# Quantitative Growth Studies with Sugarbeets, *Beta vulgaris*[1]

K. R. STORER, W. R. SCHMEHL AND R. J. HECKER[2]

*Received for publication June 25, 1969*

Total yield of dry matter from a crop depends upon the size, mode of display, and duration of leaf area or photosynthetic system in relation to seasonal income of solar radiation. Total dry matter production by sugarbeets is maximal where an optimum canopy is produced as early as possible, and where this canopy endures as long as possible. There is; however, a limit beyond which increased leaf area will not increase dry matter production, or a point at which mutual shading becomes a factor. In addition, sugar yield is a variable proportion of the total dry matter yield, depending on the balance of internal competition for assimilate. The proportion of assimilate transferred to sugar storage may be reduced by cultural treatments which increase top growth, such as nitrogenous fertilizers. Quantitative growth characteristics of sugarbeets in relation to quality and sucrose production are not well defined at this time, and some question arises as to what might be considered optimum leaf area. This experiment was conducted to intensify and expand present research in this field. Nitrogen fertilizer treatments and genetic populations were used as variables to fluctuate leaf area growth curves so that the effects of these variations in leaf area on such factors as net assimilation rate, root growth rate, dry matter formation and sucrose accumulation could be determined.

## Materials and Methods

Sugarbeets were grown on an irrigated Nunn clay loam at the Colorado State University Research Center near Fort Collins. The soil was calcareous nonsaline and contained about 2% organic matter.

The field received 40 pounds of $P_2O_5$ per acre to insure an adequate level of this nutrient. Five nitrogen treatments were imposed by adding ammonium nitrate as follows: (1) Check (no nitrogen fertilizer); (2) 125 lb nitrogen per acre applied preplant in March; (3) 250 lb nitrogen per acre applied preplant in March; (4) 125 lb nitrogen per acre applied July 12; (5) 250

[1] Published with the approval of the Director of the Colorado Agricultural Experiment Station as Scientific Series Paper No. 1450. This study was supported by Agricultural Research Service, U.S. Department of Agriculture, under Cooperative Agreement No. 12-14-100-8443(34) administered by Crops Research Division, Beltsville, Maryland.

[2] Former Graduate Research Assistant and Professor of Agronomy, Colorado State University, and Research Geneticist, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, Fort Collins, Colorado, respectively. The senior author is now Agronomist, Funk Bros. Seed Co., Bloomington, Illinois.

lb nitrogen per acre applied July 12. The preplant application of fertilizer was broadcast March 26 and harrowed into the surface soil. the delayed application in July was placed about 2 inches deep below the furrow and irrigated.

Two genetic populations were planted March 31, 1966: (1) A56-3, a variety similar to those now distributed in northeastern Colorado, and (2) an $F_1$ hybrid (52-305 × 52-307) developed by the Sugar Crops Section of the Crops Research Division, U.S.D.A., Fort Collins, Colorado.

The experiment was a factorial with the ten treatments replicated four times. Plots were 16 rows wide and 60 feet long with rows 22 inches apart. The beets were hand thinned in mid-May to about a 10-inch plant spacing. Beets were harvested beginning June 6, 1966, and approximately every 2 weeks thereafter until the 12th harvest on November 8. Fifteen feet of row containing 17 to 19 beets were harvested each time to insure approximately equal competition within the row. Alternate rows were harvested during the season to maintain normal competition between rows throughout the season. The beets were divided into blades, petioles plus crowns and roots. The fresh and dry weights of each plant part were determined, as well as leaf area and leaf number. From these measurements root yield, leaf area index, leaf area duration, net assimilation rate and growth rate were calculated. Beginning July 5, sucrose content and apparent thin juice purity were determined for each harvest.

*Leaf Area Measurement.* At each harvest a representative beet was chosen from each plot. The leaves of this plant were removed, placed on blueprint paper and exposed to sunlight for a few seconds. Later development of this paper in ammonium hydroxide gave the outline of the leaf. The leaf pattern was cut from the paper and weighed to measure leaf area. Leaves for area measurements were dried and weighed to relate area to dry weight. The total dry weight of leaves was determined for each plot, then the leaf area per plot was calculated from the dry weight-leaf area relationship previously determined.

*Leaf Area Index (LAI).* Leaf area index is the leaf area per unit ground area. This value was obtained from the ratio of leaf area to ground area; both measurements were in the same units for 15 feet of row.

*Leaf Area Duration (LAD).* Leaf area duration is the integral of the leaf area curve over a given growth period. These values may be obtained by the use of a planimeter on leaf area index curves. For this experiment, however, the leaf area duration was approximated by summing the leaf area index for each 2-week sampling period. To express the LAD on a weekly basis the values for this experiment were doubled.

