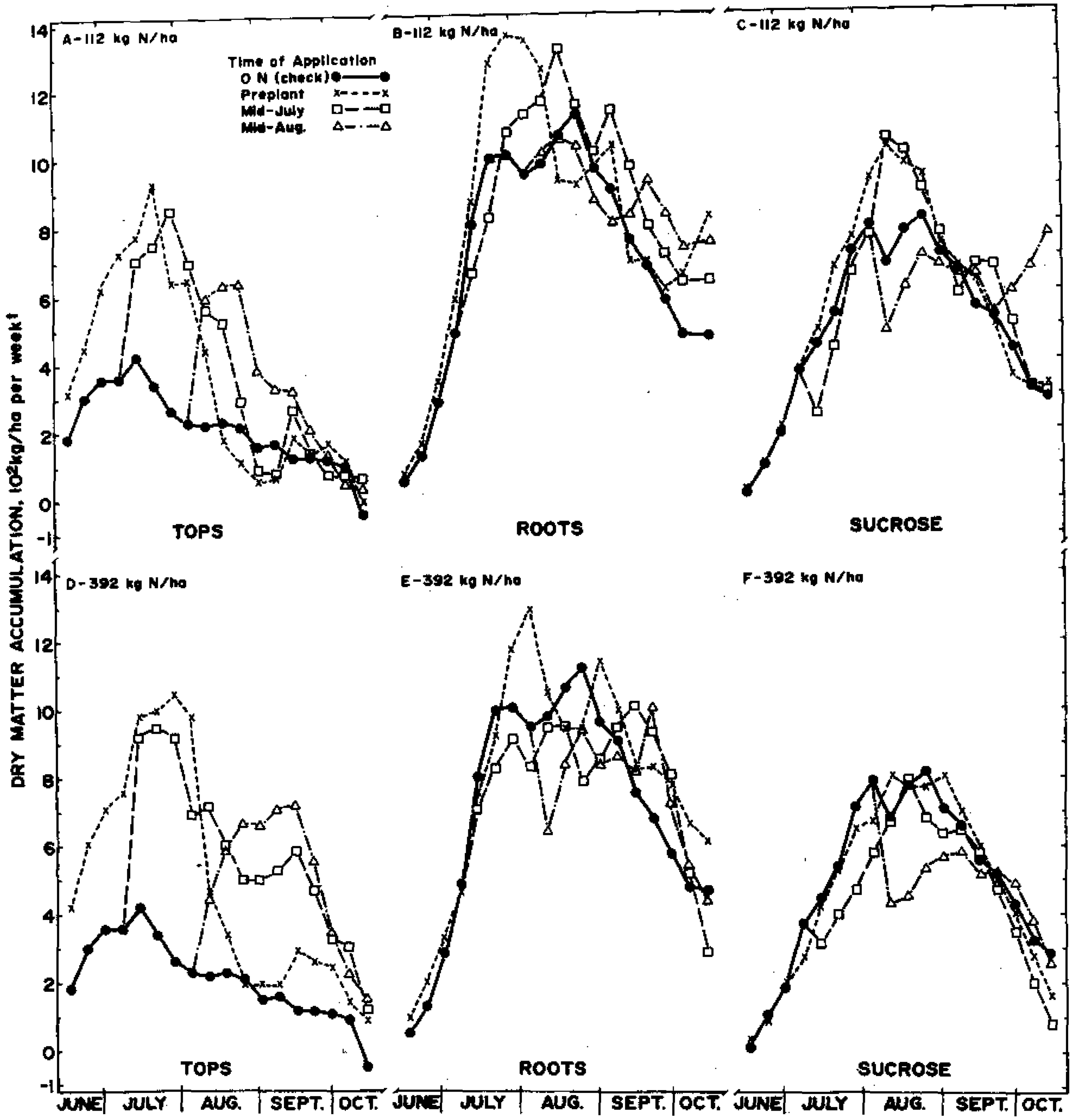

Fig. 5. Estimation of the weekly partitioning of photosynthate to the tops (A, D) and roots (B, C, E, F) as affected by time of sampling, N fertilizer level, and time of N application in 1977. Mid-June application treatment not shown.

