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# GROWTH ANALYSIS STUDIES OF SUGARBEET

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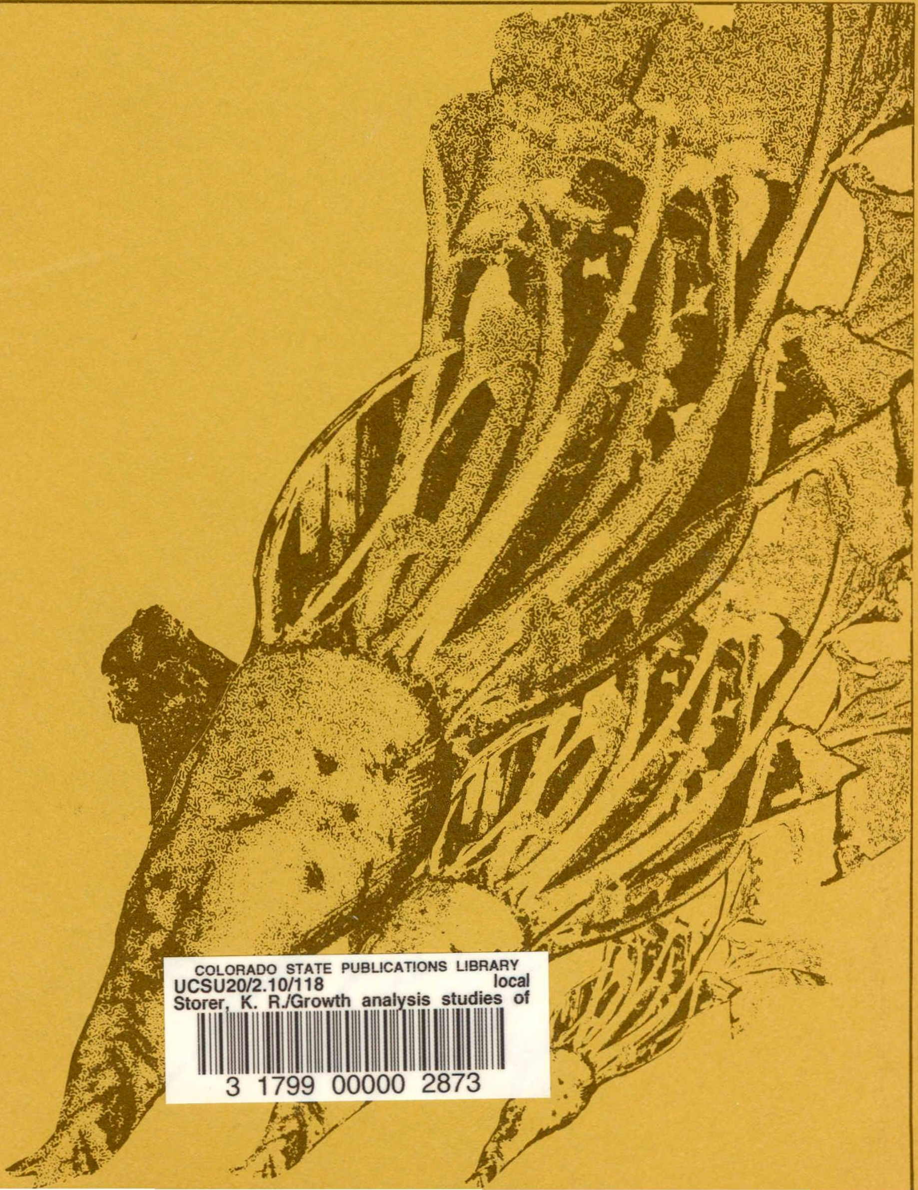

# GROWTH ANALYSIS STUDIES OF SUGARBEET[1]

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**in cooperation with the**

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# INTRODUCTION

The yield of a sugarbeet crop is the integrated effect of many factors that influence the growth of the plant throughout the season. It is well recognized that variations in management affect final yields, but the time during the season when a practice has its effect generally is not known. An understanding of the growth of the plant at specific times during the season can reveal when certain factors may limit the development of the plant. Possibly, certain cultural practices applied at such times could enhance final yields or root quality. Most research studies with sugarbeets have been designed to determine the influence of an imposed variable on final yield, but not to study when, during the season, a given practice has its greatest effect on yield. The objective of this research was: a) to evaluate the influence of certain cultural practices on growth characteristics of the plant during the season, and b) to explain final production levels on the basis of the seasonal growth characteristics.

# REVIEW OF LITERATURE

Since the introduction of such concepts as "net assimilation rate" and "relative growth rate" (Blackman 1919; Gregory 1917; Briggs et al. 1920), plant physiologists have found them useful tools in studying plant growth. These techniques, which have become known as "growth analysis," are now being used by crop scientists and agronomists (Campbell and Viets 1967; Muramato et al. 1965; Williams et al. 1965; Watson 1952; Goodman 1968) in attempts to explain variations in crop yields. This review will examine first some theoretical considerations. Secondly, a section will be devoted to use and application of growth analysis to sugarbeet production.

## GROWTH ANALYSIS FORMULAS

Two assessments are required to carry out simple growth analysis: 1) a measure of the plant material present (W); and 2) a measure of the assimilatory system (A) of that plant material (Radford 1967). In practice the most common measure of W and A are the total dry weight of the plant (W) and the total leaf area of the plant (A). If the plants being studied form a continuous leaf canopy, then the relevant measures are: 1) the total dry weight of the plant per unit land area; and 2) the total leaf area of the plant material per unit area of land, known as the leaf area index (LAI) of the canopy. Since yield of a field crop is the weight of the crop, or a specific part of it, per unit area of land, data for growth analysis with field experiments are obtained by periodic dry weight and leaf area measurements for a specified area.