*Net Assimilation Rate (NAR).* Net assimilation rate is the rate of increase in dry weight per unit of leaf area (2,18)[3]. The equation normally used for calculating NAR assumes a linear relationship between changes in dry weight and leaf area between the two sampling dates in question, i.e.

$$NAR = \frac{(W_2 - W_1)\ (\ln A_2 - \ln A_1)}{(T_2 - T_1)\ (A_2 - A_1)}$$

$W_2$ and $W_1$ are dry weight estimates of the plant material in grams per square meter of ground area at times $T_2$ and $T_1$; $A_2$ and $A_1$ are leaf area index values at $T_2$ and $T_1$; $T_2 - T_1$ is the time interval in days (11,18).

*Sucrose Percentage and Purity.* Sugar percentages on the beet pulp were determined by a method standard with commercial sugarbeet companies and similar to the method outlined in A.O.A.C. (1). Thin juice purity was determined in the clarified extract of brei as outlined by Carruthers and Oldfield (3).

*Percent Recoverable Sugar.* The quantity of refined sugar from a crop of beets is a better value for expressing sugar production economically than is gross sucrose. A method has been proposed to estimate the amount of recoverable white sugar after processing (5). The recoverable sugar percentage is calculated from the percent sucrose in the beet, the purity of the second carbonated juice and a standard factory loss and molasses purity. Values for percentage recoverable sugar were obtained from tables generated using the Great Western Sugar Co. formula for calculating recoverable sugar, assuming a 62.5 molasses purity and 0.3% factory loss.[4]

## Results and Discussion

### *Final Harvest Yields*

The last three harvests did not differ significantly; therefore, they were analyzed together to give a better estimate of final yields. The results are shown in Table 1.

The main effects for root yield were significant for variety and nitrogen fertilizer. Root yield for the A56-3 and $F_1$ varieties were 22.7 and 20.6 tons per acre, respectively, for means of harvests and nitrogen levels. Husseini[5] compared the same two varieties in a greenhouse experiment and found that the $F_1$ gave superior yields. Variety-by-environment interactions are not uncommon, and this coupled with a more severe infestation of leaf spot caused by *Cercospera beticola* on the $F_1$ are possible explanations for this difference.

[3] Numbers in parentheses refer to literature cited.

[4] Wood, R. R., personal communication.

[5] Husseini, K. K. 1966. Influence of nitrogen, potassium and sodium on sugarbeet growth and quality. Ph.D. Thesis, Colorado State University, Fort Collins.

**Table 1.—Average main effects of harvest date, nitrogen fertilizer and variety on final root yield and quality, 1966.**

| Treatment | Root yield T/A | Sucrose % | Juice purity % | Recoverable sucrose T/A |
|---|---|---|---|---|
| *Harvest date* | | | | |
| Oct. 8 | 21.3 | 17.2 | 93.2 | 3.13 |
| Oct. 22 | 21.5 | 17.3 | 94.1 | 3.24 |
| Nov. 8 | 21.5 | 17.5 | 94.3 | 3.35 |
| *Nitrogen#* | | | | |
| Check | 15.9c | 18.3a | 95.1a | 2.78b |
| 125, March | 22.7b | 18.2a | 95.0a | 3.69a |
| 250, March | 24.9a | 17.5ab | 93.5c | 3.90a |
| 125, July | 21.2b | 16.9b | 94.0b | 3.09b |
| 250, July | 22.5b | 15.8d | 91.6d | 2.76b |
| *Variety* | | | | |
| A56-3 | 22.7 | 17.3 | 94.8 | 3.41 |
| $F_1$ | 20.6 | 17.4 | 94.6 | 3.07 |
| *Significance (F-test)* | | | | |
| Harvest date | — | — | — | — |
| Nitrogen | ** | ** | ** | ** |
| Variety | ** | — | — | * |

* Significant at 5% level.

** Significant at 1% level.

\# Duncan's Multiple Range Test; values followed by the same letter are not significantly different at the 5% level.

Duncan's multiple range test (9) comparing nitrogen effects on final root yield gave the following results: (1) the yield of no-nitrogen check plant was significantly lower than yields for all other treatment at the 5% level; (2) there was no significant yield difference at the 5% level between applications of 125 lb nitrogen early, 125 lb late, and 250 lb late; (3) the 250 lb application in March caused significantly higher yields than all other nitrogen treatments at the 5% level.

The effect of variety was not significant for sucrose content; the A56-3 and $F_1$ genotypes averaged 17.4 and 17.3 percent, respectively, for all nitrogen fertilizer treatments. Nitrogen fertilizer, however, did show a significant effect on sucrose content. Roots from the check and 125 lb preplant treatments had higher sucrose contents than all other treatments. Application of nitrogen at planting had a definite advantage over side-dress applications in July, as plants from both the 125 lb and 250 lb nitrogen treatments applied in March had significantly greater sucrose contents at the 5% level than did plants receiving the same rates July 12. An interaction of variety by nitrogen was observed in the analysis of variance for sucrose. At lower rates of nitrogen the A56-3 had the same or greater sucrose than the $F_1$, but at the 250 lb rates the $F_1$ was higher in sucrose for both early and late nitrogen applications.

