Effect of Planting Date and Nitrogen Fertilization on Soluble Carbohydrate Concentrations in Sugarbeet

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ABSTRACT

In a field experiment conducted near Fort Collins, Colorado, we monitored seasonal trends in soluble carbohydrate (SC) concentrations in sugarbeet (*Beta vulgaris*). Three N fertility levels (0, 100, and 300 lb N/A) and two planting dates (April 22 and May 27) were imposed to study the SC concentration in four plant parts (leaf blade, petiole, crown, and taproot) at biweekly intervals from June 27 to September 5, then a final sampling on October 18, 1977. We found that: 1) increasing N-fertilization decreased SC concentration (% of dry weight) when averaged for all plant parts; 2) roots were highest in SC concentration followed in decreasing order by crowns, petioles, and blades; 3) when averaged for all plant parts, the maximum rate of increase in SC concentration occurred between June 27 and August 22; 4) early planting increased SC concentration in crowns and roots, but had little effect on SC concentration in blades or petioles; 5) SC concentrations were higher in early-planted than later-planted sugarbeets until August 22, but thereafter there was no difference; 6) SC concentrations in blades and crowns increased linearly as the season advanced, but root SC was a maximum by August 22; 7) early planting increased the SC concentration in roots until August 10; thereafter, there was no difference between planting dates; and 8) planting date had variable effects on SC in the petioles, but SC in blades was unaffected by planting date.

Additional Key Words: *Beta vulgaris*, partitioning, harvest date

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Soluble carbohydrate (SC) in the sugarbeet root (*Beta vulgaris*) is almost exclusively sucrose (Vukov, 1977), and the dominant sugar in other parts of the plant also is probably sucrose (Geiger and Cataldo, 1969). For sugarbeet growers, the primary focus is production of high yields of roots per acre coupled with the highest possible combination of sucrose concentration in roots and purity of the extracted juice. Growers' management practices produce a dynamic balance of N fertilizer management, other cultural practices, and environmental conditions which interact to determine partitioning of dry matter between top and root, and sucrose storage in the root (Storer, et al., 1973; Anderson and Peterson, 1988).

Sugarbeet plants can be divided into four parts as distinguished by their function and contribution to SC production and storage. Leaf blades serve as the main location for the manufacture of carbohydrate used for growth or storage. Petioles are the conductive tissue between blades and crown but also function secondarily as photosynthetic and storage organs and act to regulate fluctuations in translocation (Geiger and Fondy, 1979). The crown, which is distinguished from the root at the lowest leaf scar, is the site of the growing point. Sugarbeet taproots are enlarged storage structures adapted to accumulate SC in concentrations considered high compared to other plants.

The purpose of our study was to monitor seasonal trends in SC concentrations in each of these four plant parts for use in developing a sugar beet growth model (Lee, 1983). A search of the literature revealed no comparable study. Soluble carbohydrate is not a term commonly used in sugarbeet research. In most studies, results expressed on a dry-weight basis are conversions of sucrose percentage from fresh root analyses (Bergen, 1967; Theurer, 1979; Carter, 1986). Complex chromatographic methods have been used to analyze sugar beet tissue for sucrose, glucose, and fructose (Wyse, 1979; Geiger and Swanson, 1965). The anthrone method was used by Terry (1968), and by Milford and Thorne (1973) to analyze for material soluble in 80% ethanol; they referred to the extracted material as "sugar." Subsequent to our research, starch was identified as an important non-structural carbohydrate component in the leaves (Geiger and Fondy, 1979; Fondy and Geiger, 1980).

MATERIALS AND METHODS

This study was conducted at the Colorado State University Agronomy Research Center near Fort Collins, Colorado. A split-plot field design was used with two dates of planting as main plots (April 22 and May 27, 1977) and three levels of N fertilization as subplots (no N, control; 100; and 300 lb N/A). The six treatments (three N levels and two planting dates) were replicated four times. Soil properties and cultural practices were described by Lee et al. (1987). Daily solar radiation measurements were averaged by week from April 17 to the October 18 harvest (Lee, 1983).