**Leaf area —** Leaf area in growth analysis usually is discussed as leaf area index. However, leaf area may sometimes be expressed as leaf area duration (LAD) which is the integral of the leaf area curve over the complete growth period (Watson 1947 and 1952),

$$LAD = \int_{t_1}^{t_2} A\,dt,$$

where A = leaf area at any time, t. LAI measurements with field experiments often are made on a weekly basis with "weeks" as the units for LAD (Goodman 1963; Campbell and Viets 1967). LAD may be measured by the use of a planimeter on LAI curves (weekly points) or by summing up average weekly LAI values as an approximation to the integral,

$$LAD\ (weeks) = \sum LAI_i,$$

where i is the index for weeks.

**Relative growth rate** — Blackman (1919) suggested that the growth of the annual plant, W, increased exponentially with time and therefore followed the compound interest law, which may be stated as

$$W_2 = W_1 e^{RGR(t_2 - t_1)},$$

where RGR is relative growth rate. The equation can be solved for RGR by taking the natural logarithms,

$\ln W_2 = \ln W_1 + RGR\,(t_2 - t_1)$, and rearranging,

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}.$$

Blackman (1919) called this the "efficiency index" but it is now more commonly called relative growth rate. Fisher (1920) found the mean RGR over a given time interval by integrating the equation. If growth rate (GR) of a plant at any instant in time (t) is defined as the increase of plant material per unit time,

$$GR = \frac{dW}{dt},$$

the relative growth rate (RGR) of a plant at an instant in time is defined as the increase of plant material per unit of material present per unit time,

$$RGR = \frac{1}{W}\frac{dW}{dt} = \frac{d\ln W}{dt}.$$

From this it follows that the average value of RGR over any given time interval, say $t_2 - t_1$, is

$$\overline{RGR} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \frac{d\ln W}{dt}\,dt = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}.$$

This is the same formula as Blackman's efficiency index (1919), but in this case no assumption is necessary as to the change of W with t, providing that it is a continuous function throughout the period $t_1$ to $t_2$.

**Net assimilation rate (NAR)** — The dry weight of a plant is not all productive material as part of it is not active in photosynthesis. Since dry matter increase is caused by photosynthesis, except for the small amount of mineral uptake, a better estimate of plant material producing more new plant material is leaf area (A). Other leaf attributes have been used, however, namely leaf weight and leaf protein (Williams 1946). Ideally, the basis of reference should be a precise measure of the system responsible for dry matter accumulation (Watson 1952). Because photosynthesis occurs mainly in the leaves while respiration occurs in the whole plant, it would be impossible for any attribute of the leaf to be a precise measure for both processes. Leaf area appears to approximate photosynthetic production as well as any measurable leaf attribute, and for that reason is most often used.

Gregory (1917) was the first to calculate net assimilation rates but it remained for Briggs et al. (1920) to formulate the method of analysis. NAR of a plant at any instant in time may be defined as the increase of plant material per unit of leaf area per unit time,

$$NAR = \frac{1}{A}\frac{dW}{dt} .$$

Since the above equation describes NAR at any instant, then its average value over a given time interval $(t_2 - t_1)$ can be expressed as

$$\overline{NAR} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \frac{1}{A}\frac{dW}{dt}\,dt .$$

This cannot be integrated unless either 1) the relationship between A and W is known or 2) the relationships among A and t and W and t are known. It has been customary to solve this problem by investigating the A versus W relationship (Radford 1967; Williams 1946). Usually no information exists between harvests at $t_1$ and $t_2$ with field experiments and it is assumed that the relationship between A and W are linear. Since the line must pass through the points $(A_1, W_1)$ and $(A_2, W_2)$, the equation must take the form,

$$W = C + [(W_2 - W_1)/(A_2 - A_1)]\ A,$$

where $A_1$ and $A_2$, and $W_1$ and $W_2$ are the values of A and W at $t_1$ and $t_2$ respectively; C is a constant. From this we know the slope of the line,

$$\text{slope} = \frac{dW}{dA} = \frac{W_2 - W_1}{A_2 - A_1} .$$

A substitution for dW/dt can be made in the equation for NAR,

$$\frac{dW}{dt} = \frac{dA}{dt}\frac{dW}{dA} \text{ (identity)} .$$

The average NAR equation then becomes

$$\overline{NAR} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \frac{1}{A}\frac{dA}{dt}\frac{dW}{dA}\,dt$$

$$= \frac{1}{t_2 - t_1}\frac{W_2 - W_1}{A_2 - A_1}\int_{t_1}^{t_2} \frac{1}{A}\frac{dA}{dt}\,dt$$

$$= \frac{1}{t_2-t_1}\,\frac{W_2-W_1}{A_2-A_1}\int_{A_1}^{A_2} d\ln A$$

$$= \frac{W_2-W_1}{A_2-A_1}\,\frac{\ln A_2-\ln A_1}{t_2-t_1}\,.$$

The only assumptions needed to arrive at this equation are: 1) that over the period $t_1$ to $t_2$, A and W are linearly related; and 2) that A and W are continuous functions of time. Williams (1946) points out that for short intervals of time (1-2 weeks) the conditions for linearity of A and W usually are satisfied. Errors introduced by this assumption generally are small in comparison to sampling variation of A and W with most field crops. Estimates of NAR made by this method for larger sampling intervals may be incorrect owing to deviations from linearity. Radford (1967) suggests that a plot of A versus W for all harvests taken throughout the season might reveal the true relationship from which accurate formulas for NAR could be calculated by least squares. Radford (1967) gives examples of various equations that have been developed for NAR along with corresponding correct assumptions for the A versus W relationship in a review of this subject.