Nitrate-nitrogen contents of the petioles for the growing season, as determined by the phenoldisulfonic acid method (8), explain the low sucrose percentages for plants receiving late nitrogen. Petioles were sampled three times during 1966 and analyzed for $NO_3$-N. These results are given in Figure 1. Varieties were averaged since there was no significant difference between them for $NO_3$-N. Ulrich (14) suggested that petiole nitrate should be less than 1000 ppm 4 to 6 weeks before harvest to promote sucrose accumulation prior to harvest. Concentrations above 1000 ppm late in the season decrease sucrose content and purity while concentrations below 1000 ppm early in the season may reduce root yield. It is evident from Figure 1 that $NO_3$-N content was high late in the season for beets receiving the 250 lb side-dress application in July and caused reduced sucrose percentages at harvest. It is apparent, also, that plants in the check treatment were too low in petiole nitrate early in the season, which accounts for the low root yield.

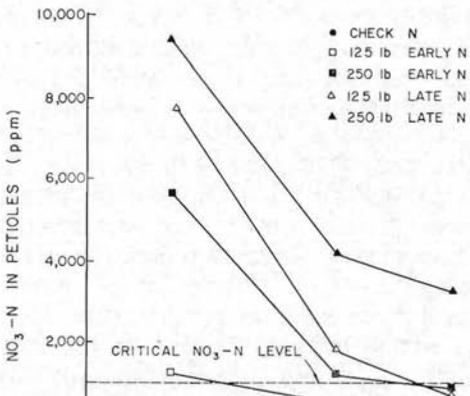


**Figure 1.—Effect of nitrogen fertilizer on petiole nitrate content; varieties combined.**

Thin juice purity for 1966 was relatively high for all treatments (Table 1). Varieties did not differ significantly for purity, but nitrogen fertilizer did have a significant negative effect on purity, caused primarily by the treatments receiving late nitrogen.

Recoverable sugar in tons per acre, which takes into account both percent sucrose and purity, was significant for the main effects of variety and nitrogen, but there was no significant interaction. The A56-3 and the $F_1$ varieties gave yields of 3.41 and 3.07 tons per acre, respectively. The difference between the varieties was caused principally by the difference in root yield between the two, since neither sucrose content nor purity differed appreciably.

The application of nitrogen had a highly significant effect on yield of recoverable sugar. The advantage of preplant over July applications of nitrogen was caused by the combined effects of root yield, sugar content and purity. When nitrogen was applied in March root yields increased, but there was no real reduction in sugar content. When nitrogen was applied in July root yields increased also, but less than with preplant applications. More significant, however, sucrose percentage and purity decreased markedly. The yield of recoverable sugar for the 250 lb nitrogen treatment in July was no greater than the check, although there was a large response in root yield (Table 1).

*Seasonal Growth Analysis*

Growth studies with a sugarbeet crop require records of dry matter production of whole or specific parts of the plants, sucrose production and leaf area. These measurements are usually made on repeated samplings at 1 or 2 week intervals. From these records growth rates and sucrose accumulation rates can be calculated, and an analysis can be obtained for yield in relation to leaf area as well as a comparison of the efficiencies of growth and sucrose accumulation. Published results (7, 15,16) indicate that yield of dry matter of sugarbeets is more closely related to leaf area than to net assimilation rate or to efficiency of the leaves. Goodman (7) has noted that this relationship may be of particular importance since the leafiness is partially within the experimenter's control. Efficiency of leaves, however, responds more to factors such as temperature and hours of sunlight which are not directly controlled by the experimenter.

*Leaf Area*—The main effects of variety and nitrogen fertilizer on the maximum leaf area index for the season are given in Table 2. The application of 125 lb of nitrogen more than doubled the maximum LAI over the check treatment and the 250 lb application further increased the LAI. The A56-3 variety had the larger maximum values for all nitrogen treatments.

The effect of time and rate of application of nitrogen on LAI during the growing season is illustrated in Figure 2. Varieties were averaged because there was no interaction between variety and nitrogen treatments. Maximum leaf areas were reached by the first of August for all treatments receiving preplant applications of nitrogen, but when the nitrogen was delayed until mid-July, maximum leaf areas were not attained until the end of

Table 2.—Effect of variety and nitrogen fertilizer on growth of leaves and net assimilation rate.

| Treatment | LAI Maximum | LAD Weeks | Leaf number Avg for season | NAR, avg[1] g/m²/day |
|---|---|---|---|---|
| *Nitrogen* | | | | |
| Check | 1.4 | 18.6 | 20.1 | 8.0 |
| 125, March | 3.2 | 37.8 | 22.3 | 7.3 |
| 250, March | 4.0 | 51.8 | 22.9 | 6.8 |
| 125, July | 3.6 | 43.9 | 22.6 | 7.6 |
| 250, July | 4.2 | 53.0 | 23 6 | 7.7 |
| *Variety* | | | | |
| A56-3 | 3.7 | 46.0 | 22.6 | 6.8 |
| F1 | 3.1 | 36.0 | 21.9 | 7.3 |

[1] Average NAR values calculated through the September 24th sampling.