Sampling Method

Leaf blades, petioles, crowns, and roots were harvested at two-week intervals from June 27 to September 5. A final harvest was conducted on October 18. Root samples were not taken on September 5 because of the bulk of material harvested. Instead, roots sampled on September 21 were used to estimate a value for September 5 based on a seasonal regression analysis for SC in the root.

On each harvest date two plants from each plot were sampled in the morning at 8:00 A.M. (AM) and two more from the same row in the evening at 5:00 P.M. (PM). Alternate rows were used for each sampling to maintain competition. Plants were hand-washed in distilled water and separated into four plant parts: root, crown, petioles, and blades. The plant parts were sliced and placed in a forced-air oven at 100°C for one hour to stop respiration and enzymatic processes (John Hendrix, personal communication). The temperature was then reduced to 56°C, and the samples were dried to constant weight. The dried samples were ground in a mill to pass a 20-mesh screen, transferred to bottles, tightly capped, and stored at 2°C until analyzed.

Soluble Carbohydrate (SC) Determination

Soluble carbohydrate (SC) was determined colorimetrically with anthrone. The method includes glucose, fructose, sucrose, and other sugars as sucrose equivalents (Hansen and Moller, 1975). The reagent used in this study was Morris' anthrone reagent (Morris, 1948) as modified by Olson (1963). Soluble carbohydrate (SC) is defined as carbohydrate extracted from dry plant material by hot 80% ethanol. The method extracts all non-structural carbohydrate except starch. We initially assumed that there was no starch in any of the sugarbeet parts. Fondy and Geiger (1980, 1982) reported, however, that starch does accumulate in the blades of sugarbeet, although apparently not in other plant parts. Thus, the SC method used in this study determined total non-structural carbohydrate in the roots, crowns, and petioles, but did not include starch in blades. This must be considered when interpreting the results. Sucrose concentration in the fresh roots also was determined and has been reported by Lee et al. (1987).

Statistical Analysis

To reduce the large number of field samples, the four field replications were composited for chemical analysis. A t-test analysis of means of AM and PM harvests (168 paired comparisons) indicated no difference at 0.01 probability. Therefore, AM and PM samplings from each harvest date were considered to be replications for the split-plot analysis of variance (Carmer et al., 1964). The error terms for the split plot analysis (Table 1) were composed of all higher order interactions with replication (AM and PM samplings).

Table 1. Analysis of variance of main effects and significant interactions for SC concentration.

Source of variation	D.F.	Mean Square	P values of F
Total	335	–	–
Replication (AM/PM samplings)	1	148	>0.20
Planting date (D)	1	1335	0.084
Error a	1	24	–
Nitrogen (N)	2	332	0.024
Error b	4	31	–
Harvest (H)	6	2269	<0.010
D x H	6	113	0.012
Error c	36	24	–
Plant Part (PP)	3	48780	<0.010
D x PP	3	346	<0.010
H x PP	18	191	<0.010
D x H x PP	18	96	<0.010
Error d	126	16	–

RESULTS AND DISCUSSION

Soluble carbohydrate (SC) concentration in the plant is expressed on a dry-weight basis in contrast to the usual commercial practice of expressing sugar in the fresh root. Milford and Thorne (1973) and Carter (1986) state that analysis on a dry-weight basis eliminates much of the variation in sugar concentration caused by differences in water content and in the sugar/non-sugar, dry-matter ratio.

As noted earlier, SC concentrations for AM and PM samplings were not significantly different at the 0.01 probability level. Fondy and Geiger (1982) also found that SC in the sugarbeet blade tissues did not show a diurnal fluctuation pattern which we had expected initially.

The main effect of N fertilization was significant, but the N interactions were not significant (Table 1). Increasing levels of N decreased the mean SC concentration averaged over plant part, harvest date, and planting date from 33.3% for the control to 32.2% for 100 lb N, to 30.0% for 300 lb N/A (Table 2). Decreasing SC in the plant in response to added N fertilizer is associated with a change in the top/root, dry matter ratio (Lee et al., 1987). As the level of N increased, SC was partitioned to increased blade and petiole dry matter rather than being stored as sucrose in the root. Many researchers have found that management of the available soil N is critical to quality control in sugarbeet production (Hills and Ulrich, 1971; Storer et al., 1973; Houba, 1973; Carter et al., 1976; Anderson and Peterson, 1988). Lack of significant interactions with N-fertilization indicates that N affected SC levels similarly throughout the season for both planting date and plant part.