**Leaf area ratio (LAR)** — Leaf area ratio, which is the ratio of leaf area to total plant dry weight is sometimes calculated in growth analysis. For any instant in time relative growth rate is equal to the product of net assimilation rate and leaf area ratio,

RGR = NAR x LAR,

or $\frac{1}{W}\frac{dW}{dt} = \frac{1}{A}\frac{dW}{dt} \times \frac{A}{W}$.

The most commonly used equation for calculating average LAR values assumes a linear relation of A/W with time,

$$\overline{LAR} = \tfrac{1}{2}\left(\frac{A_2}{W_2} - \frac{A_1}{W_1}\right).$$

It should be noted that this relationship may deviate considerably from linearity. Radford (1967) suggests that a plot of the actual points may be beneficial in order to arrive at the relationship by means of least squares. Williams (1946), however, notes that the method of least squares may demand more extensive data than are usually available and often oversimplifies the true relation.

## APPLICATION OF GROWTH ANALYSIS TO SUGARBEET PRODUCTION

Watson (1968) has suggested that the main object of growth studies is to learn how the morphological characters and the physiological activities of crops interact with environment to determine yield. Therefore, one of the most useful applications might be to show how plant form and behavior can be adjusted to the environment to give maximum yield. Growth studies may also reveal sources of inefficiency in crop production that can be remedied by changes in cultural methods. Ivins and Bremner (1966) noted that growth studies may help in the interpretation of results of highly variable field experiments, and may aid the breeding of better varieties and the evolution of better production practices.

**Correlation with climate** — Growth analysis techniques often are used to relate yield to climatic conditions. From measurements of NAR, LAR, and RGR for each interval, a multiple regression analysis can be made on mean values of weather variates in corresponding intervals. Correlations of growth with climatic factors should be independent of plant size, thus the use of NAR, LAR, and RGR. This kind of analysis enables the experimentor to see how RGR and its components depend on short period variation in climatic factors. Watson (1963), in a review of this subject, indicated that in general NAR correlates positively with daily radiation. LAR generally is negatively correlated with radiation and positively correlated with mean daily temperature. The opposite effects of radiation on NAR and LAR tend to make RGR relatively constant in spite of the change in light environment, but usually the effect of NAR predominates over LAR so that RGR is positively correlated with mean daily radiation as well as with mean daily temperature. Watson (1963) points out, however, that it is not possible to predict what weather conditions at particular stages of growth will do to to final yield. The fundamental difficulty is that the effect of a change in RGR at any time on final yield must depend on the subsequent progress of growth in dry weight, which is determined by internal factors affecting leaf area and possibly NAR, as well as by subsequent weather.

**Dry matter production** — Growth analysis studies also have been used to determine whether photosynthetic production, as measured by growth rate (GR), depends more on the amount of leaf area, as measured by LAI, or on efficiency of the leaves as measured by NAR, since GR is a product of the two, i.e.,

GR = LAI x NAR.

Most work (Watson 1952, 1956, 1968; Goodman 1963) indicates that LAI is far more important then NAR in determining GR. As it happens, leaf area is the parameter which is most amenable to control by the experimentor, and NAR is more likely to respond to factors not controlled by the experimentor such as temperature and hours of sunlight (Ivins and Bremner 1966; Goodman 1967). Many growth analysis experiments, therefore, involve methods to vary the leaf area curve for the season in an attempt to relate these changes to differential plant growth and activity.

## EFFECT OF CULTURAL PRACTICE ON LEAF AREA OF SUGARBEET

One of the commonly recognized ways of increasing leaf area, as well as other attributes of the plant, is by adding nitrogen, especially if the soil is low in available nitrogen. Variation in available nitrogen affects all phases of leaf growth and has been shown to increase leaf number as well as leaf size. Morton and Watson (1948) found that the larger leaves of sugarbeet plants receiving a high nitrogen supply had more and larger cells. Nitrogen will increase leaf area of sugarbeets when added at any time during the vegetative growth period. Campbell and Viets (1967) found almost immediate results when applying nitrogen in August to sugarbeets that already had reached their maximum LAI. Leaf areas nearly doubled by the last of October with a 200-lb-per-acre application of nitrogen. Actual market benefits obtained by the larger leaf growth will depend on other factors. Much research has been carried out concerning nitrogen fertilization, root yield, sucrose content, and purity. A good review of the effect of nitrogen fertilization on sugarbeet production can be found in a paper by Follett et al. (1964). In most cases, application of nitrogen increases root tonnage and decreases sucrose percentage and purity. The increase of root tonnage may not be sufficient to overcome the decrease in sucrose content and purity; hence, sucrose yield is decreased. Most research (Ulrich 1950; Ivins and Bremner 1966) shows that the key to nitrogen fertilization is the application of an amount to give large leaf areas during the first half of the growing season and to produce large roots in this period. Retardation of growth should then occur later in the season to allow the assimilate to be stored as sucrose.

Plant spacing, which can be controlled by the experimentor to a certain degree, also affects LAI values. Campbell and Viets (1967) working with different within-row plant spacings in Montana (6-, 12-, and 18-in) found that final LAI was not significantly affected by the spacings. The trend was for higher LAI with closer spacing even though average leaf areas per plant increased considerably with wider spacings. With the wider spacings the roots had a lower sucrose percentage and purity but still produced the most sucrose because of the greater root yield. Ivins and Bremner (1966) noted that increasing plant population usually leads to a decreased root/shoot ratio.