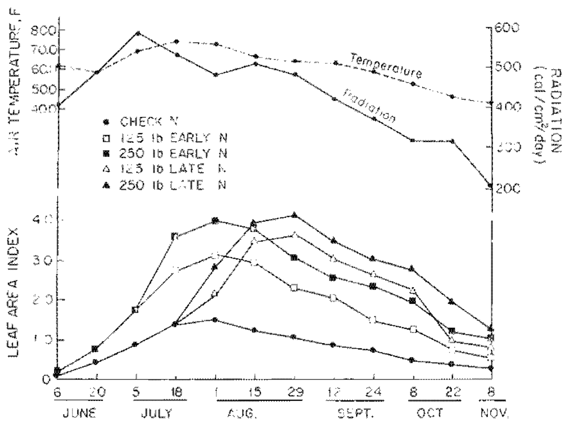

Figure 2.—Effect of nitrogen fertilizer on leaf area index (varieties combined), and average air temperature and total solar radiation for the same periods.

August. In all cases leaf areas decreased after a midseason peak. The temperature dropped to 22°F on October 15 and 16, which explains the marked decline in leaf area for the last two samplings.

Figures 3a and 3b show some leaf growth characteristics for the effect of early nitrogen (nitrogen rates and varieties combined). Figure 3a indicates that the decline in LAI throughout the later part of the growing season was attributed more to a decrease in size of leaf than to leaf number, since the number of leaves was actually increasing part of the time while LAI was decreasing. Figure 3b shows the change in the dry weight per unit leaf area with season. The ratio of dry weight to leaf area increased rather steadily throughout the growing season, indicating a thicker leaf. This effect was even more pronounced for the late nitrogen treatments.

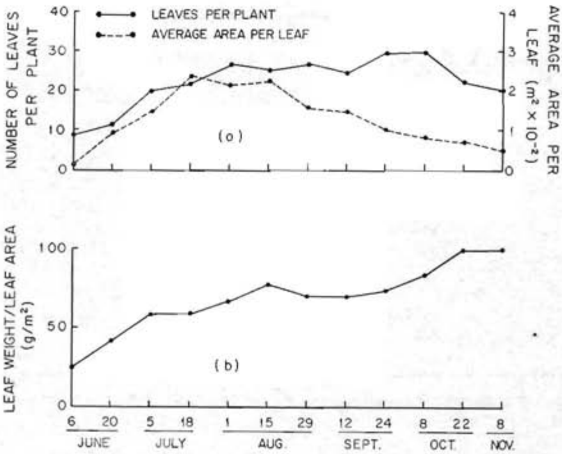


**Figure 3.—Effect of preplant nitrogen (nitrogen rates and varieties combined) on (a) number of leaves per plant and average leaf area, and (b) leaf weight per unit leaf area.**

Leaf area duration (LAD) has been proposed as a more significant measure of the plant's ability to conduct photosynthesis because it considers both the magnitude and persistence of leaf area (17). LAD is usually expressed in terms of weeks. Harvests for this experiment were at 2-week intervals, so that the LAI for each harvest was doubled and summed to give LAD for the whole season in terms of weeks (Table 2). The differences in LAD caused by nitrogen treatment can be explained in part by the small changes in average number of leaves per plant (Table 2). The application of nitrogen also increased the average leaf area. Thus, both the size of the leaf and number of leaves per plant were responsible for the increase in LAD when nitrogen was applied. Morton and Watson (10) found that both increased cell division and cell enlargement were responsible for larger leaves in sugarbeets when nitrogen fertilizer was added.

The late application of nitrogen produced as great a LAD for the season as did the early nitrogen, but sucrose yields for the early nitrogen treatments were higher, as noted in Table 1. Two reasons can be postulated for the lack of close relation between LAD and yield. First, the preplant nitrogen provided larger leaf areas early in the season when solar radiation and air temperatures also were high (Figure 2), thus increasing the potential to produce photosynthate. Second, nitrogen applied in July decreased sugar yield by inducing late vegetative growth which delayed the accumulation of sugar in the root.

*Net Assimilation Rate*—Air temperature and total solar radiation were measured daily at Fort Collins during the 1966 growing season. The average values for 2-week periods corresponding to harvest dates are plotted in Figure 2. Radiation was relatively high from mid-June to mid-September, but highest readings were present during early July. The leaf area curves show that the preplant nitrogen treatments produced greater leaf area for periods of highest radiation than did the July applications of nitrogen. The preplant application of nitrogen would be expected, therefore, to produce more photosynthetic material provided the leaf area was not so large as to cause excessive mutual shading. Stout (12) pointed out that a surplus of leaves may be a liability rather than an asset. As the leaf area increases and mutual shading increases, light intensity on the lower leaves may be so low that respiration exceeds photosynthesis, thus reducing total carbohydrate accumulation by the plant.