Table 2. The effect of N fertilizer rate on the SC concentration in sugarbeet plant parts averaged for planting date and harvest date.

Plant Part, PP	Nitrogen lbs/A, N			Mean, N
	0	100	300	
	% dry weight			
Blades	6.7	7.0	5.5	6.4
Petioles	18.9	17.7	14.5	17.1
Crowns	48.9	45.9	43.2	46.0
Roots	58.9	58.1	56.5	57.8
Mean, PP	33.3	32.2	30.0	–

Main effects LSD: N (0.05) = 2.0; PP (0.01) = 1.6

The main effect of plant part, significant at the 0.01 probability level (Table 1), is shown in Table 2. The two storage organs, root and crown, were highest in SC (57.8 and 46.0%, respectively). SC leveles in blades and petioles, organs of photosynthesis and translocation, respectively, were much lower (6.4% and 17.1%). The difference in SC concentration between crown and root resulted possibly because of the higher metabolic rate of growth tissue in the crown, or because of dilution by stem tissue. Concentrations of SC were higher in the petiole than in leaf blade, probably in part because of the petiole's role as an intermediate sink (Geiger et al., 1969), but perhaps also because of the conversion of SC to starch in the blade (Fondy and Geiger, 1980; 1982).

The main effect of harvest date on SC concentration averaged for plant part, N rate, and planting date, was shown by a progressive increase from 21.5% on June 27 to 40.0% on October 18 (Figure 1). The average rate of increase in SC concentration was 0.27% day^{-1} during the period June 27 to August 22, then it declined to an average of 0.05% day^{-1} during September and October.

The interaction of harvest date (H) X plant part (PP) is illustrated in Figure 2. Soluble carbohydrate concentrations in both crowns and blades increased linearly throughout the season and reached a maximum at the October 18 harvest. The average rate of increase in SC was 0.07% and 0.17% day^{-1}, respectively, for blades and crowns. In contrast, SC concentrations increased linearly only to September 5 for the petioles (0.33% day^{-1}) and to August 22 for the roots (0.48% day^{-1}), then little change occurred until the October 18 harvest. In the same experiment, Lee (1983) found only a small increase in sucrose concentration in the root after mid-August when expressed on a dry-weight basis.

The pattern of change in SC concentration in the root may be related to seasonal variations in solar radiation and LAI. Solar radiation (Figure 1) was above 22.5 MJ m^{-2} day^{-1} from early June to early August except for a two-week period in mid-July, then

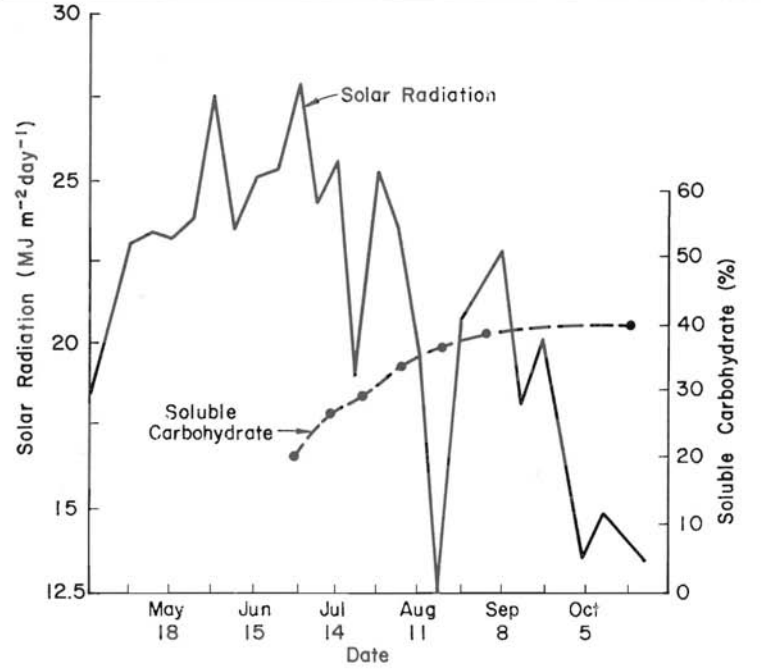

Figure 1. Average weekly solar radiation and SC concentration (% dry weight) averaged for N rate, planting date, and plant part for the 1977 season.