An estimation of the weekly partitioning of photosynthate to the tops and roots throughout the season as affected by rate and timing of N fertilizer treatments is given in Fig. 5. For the check, preplant, and mid-June N treatments, total dry matter produced and that accumulated per week in the tops and roots steadily increased from the earliest sampling date in June until late July or early August and then decreased until harvest (Fig. 5A, B, D, E). For these same treatments, sucrose accumulation in the roots (root minus crown) per week steadily increased until late July or early August and then decreased during September and October (Fig. 5C and F). Preplant and mid-June N treatments increased the total dry matter production and accumulation in both the tops and roots. Increasing the N level above that needed for maximum sucrose production increased dry matter accumulation per week in the tops, but reduced that accumulated in the roots as compared with that for the lower N treatments. Sucrose production and accumulation were increased when adequate N was applied but it leveled off or was reduced at the higher N levels. End of season differences were mainly caused by the rates of dry matter and sucrose production and accumulation during mid-season (from late July until early September) when sucrose accumulation rates were highest. The addition of N fertilizer during this period (mid-July or mid-August) increased the dry matter accumulation per week in the tops for each addition of N, with a lower percentage or amount of the photosynthate being partitioned to the roots for dry matter and sucrose accumulation. The mid-July N application lowered sucrose accumulation in the roots but the cumulative decrease was less than that for the mid-August N application (Fig. 5). This was mainly caused by the rate of sucrose accumulation during mid-August being greater than that during mid-July for sugarbeet fertilized preplant or in mid-June. Sugarbeets fertilized in mid-July also had a longer period to take advantage of the increased leaf area and the accompanying increase in photosynthate produced. This reduction in sucrose accumulation caused by mid-season N applications was increased with each increase in N fertilizer addition. There was no evidence in these experiments that stored sucrose was used for increased dry matter production in the tops and roots with midseason application of N fertilizer. Although the sucrose accumulation rate was lowered after seasonal N application and increased top growth, accumulation of sucrose in the roots during this period was substantially positive. The energy used for increased top growth probably came from the solar energy intercepted during this period and was at the expense of the photosynthates that would have been partitioned to the beet roots for storage as sucrose (14). Similar results were obtained following top regrowth after hail damage and seasonal N additions in 1976 (6).

The sucrose concentrations in the beet roots at harvest were generally decreased with each increase in N fertilizer and with increased N uptake by the plants in 1976 and 1977 (Table 2). However, the relationship between N uptake and sucrose percentage was more sensitive than that between the actual amount of N applied and sucrose percentage which was probably caused by the efficiency of N fertilizer use by the plant. Applying N during the growing season and subsequent late season N uptake reduced sucrose percentage more than did applying N preplant. This was particularly noticeable from the mid-August N application in both 1976 and 1977.

The percent moisture increased with a corresponding decrease in percent dry matter in beet roots throughout the growing season and at final harvest with each increase in N fertilizer above the check (Fig. 6A). This relationship between N fertilizer level and dry matter concentration was associated with a strong positive relationship between percent dry matter and sucrose percentage in the best roots (Fig. 6B). If sucrose concentration was determined on an equal root moisture level, the decreases in sucrose percentage, associated with increased N fertilizer (Fig. 6C) and increased N uptake by the plant, were not nearly as great (Fig. 6D). However, since excess N fertilizer did not increase fresh root weight, the actual sucrose produced

Table 2. Regression of sucrose percentage on N fertilizer level or total plant N uptake for each of four times of N fertilizer application in 1976 and 1977.