The rate at which dry matter was produced per unit leaf area (NAR) was computed for each harvest throughout the season and average rates were calculated through September (Table 2). Considerable variation was found in NAR for harvests after September 24. By the end of September, roots had attained most of their weight, leaf area was declining rapidly, and the total dry weight for the above-ground portion of the plant was decreasing. These factors are, no doubt, the principal contributors to the late season extreme variation in NAR.

No significant difference was found between average NAR values for the season for treatments, although the check treatment might appear to be most efficient (Table 2). The $F_1$ variety appeared also to be slightly more efficient than the A56-3 variety. This might be expected since the hybrid was known to develop greater root-top ratios[6]. The time at which nitrogen was applied also had different effects on NAR values during the season, even though final results were about the same.

The effect of time of application of nitrogen on NAR during the season is shown in Figure 4; the 125 and 250 lb rates of nitrogen and varieties were combined. After a maximum in early July, the NAR decreased with time throughout the rest of the season and approached zero in September. This decrease with time is in agreement with data presented by Watson (17) and Campbell and Viets (4). The NAR values declined more rapidly during July and August for plants fertilized with nitrogen in March than for those in the check treatment or the treatment that received late nitrogen in July (Figure 4). This may have been caused by the larger leaf area for the preplant treatment

[6] Husseini, op. cit.

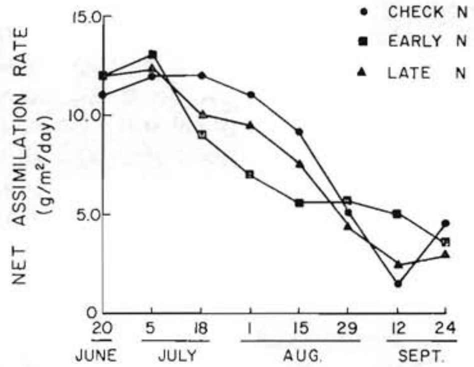


**Figure 4.—Effect of time of application of nitrogen on net assimilation rate; nitrogen rates and varieties combined.**

and less efficient exposure to solar radiation. Correlations between NAR and LAI were negative throughout the season, and the coefficients were more highly negative for periods with greatest leaf area. The correlation coefficient between LAD and average NAR for the season for all treatments was –0.60. This correlation is less than the –0.86 correlation obtained by Campbell and Viets (4) who worked with plants having much larger leaf areas. No significant correlation could be found between NAR and total dry weight for any of the harvests and values varied considerably from one harvest to the next. LAI, however, was significantly correlated with total dry weight for harvests throughout the season. The correlation coefficients for the various harvests ranged from 0.90 to 0.60. Net photosynthesis for the range of leaf area obtained in this experiment thus was dependent more upon the total leaf area than upon the efficiency of the leaf area. This is consistent with the findings of other workers (7, 15, 16).

*Root Growth*—The accumulative root yield during the season is given in Figure 5. The two nitrogen rates for each time of applying nitrogen were averaged because there was no interaction. The varietal effect, significant at the end of the season, did not appear until September, and then only for those treatments receiving nitrogen. The lower yield of the $F_1$ may have been the result of a *Cercospora* leaf spot infection which was considerably greater on this variety during the latter part of the season. Differences in leaf area between varieties that appeared early in the season had little effect on early season root yield. Any advantage of the lower top-root ratio of the $F_1$ may possibly be realized only when grown at a higher stand.

The advantage of the preplant application of nitrogen on root yield appeared as early as June 20, and by July 12, at the time of the late application of nitrogen, the response over the check was 2 to 3 tons per acre. The difference in yield between plants receiving early and late applications of nitrogen remained about 2 tons for the rest of the season (Figure 5).

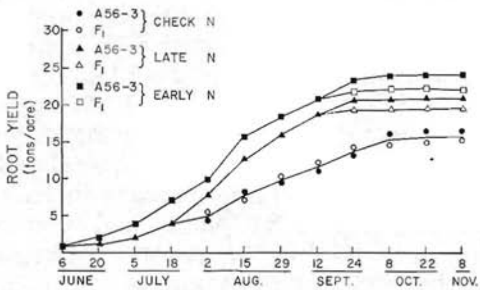


**Figure 5.—Effect of variety and time of application of nitrogen fertilizer on fresh root yields; nitrogen rates combined.**

From these data it would seem that timely leaf area is important for maximizing root yield. It was noted in Table 1 that the early application of nitrogen was more effective for increasing root yields than was the late application. The rate of root growth, for plants receiving early and late applications of nitrogen, is given in Figure 6 with corresponding LAI values; fertilizer rates and varieties were averaged for convenience in presenting the data. Early in the season, the rate of root growth, in tons per acre per 2 weeks, was greater for plants fertilized with nitrogen before planting; this was coincident with a greater leaf area for