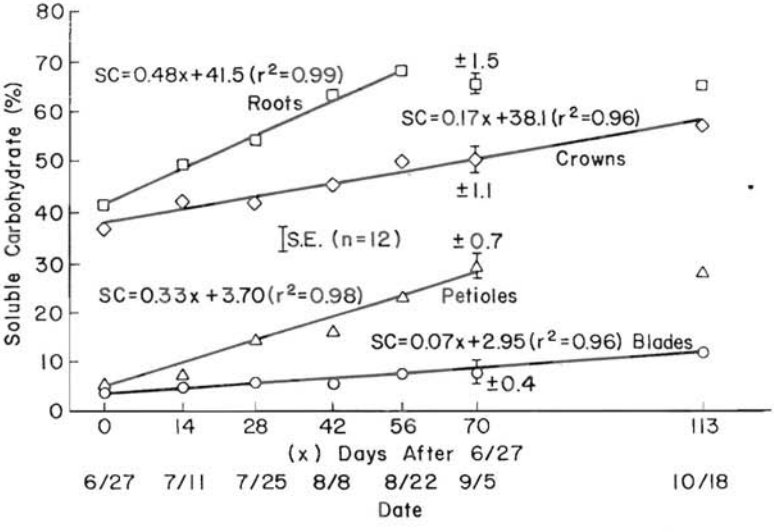

Figure 2. Effect of harvest date on SC concentrations (% dry weight) in sugarbeet plant parts averaged for N rate and planting date.

declined the remainder of the season. The LAI (Lee et al., 1987) averaged for all treatments was maximal from late July to late August. Maximum SC concentration also was attained while LAI was highest. After solar radiation and LAI declined in late August, SC concentrations remained about the same to final harvest. These findings are similar to those of Theurer (1979) and Bergen (1967) when they expressed sucrose concentrations in the root on a dry-weight basis. Bergen found a higher sucrose concentration in the root in August than in September, and Theurer found only a small increase in sucrose concentration in the root after mid-season. In our experiment, and generally so under many conditions, total sucrose production will continue to the final harvest. Lee et al. (1987), in other data from our experiment, found that total sucrose production increased linearly from July 28 to October 18, suggesting that a combination of factors including reduced solar radiation, air temperature, and available soil N probably were responsible for increasing the partitioning of photosynthate from top dry-matter production to SC storage in the root as the season progressed.

Leaf appearance rate and leaf death rate (Lee and Schmehl, 1988) help explain the increase over time in SC concentration of the blades. Blade SC increased from 3.1% on June 27 to 11.8% on October 18 (Figure 2). Leaf appearance rate was decreasing from June to October while leaf death rate was increasing; thus, as time progressed the average leaf age increased. Blades both store and export photosynthate, depending on the stage of development. Immature blades act as a sink by drawing on the photosynthate of the mature blades for growth until they are able to meet their own needs and then finally contribute SC to the entire plant (Geiger and Batey, 1967). Because immature blades have lower SC than mature blades, a decrease in the proportion of immature blades will result in a higher average SC concentration for all blades.

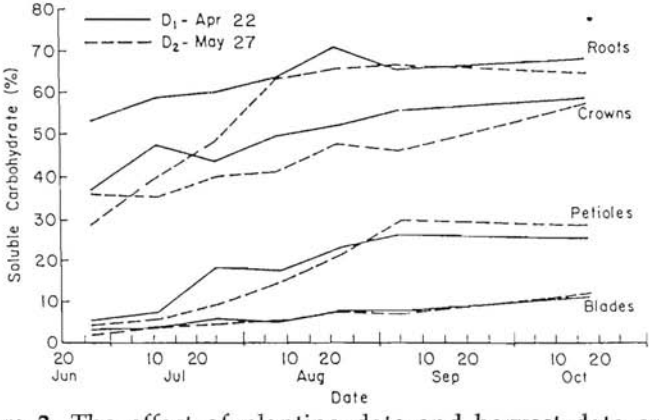

Figure 3. The effect of planting and harvest date on SC concentrations (% dry weight) in sugarbeet plant parts averaged for N rate.