Leaf area may be affected by planting date. Watson (1947) working with sugarbeets in England found that delay in sowing reduced leaf area per plant and LAI during the early part of the season, but the late-sown plants eventually developed a larger leaf area than the early-sown plants. This was brought about by an increase in leaf size since leaf number decreased with late planting. Watson (1947) suggested that this difference was caused by climatic conditions at the beginning of the growth period which induced differences in the internal factors controlling leaf expansion. Ivins and Bremner (1966) suggested that early sowing increases the root/top ratio because the seedlings are exposed to lower temperatures and soil nutrient regimes, which tend to limit leaf growth.

Different sugarbeet varieties may be expected to produce different leaf areas. Some varieties have been selected for high fresh-weight yield of roots having a reasonable sucrose percentage, while others have been selected for maximum sucrose. Watson (1952) suggested that over the range of most agricultural varieties of sugarbeets, leaf size tends to decrease and leaf number to increase as sucrose content and dry matter increase, and that the increase in leaf number depends both on more rapid production and longer life of leaves. Differences in leaf area caused by varieties also may be accompanied by changes in NAR independent of LAI. Some varieties have greater root/top ratios and are able to produce as much dry matter on less leaf area.

**Optimum leaf areas for sugarbeets** — One of the disconcerting features of field growth analysis studies with sugarbeets is the lack of agreement for an optimal leaf area. If NAR were independent of LAI, the rate of increase of dry matter per unit area of land (GR = NAR x LAI) would increase indefinitely with increase in LAI. But as LAI increases, mutual shading of the leaves begins to decrease photosynthesis in part of the leaves and thus NAR decreases. Leach and Watson (1968) used phytometers, i.e., small standard plants provided with water and nutrients placed at different positions under a leaf cover, to study rates of photosynthesis in the plant cover profile. They found a definite decrease in NAR values with increasing leaf cover and decreasing light in sugarbeet canopies. Since NAR may decrease nearly linearly with increase in LAI during portions of the season, the crop growth rate cannot be linearly related to LAI, but must pass through a maximum (Watson 1956; Goodman 1968). Watson (1956, 1958) suggested that LAI responsible for maximum growth rates in sugarbeets might be

6 to 9 or near the upper limit attained in current agricultural production. Goodman (1968), however, found LAI values of 3 to 4 during August produced the greatest crop growth rates for that time period.

Leaf areas for maximum crop growth rates do not necessarily imply maximum sucrose accumulation rates, however, since assimilate may be transformed to excessive vegetative growth at the expense of sucrose accumulation. Some workers have therefore attempted to estimate leaf areas at which sucrose accumulation rates are maximized. Scott and Bremner (1966) suggested that LAI of 4 to 5 was optimum for sucrose accumulation. Campbell and Viets (1967) attained highest sucrose yields with lowest production of tops and a LAI that never exceeded 3 during the entire season.

Lack of agreement for optimum leaf area values between studies for both dry matter and sucrose accumulation rates would indicate that other factors besides leaf area are involved. Optimum leaf areas could be expected to vary during the season and between experimental sites because the sun's angle would be affected by latitude. Ivins and Bremner (1966) pointed out that total dry matter depends not only on the size and efficiency of leaf area, but its relationship in time with seasonal income of solar radiation. Degree of cloudiness, temperature affecting respiration, and varietal differences in leaf display could also be factors causing deviations in predicted optimum LAI values between experiments (Campbell and Viets 1967).

Even though agreement between experiments on optimum leaf areas for sugarbeets has been poor, most researchers agree there would be little value in raising present peak leaf area values, especially for yield of sucrose (Watson 1956; Goodman 1968; Scott and Bremner 1966; Campbell and Viets 1967). The main possibilities for increasing sugarbeet yields may lie in attaining greater leaf areas earlier in the season as Ivins and Bremner (1966) have suggested, or by maintaining optimum leaf area index over a longer part of the growth period as noted by Watson (1956).

# METHODS AND MATERIALS

Sugarbeets were grown on an irrigated Nunn clay loam at the Colorado State University Research Center near Fort Collins in 1966 and 1967. The soil is calcareous and nonsaline and contains about 2 percent organic matter. The 1966 experiment followed corn and the 1967 experiment followed barley. Each experiment received a preplant application of 100 lb per acre of concentrated superphosphate. Soil tests showed that available soil potassium was high. Preplant nitrogen fertilizer treatments were broadcast and harrowed into the surface soil, and delayed nitrogen in July was applied in the furrow and irrigated.

## TREATMENTS

**1966 experiment—**Two genetic populations were planted March 31: (1) A56-3, a former commercial variety adapted to the Colorado plains, and (2) an $F_1$ hybrid (52-305 x 52-307) developed by the Plant Science Research Division, USDA, Fort Collins, Colorado. Five nitrogen treatments were imposed by adding ammonium nitrate as follows: (1) check - zero nitrogen; (2) 125 lbs nitrogen per acre applied March 26; (3) 250 lbs nitrogen applied March 26; (4) 125 lbs nitrogen side-dressed July 12; (5) 250 lbs nitrogen side-dressed July 12. These ten treatments (2 varieties x 5 nitrogen treatments) were replicated four times in a factorial design to give a total of 40 plots. No herbicide was used.