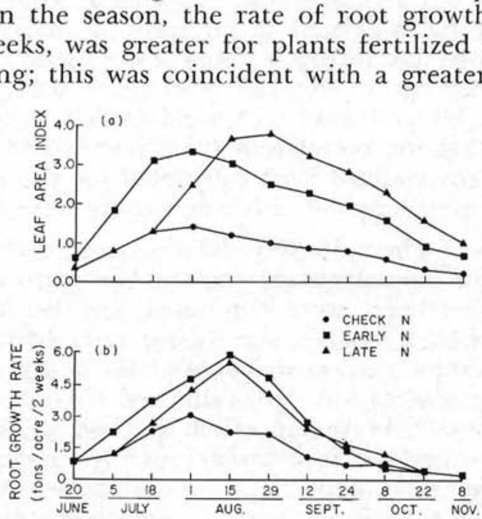


**Figure 6.—Effect of time of application of nitrogen on (a) leaf area index, and (b) rate of root growth; nitrogen rates and varieties combined.**

plants from the same treatment. Solar radiation and air temperature (Figure 2) also were higher early in the season. Ideally, leaf area probably should have reached a maximum even earlier than that attained with the preplant application of nitrogen.

Even though leaf area of the beets was greater after mid-August for the July nitrogen treatment, the rate of root growth was greater through mid-September for the preplant treatment. The slower rate of root growth for the July treatment during this period was due, apparently, to the high nitrogen status of the plant. With the early application of nitrogen there was a lower level of nitrogen in the plant during August and September (Figure 1) and more assimilate accumulated in the root. On the other hand, plants receiving nitrogen in July had a higher nitrogen status; therefore, these plants had a greater tendency for the assimilate to be used in top growth. After mid-September the leaf area of the beets for the preplant treatment was greatly reduced, but by this time the solar energy and air temperature were so low that the extra leaf area for the July application had little advantage (Figure 6).

The LAI for each harvest throughout the season was correlated with final root yield. Correlations were highest for the July 18 harvest, where a coefficient of 0.60 was obtained; thereafter, correlation of LAI values from later harvests with final root yield decreased as the season advanced. It would appear that leaf area early in the season had more bearing on the final root yield than did a comparable leaf area at a later date. The net effect is probably related to interactions among solar radiation, temperature, and nitrogen status of the plant. A correlation coefficient, significant at the 1% level ($r = 0.71$, 38 d.f.) was obtained for LAD and final root yield for all treatments. The data indicate that the correlation coefficient would be considerably higher if correlations were calculated for the early application only, and even larger if only one variety were considered.

*Recoverable Sucrose*—Variety differences in leaf area had no significant effect on percentage recoverable sucrose throughout the season, so varieties were combined for the following discussion. Plants that received the higher rates of nitrogen were lower in recoverable sucrose throughout the season, but because rates within an application date exhibited the same trend, they were averaged to indicate the effect of time of application of nitrogen on percentage recoverable sucrose (Figure 7). Beets that received an early application of nitrogen were low in recoverable sucrose early in the year but increased steadily throughout the season. Although plants receiving preplant nitrogen were lower in sucrose than those of the check for the season,

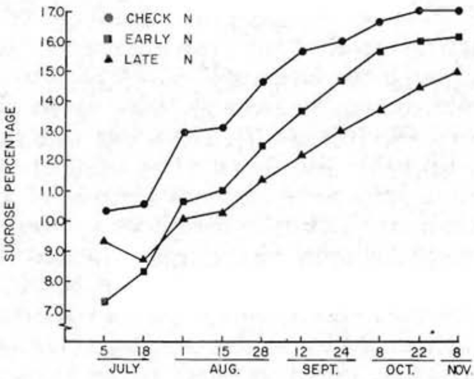


**Figure 7.—Effect of time of application of nitrogen on the percentage of recoverable sucrose; nitrogen rates and varieties combined.**

they still managed to give recoverable sucrose percentages over 16% by October. Nitrogen applied July 12 caused the recoverable sucrose to remain low until mid-August before it began to increase. Leaf area curves (Figure 2) show that it was mid-August before maximum leaf areas were achieved in plants that received late nitrogen. Thus, most photosynthate to that time was used for producing top growth.

LAD and final recoverable sucrose percentage for all treatments were negatively correlated (r = –0.55, 38 d.f.). Although significant at the 1% level, only about 30% of the variability in sucrose percentage could be accounted for by LAD. LAD was positively correlated with the yield of recoverable sucrose, but only about 22% of the variability in yield of sucrose (r = 0.47, 39 d.f.) could be attributed to LAD. This was a direct consequence of the higher positive correlation (r = 0.71, 38 d.f.) between LAD and final root yield.