Although the main effect of planting date was not significant at 0.05 probability, there were three significant interaction effects involving planting date. A three-way interaction involving planting date, harvest date, and plant part is shown graphically in Figure 3. This interaction helps to clarify the significance observed in the two-way interactions of planting date X plant part (Figure 4) and planting date X harvest date (Figure 5). The SC concentration in blades or petioles for date of planting was not different at any time during the season. Roots of the April 22 planting date were higher in SC concentration through the July 25 harvest; beginning August 10 and thereafter there was no difference between planting dates. Crowns of the April 22 planting date were higher in SC at several times in the season, but by season's end there was essentially no difference between planting dates. This seasonal effect explains why the planting date X harvest date interaction was significant (Figure 5). Similarly, the significant two-way plant part X planting date interaction is focused on the effect of planting date on the roots and crowns but not the blades and petioles (Figure 4).

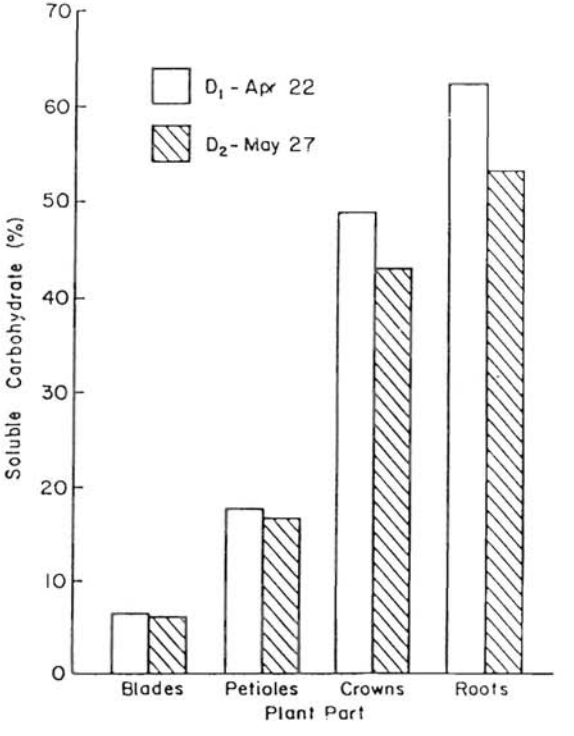

Figure 4. The effect of planting date on SC concentrations (% dry weight) in sugarbeet plant parts averaged for N rate and harvest date.

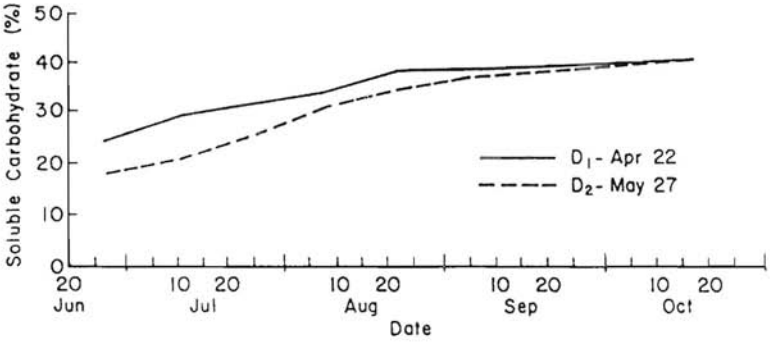

Figure 5. The effect of planting date and harvest date on SC concentrations (% dry weight) in sugarbeets averaged for plant part and N rate.

Our finding that SC concentration in blades and petioles did not respond to date of planting may have a physiological explanation. Both blades and petioles increased in SC concentration from June 27 to October 18, but as noted earlier, the increase in blades probably was the result of an increase in average leaf maturity. The increase in petiole SC may be for the same reason, but that is unclear.

Our findings agree with the results of Theurer (1979) and Bergen (1967) on seasonal sucrose concentration in the dried root. Probably Milford and Thorne (1973) were correct in assuming that the variability in moisture content of the root, when analyzed on a fresh-weight basis, confounds the understanding of the actual sucrose accumulation mechanism. It should be noted, also, that a marked change in climatic environment at any point in the season may have a significant effect on SC concentration and storage.

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