**1967 experiment—**Only one variety (A56-3) was used, but two planting dates were employed in 1967. Beets were planted April 30 and May 18. Earlier dates were planned, but frost killed a March planting. The beets were planted in beds and pre-emergence herbicides were incorporated at planting. Pyramin and TD-282 were applied in a band at rates of 3.75 and 2.50 lbs per acre respectively. Six nitrogen treatments were employed by adding ammonium nitrate as follows: (1) check - zero nitrogen; (2) 125 lbs nitrogen per acre applied March 20; (3) 250 lbs nitrogen applied March 20; (4) 375 lbs nitrogen applied March 20; (5) 125 lbs nitrogen side-dressed July 13; (6) 250 lbs nitrogen side-dressed July 13. The 12 treatments were replicated four times in a factorial design for a total of 48 plots.

## SAMPLING PROCEDURES

Plots in the 1966 and 1967 experiments were 16 rows wide (22-in rows) and 60 ft long. The beets were hand-thinned in mid-May and mid-June in 1966 and 1967 respectively to about 10-in plant spacings. Beginning June 6, 1966 or June 24, 1967, and approximately every 2 weeks thereafter, 15-ft rows of beets were harvested. Actual sampling dates for both years are given in Table 1. Sections of rows were selected to give 17 to 19 beets each harvest to insure uniform stands for all treatments. One unharvested row was left between harvested sections to maintain uniform competition throughout the season. The beets from each harvest were divided into blades, petioles plus crowns, and roots. The fresh and dry weights of each plant part, as well as leaf area and leaf number, were determined for growth analysis. Beginning July 5, 1966, and July 8, 1967, sucrose content and purity of the roots were determined on all samples to measure quality changes.

Table 1. Sampling dates for 1966 and 1967 experiments.

| | 1966 | 1967 |
|---|---|---|
| 1 | June 6 | June 24 |
| 2 | June 20 | July 8 |
| 3 | July 5 | July 22 |
| 4 | July 18 | Aug. 5 |
| 5 | Aug. 1 | Aug. 19 |
| 6 | Aug. 15 | Sept. 2 |
| 7 | Aug. 29 | Sept. 16 |
| 8 | Sept. 12 | Sept. 30 |
| 9 | Sept. 24 | Oct. 14 |
| 10 | Oct. 8 | Oct. 28 |
| 11 | Oct. 22 | Nov. 11 |
| 12 | Nov. 8 | |

## MEASUREMENTS OF GROWTH

**Leaf area index(LAI)**—Leaf area index is the area of green leaves per unit ground area. Dry weights of the leaves per 15 ft of row were recorded at each harvest. Areas were determined from dry weight versus leaf area relations determined by either a planimeter method or a punch method, and LAI was calculated for each 15-ft plot. In 1966, 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 for area measurement. Leaves that were used were then dried and weighed to get the area versus dry weight relationship. In 1967 the punch method as described by Campbell and Viets (1967) was used. This method was equally effective for all leaves and was unaffected by leaf size or thickness as long as sufficient care was taken to assure that all sections of the leaves were proportionately represented in the punch sample.

**Leaf area duration (LAD)**—Leaf area duration is the integral of the leaf area curve over a given growth period. When leaf areas (A) are measured on a weekly basis throughout the period $t_1$ to $t_2$, a good approximation of this integral is the sum of weekly values obtained for $A(A_1 \ldots A_n)$ throughout the period. To express leaf area index on a weekly basis the values for biweekly samples were doubled.

**Growth rate (GR)**—Growth rates for this study were obtained from smooth curves generated by taking the first differential of the following logistic growth curve function:

$$W = \frac{a}{1 + be^{-ct}} .$$

The function was fitted to each set of data by means of least squares with a computer program adapted specifically for this study. The dry weight at time t is W; a, b, and c are parameters which were estimated by the computer for each curve. The growth rate, or first differential of the function, is

$$\frac{dW}{dt} = \frac{abce^{-ct}}{(1 + be^{-ct})^2} .$$

Since this is a continuous function, growth rates can be calculated for any given day once the parameters are estimated. The same function was used for determining root growth rates and sucrose accumulation rates since they also showed the same sigmoid accumulation pattern.

**Net assimilation rate (NAR)**—Net assimilation rate is the rate of increase in dry weight per unit leaf area per unit time (Blackman 1919; Briggs et al. 1920; Williams 1946; Radford 1967). For this experiment NAR was calculated only for the days on which samples were taken. Growth rates for the harvest dates were taken from calculated curves and divided by leaf area index values of the same samples to obtain NAR,

$$NAR = \frac{GR}{LAI} .$$

Estimates of NAR were limited to specific sampling dates since smooth curves were not derived for LAI.

## CHEMICAL PROCEDURES

**Sucrose percentage and thin juice purity**—Sucrose percentages were determined on the beet pulp using a method standard with commercial sugarbeet companies and similar to the method outlined in A.O.A.C. (1965). Sugar purity was determined using clarified extract of brei as outlined by Carruthers and Oldfield (1961).

**Percent recoverable sugar (PRS)**—The quantity of white crystalline sugar obtained from sugarbeets by ordinary processing procedures is a measure of net sucrose. A method had been proposed whereby the amount of net sucrose may be approximated. PRS is dependent upon the percent sucrose of the beet and purity of the second carbonated juice assuming a standard factory loss and molasses purity (Dexter et al. 1967). Values for PRS for this study were obtained from tables generated from the Great Western Co. formula for calculating recoverable sugar assuming a 62.5 percent molasses purity and 0.3 percent factory loss (R. R. Wood, personal communication).

**Chemical analysis for nitrogen in plant material**—After drying, samples of the three plant parts (roots, petioles + crowns, and leaves) were ground in a Wiley mill for analysis of total nitrogen. Nitrate-nitrogen also was determined in the petioles from youngest fully matured leaves as suggested by Ulrich (1946).