Higher correlation coefficients were found for the relationship between LAD and percentage recoverable sucrose or yield of sucrose when each date of application of nitrogen was considered separately. This was because the relationship between leaf area and yield of roots or sucrose depended upon the time when nitrogen was applied (Tables 1 and 2). For example, LAD accounted for 85% of the variability in the yield of recoverable sucrose for the season (r = 0.92, 16 d.f.) when only preplant applications of nitrogen were considered.

Rates of accumulation of recoverable sucrose during the season were calculated to explain the influence of treatment on final yield of sucrose. Sucrose accumulation rates for the early and late applications of nitrogen with rates and varieties combined (Figure 8) show the definite advantage of the preplant applications through most of the growing season. It is interesting to note that although the late applications of nitrogen developed leaf areas by mid-August as great as those given where nitrogen was applied preplant (Figure 2), the roots did not accumulate sucrose at a comparable rate until after mid-September; by this time accumulation rates were very low because of a less favorable climatic environment. Lower recoverable sucrose plus a slower rate of root growth for most of the season caused the lower yield of sucrose where nitrogen was not applied until July 12. It is also possible that the capacity of the root to absorb sucrose (sink capacity) may have an influence on sugar accumulation (13), although the magnitude of this effect is not known. If sink size is significant, then an early application of nitrogen would have had a definite advantage over the check or delayed applications of nitrogen by providing a larger sink earlier in the season.

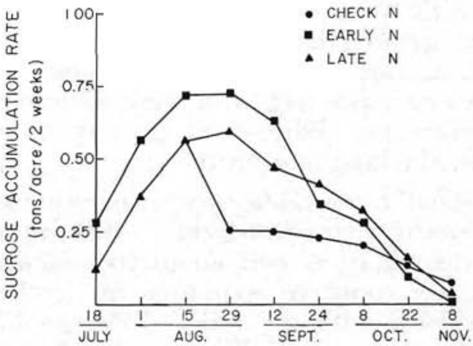


**Figure 8.—Effect of time of application of nitrogen on the rate of accumulation of recoverable sucrose; nitrogen rates and varieties combined.**

Results for the preplant nitrogen treatments (Figure 9) show that the rate of sucrose accumulation in the root was greater for the 125 lb rate of nitrogen than for the 250 lb rate until about September 1, although leaf area was greater for the 250 lb rate. The lower rate of accumulation of sucrose for the 250 lb treatment prior to September 1 was apparently the result of a higher nitrogen content of the plant (Figure 1). This caused more vegetative growth and less sugar accumulation. It should be noted here, however, that the sacrifice in early accumulation of sucrose is not necessarily detrimental. The results indicate that a large leaf area should be established early in the season when radiation and temperature are optimum. This promotes early root growth and greater sucrose accumulation later in the season. This was evidenced by the greater final yield of sugar

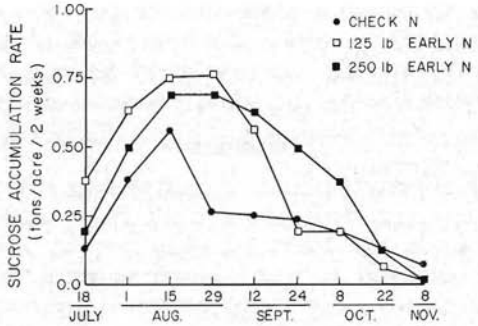


**Figure 9.—Effect of preplant applications of nitrogen on the rate of accumulation of recoverable sucrose; varieties combined.**

for the 250 lb rate over the 125 lb rate of preplant nitrogen. Roots from the check treatment, although highest in sucrose percentage, were not high-producing because plant growth was severely restricted much of the season.

Some question exists then, as to what should be considered optimum leaf area. Watson (16) suggested that a LAI between 6 and 9 may be near the upper limit of the agricultural range for maximum growth rate of sugar beets. Although values of this magnitude were not obtained in this experiment, the largest leaf areas for the season did produce greatest amount of dry matter. Since dry matter production was still increasing at the highest rates of nitrogen fertilization, it can be assumed that optimum leaf areas for dry matter production were above those encountered in this experiment. Although high leaf area often gives greater root growth and total dry matter production, a higher sucrose accumulation does not necessarily follow. Campbell and Viets (4) and Goodman (6) suggested that the optimum LAI may be closer to 3 for maximum sugar production. Results of the present study indicate that the optimum LAI may be 3 to 4 when attained early in the season. It is doubtful that a LAI greater than 3 or 4 would have been beneficial in this experiment unless the maximum was reached earlier in the season. The optimum leaf area would be expected to vary during the season because of fluctuations in temperature and radiation. A high LAI late in the season, caused by abundant supplies of nitrogen, was inferior not only because it delayed sucrose accumulation, but also because an excessive leaf area was presented at a time when climatic conditions were less favorable for photosynthesis. Differences in optimum leaf areas for sugar production may exist also between varieties. The $F_1$ hybrid of this experiment was able to produce more sucrose per unit leaf area than the commercial variety. Since the hybrid had a lower leaf area and higher root-top ratio, sucrose yield for the $F_1$ might have been raised by increasing the stand to increase the LAI.