Time of N application	1976 Regression equation†	r	1977 Regression equation†	r
	N fertilizer‡			
Preplant	$Y = 17.38 - 0.0040\,X_1$	−0.94	$Y = 19.50 - 0.0067\,X_1$	−0.96
Mid-June	$Y = 17.42 - 0.0045\,X_1$	−0.94	$Y = 19.62 - 0.0081\,X_1$	−0.95
Mid-July	$Y = 17.28 - 0.0058\,X_1$	−0.98	$Y = 19.37 - 0.0075\,X_1$	−0.97
Mid-Aug.	$Y = 17.19 - 0.0068\,X_1$	−0.95	$Y = 19.21 - 0.0085\,X_1$	−0.91
	Total N uptake§			
Preplant	$Y = 18.74 - 0.0060\,X_2$	−0.87	$Y = 20.66 - 0.0090\,X_2$	−0.94
Mid-June	$Y = 18.96 - 0.0068\,X_2$	−0.87	$Y = 20.77 - 0.0095\,X_2$	−0.91
Mid-July	$Y = 19.23 - 0.0086\,X_2$	−0.99	$Y = 20.58 - 0.0092\,X_2$	−0.95
Mid-Aug.	$Y = 20.13 - 0.0140\,X_2$	−0.99	$Y = 21.07 - 0.0128\,X_2$	−0.92

† Y = Sucrose percentage, X_1 = N fertilizer addition, X_2 = N uptake.
‡ s_b = 0.00087.
§ s_b = 0.0013. S_b = Common standard error of the slopes.

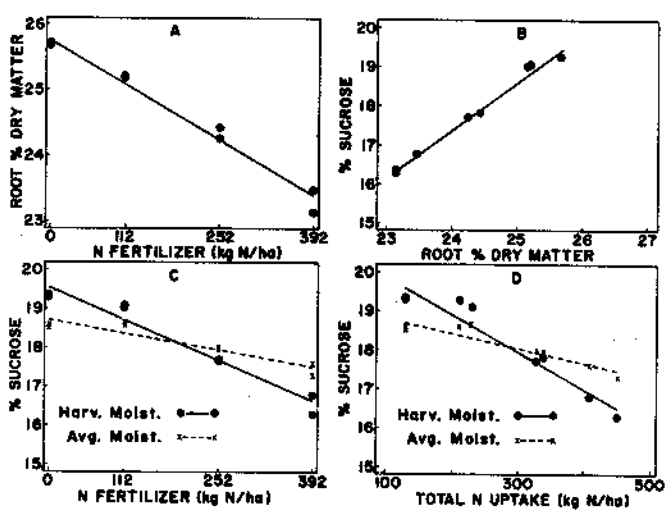

Fig. 6. Effect of: A) N fertilizer level on root percent dry matter (r = −0.99), B) root percent dry matter on percentage sucrose (= 0.99), C) N fertilizer level on percentage sucrose at harvest (harv.) moisture (moist.) level (r = −0.97) and sucrose percentage adjusted to average moisture level of 75.38% (r = −0.92), D) total N uptake on percentage sucrose at harvest moisture level (r = −0.97) and percentage sucrose adjusted to average moisture level of 75.38% (r = −0.92) in beet roots in 1977.