*a) Total nitrogen.* Total nitrogen was determined on oven-dried plant material with micro-Kjeldahl equipment by the improved Kjeldahl method for nitrate-containing samples (A.O.A.C. 1965).

*b) Nitrate-nitrogen.* Nitrate-nitrogen concentration in petioles was determined by the phenoldisulfonic acid method as described by Johnson and Ulrich (1959).

**Determination of soil nitrogen**—Each check plot was sampled in the spring to 4 ft in 6-in increments and analyzed for mineral nitrogen and total nitrogen. The mineral nitrogen was determined on the moist soil but total nitrogen was determined after air drying.

*a) Mineral nitrogen.* Ammonium nitrogen was determined in normal sodium chloride extracts by distillation in sodium hydroxide. Nitrate-nitrogen was then determined by a second distillation after the addition of Devardo's alloy (A.O.A.C. 1965).

*b) Total nitrogen.* This was determined by the Kjeldahl method described in A.O.A.C. (1965).

## MEASUREMENT OF SOLAR RADIATION AND AIR TEMPERATURE

Total radiation (cal $cm^{-2}$ $day^{-1}$) was measured for the 1966 and 1967 growing seasons at the Colorado State University campus at Fort Collins, with a standard-weather, 16-junction Epply pyreheliometer.

Air temperature data were obtained from weekly thermograph readings measured at the Agronomy Research Center where the experiment was located.

# RESULTS AND DISCUSSION

The results and discussion will be divided into two sections. The first section will present final yield and quality measurements for the sugarbeet crops in 1966 and 1967. The second section will cover the growth analysis of the crop throughout the growing season, along with an explanation of final yields based on the seasonal growth characteristics.

## FINAL HARVEST RESULTS

Maximum yields were obtained by October 8 in 1966 and October 28 in 1967. Since the last three harvests in 1966 and the last two harvests in 1967 did not differ significantly for final yield and quality measurements, they were analyzed jointly within each year. Means for the main effects for 1966 and 1967 are presented in Tables 2 and 3, respectively. Only one interaction of the main effects was present for either experiment; this was a nitrogen fertilizer x variety interaction for sucrose in 1966 (Figure 1).

**1966 experiment —** Root yields were significantly affected by variety and nitrogen fertilizer in 1966 (Table 2). The root yields for the A56-3 and $F_1$ varieties were 22.7 and 20.6 tons per acre, respectively, for means of all nitrogen levels. Husseini (1966) 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, combined with a slight infestation of leaf spot (*Cercospera beticola*) on the $F_1$, are possible explanations for the superiority of A56-3 in the field.

Duncan's Multiple Range Test (LeClerg, Leonard, and Clark 1962), based upon tables of the Studentized Range, was employed to compare nitrogen fertilizer means averaged over three harvests and two varieties (Table 2). The results were as follows: (1) the yield of the no-nitrogen check was significantly lower than all other treatments; (2) there were no significant yield differences, at the 5 percent level, among applications of 125 lbs nitrogen in March, 125 lbs in July, and 250 lbs in July; and (3) plants receiving the 250-lb preplant nitrogen treatment in March were significantly higher yielding than all other nitrogen treatments.

The sucrose percentage was not affected by variety as noted in Table 2. Nitrogen fertilizer, however, did have a significant effect on sucrose. The check treatment had a higher sucrose than all other treatments. The preplant applications of nitrogen had a definite advantage over side-dress applications in July as shown by the significantly higher sucrose for the 125-lb and 250-lb treatments applied in March when compared with the same rates applied July 12 (Table 2). An interaction of variety by nitrogen was observed in the analysis of variance for sucrose; a plot of the interaction means is shown in Figure 1. At lower rates of nitrogen the A56-3 variety had the same or greater sucrose percentage than the $F_1$, but at the 250-lb rate the $F_1$ was higher in sucrose for both early and late nitrogen applications.

Table 2. Effect of harvest date, nitrogen fertilizer, and variety on final root yield and quality, 1966.

| Treatment | | Root Yield | Sucrose | Thin Juice Purity | Recoverable Sucrose |
|---|---|---|---|---|---|
| | | *(T/A)* | *(%)* | *(%)* | *(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 | 15.8c | 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)** | | | | | |
| | df | | | | |
| Nitrogen | 4 | 40.5** | 28.8** | 12.5** | 22.1** |
| Variety | 1 | 13.2** | N.S. | N.S. | 5.8* |
| NXV | 4 | N.S. | 4.0** | N.S. | N.S. |