## Summary

A factorial experiment that included two sugarbeet varieties and five nitrogen treatments was conducted on a calcareous Nunn clay loam to study the effect of variations in leaf canopies on the yield of roots and sucrose. Harvests were made at 2-week intervals throughout the growing season for growth analysis.

The genetically heterogeneous commercial variety grown in northeastern Colorado gave greater leaf areas, root yields and sucrose yields than did the $F_1$ hybrid. The hybrid, however, did have higher root-top ratios and higher net assimilation rates throughout the growing season. Varietal differences in final yields of sucrose were caused by varietal effects on root yields late in the season. No varietal differences were noticed for sucrose content or thin juice purity.

Nitrogen effects on leaf area were highly associated with yields of roots and sucrose. When nitrogen was applied in March before planting, the higher rates of nitrogen produced greater leaf canopies early in the season and caused greater yields of sucrose in the fall harvests. The greater sucrose yields were a consequence principally of larger root yields with only small reductions in sugar content.

When nitrogen was applied as a side-dress application in July, a comparable leaf area index was obtained about a month later than when nitrogen was applied in March. Root yields were lower, however Sucrose content and sucrose production were reduced also when compared with the preplant treatment.

Optimum leaf area index values for sugar production for this experiment appeared to be 3 to 4. No single nitrogen treatment maintained highest sucrose accumulation rates throughout the season; highest accumulation rates during the season shifted from treatment to treatment and depended upon both leaf area and nitrogen status of the plant.

### Literature Cited

(1) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. 1960. *Official Methods of Analysis.* Assoc. Offic. Agr. Chemists. 9th Edition.

(2) BRIGGS, G. E., F. KIDD and C. WEST. 1920. A quantitative analysis of plant growth. Ann. Appl. Biol. 7: 202-223.

(3) CARRUTHERS, A. and J. F. T. OLDFIELD. 1961. Methods for the assessment of beet quality. I. Purity determinations using clarified extract from brei. Internat. Sugar J. 63: 72-74.

(4) CAMPBELL, R. E. and F. G. VIETS, JR. 1967. Yield and sugar production by sugar beets as affected by leaf area variations induced by stand density and nitrogen fertilization. Agron. J. 59: 349-354.

(5) DEXTER, S. T., M. G. FRAKES and F. W. SNYDER. 1967. A rapid and practical method of determining extractable white sugar as may be applied to the evaluation of agronomic practices and grower deliveries in the sugar beet industry. J. Am. Soc. Sugar Beet Technol. 14: 433-454.

(6) GOODMAN, P. J. 1967. What determines sugar beet yields? 1. Soil and weather. Brit. Sugar Beet Review 37: 115-117.

(7) GOODMAN, P. J. 1967. What determines sugar beet yields? 2. Plant population and leaf area index. Brit. Sugar·Beet Review 35: 171-172.

(8) JOHNSON, C. M. and A. ULRICH. 1959. Analytical methods for use in plant analysis. Calif. Agr. Exp. Sta. Bul. 766: 1-78.

(9) LECLERG, E. L., W. H. LEONARD and A. G. CLARK. 1962. *Field Plot Technique*. Burgess Publishing Co., Minneapolis, Minn. 144 p.

(10) MORTON, A. G., and D. J. WATSON. 1948. A physiological study of leaf growth. Ann. Bot. N.S. 12: 281-310.

(11) RADFORD, P. J. 1967. Growth analysis formulae—their use and abuse. Crop. Sci. 7: 171-175.

(12) STOUT, M. 1961. A new look at some nitrogen relationships affecting the quality of sugar beets. J. Am. Soc. Sugar Beet Technol. 11: 388-398.

(13) THORNE, G. N. and A. F. EVANS. 1964. The influence of tops and roots on net assimilation rate of sugar-beet and spinach beet and grafts between them. Ann. Bot. N.S. 28: 499-508.

(14) ULRICH, A. 1950. Critical nitrate levels of sugar beets estimated from analysis of petioles and blades, with special references to yields and sucrose concentrations. Soil Sci. 69: 291-309.

(15) WATSON, D. J. 1952. The physiological basis of variation in yield. Adv. Agron. 4:101-145.

(16) WATSON, D. J. 1956. Leaf growth in relation to crop yield. *In* F. L. Milthrope (ed.) *The Growth of Leaves*. Butterworths Publications, London. pp. 178-191.

(17) WATSON, D. J. 1958. The dependence of net assimilation rate on leaf area index. Ann. Bot. N.S. 22: 37-54.

(18) WILLIAMS, R. F. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate. Ann. Bot. N.S. 10: 41-72.