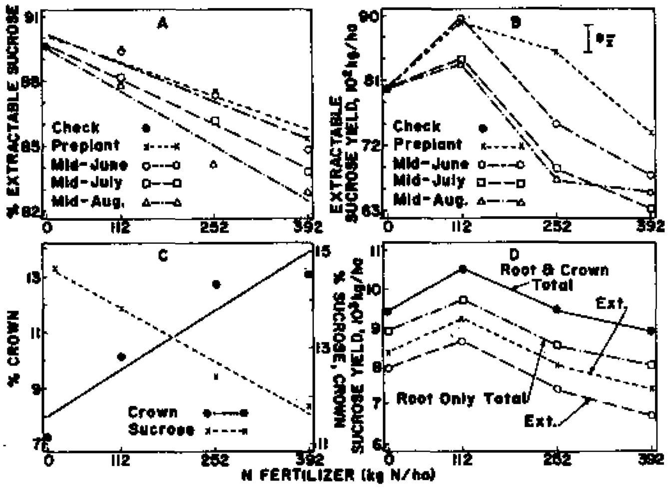

Fig. 7. Effect of N fertilizer level and time of N application on: A) extractable (ext.) sucrose percentage (preplant, r = −0.96; mid-June, r = −0.96; mid-July, r = −0.99; mid-Aug., r = −0.97) (Pooled S_b = 0.0014), and B) extractable sucrose yield. Effect of N fertilizer level on: C) percent crown (r = 0.95) and sucrose percentage in crowns (r = −0.99), and D) sucrose yield with (total = ●, extractable = x) and without (total = □, extractable = ○) crowns in 1977.

was still substantially decreased. The percent moisture in the best roots may vary considerably due to irrigation level during the growing season and at harvest (5). These differences in moisture level in the beet roots caused by irrigations or differences between years under similar N levels may account for some of the variability in sucrose percentage of beets delivered to the processing factory and for some of the differences in sucrose percentage obtained from experimental fields. Moisture or dry matter percentages in the roots should always be considered if the sucrose concentration of fresh roots is used as an indicator of quality.

Increasing the N fertilizer rate and the corresponding N uptake by the sugarbeets decreased the percent extractable sucrose in the beet roots during the season and at final harvest (Fig. 7A, Table 1). Applying N mid-July and mid-August further decreased the extractable sucrose. Because of the decrease in sucrose concentration and extractability, and in some cases the reduced root yield with N addition, extractable sucrose yields were only increased above the control for all 112 kg N/ha treatments and for the preplant 252 kg N/ha treatment (Fig. 7B). Applying N preplant or as a side dressing in mid-June at the rate of 112 kg N/ha gave the highest extractable sucrose yield and seemed to be the optimum level for the yield potential for this season.

The percentage of the root which is in the crown increased with increased N level, N uptake, and leaf growth (Fig. 7C). At harvest, crowns constituted from 7 to 15% of the roots and during certain years they can constitute as much as 20%. The crowns contained from 11.8 to 14.6% sucrose (Fig. 7C), whose extractability ranged from 73 to 76%. The extractable sucrose would then range from 400 to 840 kg/ha, constituting from 4.8 to 10% of the sucrose in the harvested root. This crown tisue is normally cut from the harvested root and left in the field. If sugarbeet tops were removed by flailing or some other mechanical means and the whole root harvested, the harvested sucrose per unit area could be greatly increased (Fig. 7D). Similar results have been found in previous research (1, 9). In addition, beet roots in piles may be stored better with less loss caused by fungi decomposition because of the surface cut in removing crowns (19).

SUMMARY

From these experiments we conclude that: 1) N fertilizer should be applied before planting or during the early plant growth stages so that N uptake and plant growth will occur at the earliest possible time; 2) the addition of N fertilizer above that needed for optimum plant growth causes a greater proportion of the photosynthate to be used for excess top growth at the expense of dry matter and sucrose accumulation in the roots; 3) delaying N application until after June delays N uptake and plant growth, reducing sucrose concentration and production throughout the season and at harvest below that of preplant applications; 4) sucrose production and accumulation in the roots are maximum from late July until early September so that sucrose yield will be reduced most from adding N during this period; 5) the decrease in sucrose concentration from adding N was caused by a decrease in sucrose percentage of the dry matter and by an increase in water percentage in the fresh beet roots; 6) moisture percentage in the roots should always be considered if the sucrose concentration of fresh roots is used as an indicator of quality; 7) reduced sucrose concentration and production throughout the season after N application was caused by the partitioning of more of the photosynthate to the tops than to the roots and not by sucrose stored in the roots being used to support increased top growth; 8) excess and late application of N fertilizer decreases the extractability of sucrose from the roots and further reduces the refined sucrose production; 9) serious consideration should be given to using the whole beet root that would include the crown for processing; 10) for maximum economy in sugarbeet production, N fertilizer should be applied before planting or during the early plant growth stages at amounts needed for optimum plant growth and sucrose production that are based on reliable soil tests.

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