**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.*

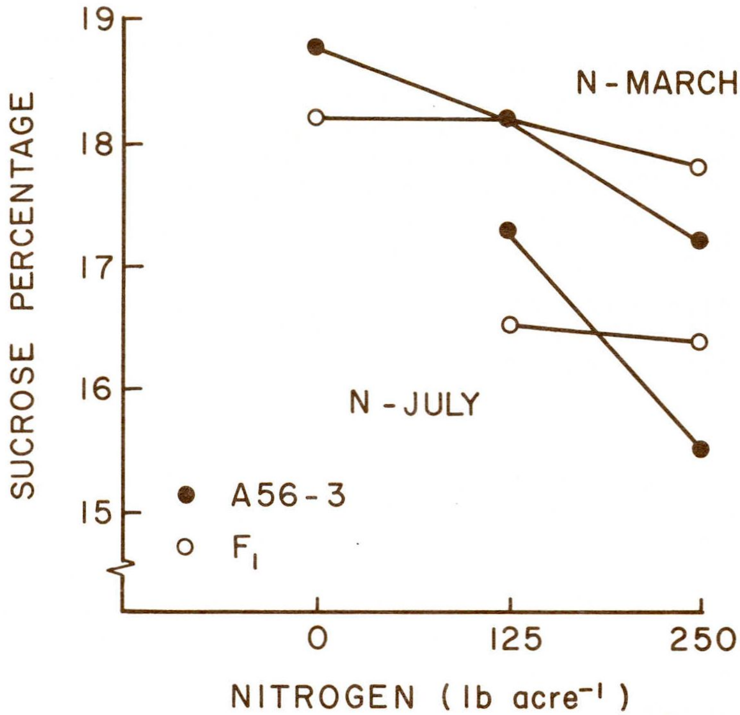


Figure 1. Interaction of nitrogen fertilizer and variety for sucrose percentage, 1966.

Thin juice purity for 1966 was relatively high for all treatments (Table 2). Varieties did not differ significantly for purity, but nitrogen fertilizer did have a significant negative effect on purity, caused primarily by the late-nitrogen treatments.

There were significant differences among varieties and nitrogen treatments for recoverable sucrose (tons per acre), which takes into account both percent sucrose and purity, but there were no significant interactions. The A56-3 and $F_1$ varieties gave yields of 3.41 and 3.07 tons per acre, respectively. This difference was caused principally by the variation in root yield of the two, since neither sucrose percentage nor purity differed appreciably. Maximum recoverable sucrose was produced with the 250-lb and the 125-lb preplant rates of nitrogen. Plants receiving nitrogen applications in March produced significantly greater sucrose yields than those receiving the same amount of nitrogen in July. The advantage of preplant over July applications of nitrogen was caused by the combined effects of root yield, sucrose, and purity.

When nitrogen was applied preplant in March, reduction in percentage sucrose was more than balanced by increased root yields. Applications of nitrogen in July caused root yields to increase, although not as much as did the earlier applications, and at the same time caused a greater decrease in percentage sucrose and purity. The yield of recoverable sucrose for the 250-lb nitrogen treatment in July was no greater than the check although there was a large response in root yield.

**1967 experiment**—In 1967, planting date significantly affected root yield (Table 3). Beets planted April 30 and May 18 averaged 16.4 and 12.6 tons per acre, respectively, demonstrating the definite

Table 3. Effect of harvest date, nitrogen fertilizer, and planting date on final root yield and quality, 1967.

| Treatment | | Root Yield | Sucrose | Thin Juice Purity | Recoverable Sucrose |
|---|---|---|---|---|---|
| | | (T/A) | (%) | (%) | (T/A) |
| **Harvest date** | | | | | |
| Oct. 28 | | 14.3 | 16.1 | 93.6 | 2.00 |
| Nov. 11 | | 14.8 | 15.7 | 93.8 | 1.94 |
| **Nitrogen†** | | | | | |
| Check | | 12.7a | 17.2a | 95.8a | 1.97a |
| 125-March | | 15.1a | 16.0b | 94.8ab | 2.19a |
| 250-March | | 15.0a | 15.4b | 93.9abc | 2.01a |
| 375-March | | 14.7a | 14.7c | 91.9c | 1.82a |
| 125-July | | 15.0a | 16.1b | 93.6abc | 2.12a |
| 250-July | | 14.7a | 15.5b | 92.7bc | 1.96a |
| **Planting date** | | | | | |
| April 30 | | 16.4 | 16.0 | 94.1 | 2.34 |
| May 18 | | 12.6 | 15.6 | 93.3 | 1.73 |
| **Significant (F-test)** | df | | | | |
| Nitrogen | 5 | N.S. | 10.9** | 6.75** | N.S. |
| Planting date | 1 | 56.4** | N.S. | N.S. | 56.4** |

**Significant at the 5% level.*

***Significant at the 1% level.*

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

advantage of a longer growing season. Contrary to results in 1966, nitrogen fertilizer failed to have a significant effect on root yield in 1967. The check treatment had lowest root yields, but no significant increase in yields was attained with added nitrogen. Date of application of nitrogen also had little effect; preplant nitrogen in March and side-dress nitrogen in July caused approximately equal root yields.

Sucrose percentage and thin juice purity were significantly affected by nitrogen fertilizer in 1967 (Table 3). Roots from the check treatment were highest in sucrose and purity, as in 1966. Increasing the nitrogen rate for both March and July applications caused sucrose and purity to decrease significantly. It is surprising to note, however, that the application of nitrogen in March had no advantage for sucrose percentage over that applied in July. This is contrary to what one might expect and does not agree with data obtained in 1966. Also, it was surprising that at harvest, beets planted in May were almost as high in sucrose percentage as beets planted in April. Apparently, the late planting date had a greater disadvantage for vegetative root growth than for storage of sucrose.

Recoverable sucrose, in tons per acre, was affected significantly by planting date. Sugarbeets planted April 30 and May 18 produced 2.34 and 1.73 tons of sucrose per acre, respectively. This large difference in yield was due mainly to the very large root yield difference, since the early planting date had only a slight advantage for sucrose percentage and purity. Although nitrogen had a significant effect on both sucrose and purity, no significant difference was obtained for sucrose yield. The gain in root weight resulting from added nitrogen was counterbalanced by lower sucrose concentration and purity and resulted in final sucrose yields about the same level as the check treatment.

## SEASONAL GROWTH PATTERNS

Several parameters were measured throughout the season in 1966 and 1967 to characterize plant growth within and between years. The effects of treatment and climate during the season were then used to explain differences in final yield.

**Leaf area**—The effect of time and rate of application of nitrogen on LAI during the 1966 growing season is shown in Figure 2a. Varieties were averaged since there was no interaction between variety and nitrogen. Maximum leaf areas were reached by the first of August for all treatments receiving preplant nitrogen, but late application of nitrogen delayed maximum leaf canopies until the end of August. Varietal differences in leaf area, with nitrogen

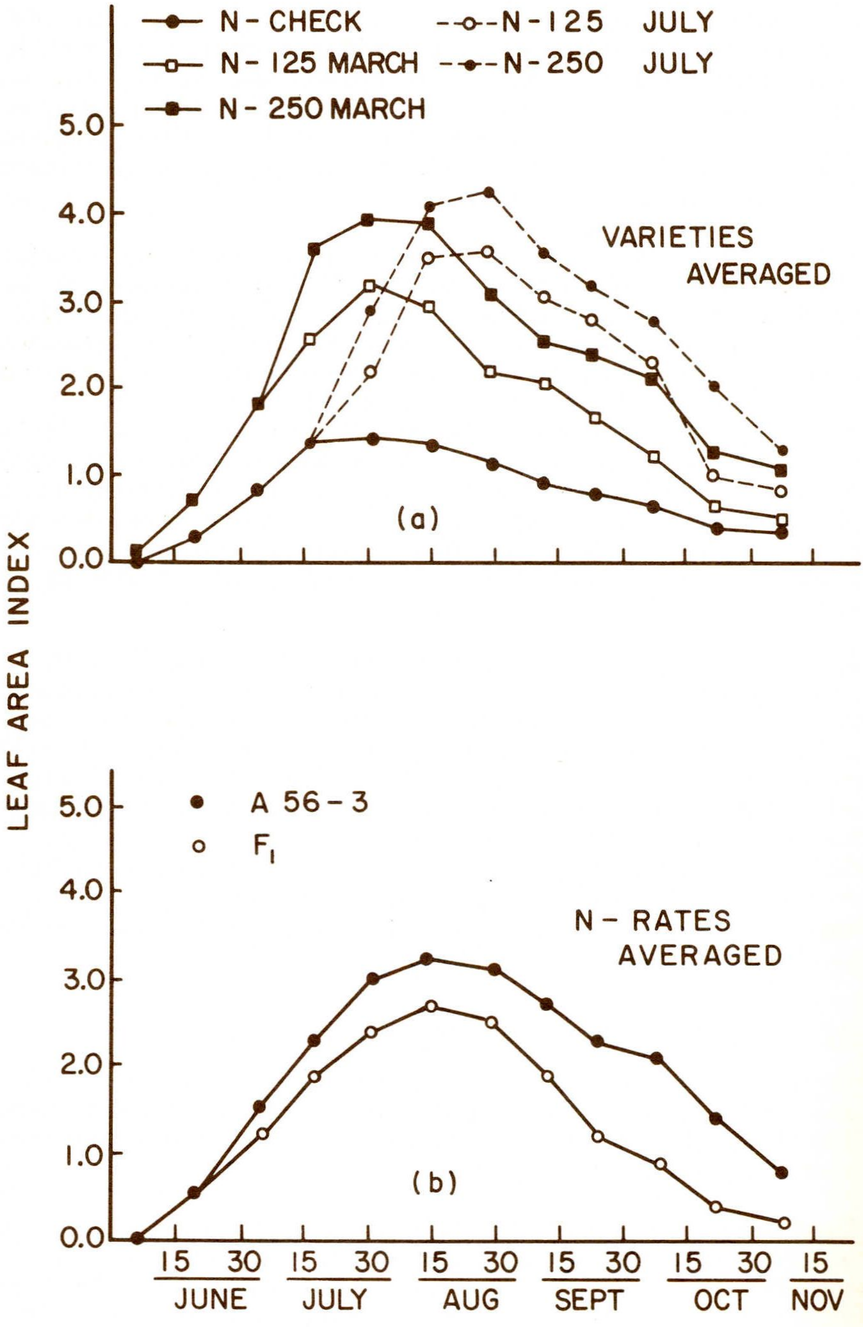


Figure 2. Effect of nitrogen fertilizer (a) and variety (b) on leaf area growth curves, 1966.

treatments averaged, are given in Figure 2b. The A56-3 variety had greater leaf areas than the $F_1$ hybrid throughout the season and confirms Husseini's (1966) results in greenhouse studies with the same genetic material.

Nitrogen treatments in 1967 (Figure 3a) had less effect on leaf area than in 1966. Increasing nitrogen to 250 lb per acre increased the LAI for both early and late-applied nitrogen, but the effect of increasing nitrogen on LAI was not as pronounced. This was caused by the greater leaf area for the check treatment in 1967 than in 1966. Earlier planting in 1967 had the effect of increasing early leaf area compared to the late planting. However, late season leaf areas were approximately the same for both planting dates (Figure 3b).

Leaf area curves were quite different between years for the same variety and nitrogen treatments (Figures 4a and 4b). Part of this difference probably was caused by the planting date effect; however, environmental differences between years caused by soil and climate were undoubtedly responsible also.

One major difference between years for leaf area growth curves was the relatively rapid decline in leaf area in 1966 as compared to 1967 (Figures 4a and 4b). Leaves in 1966 yellowed much earlier than in 1967 and new leaf production was greatly reduced. This difference may have been caused by either or both of the following effects:(1) the lower plant nitrogen levels throughout the season in 1966 (Appendix Table 6) would reduce vegetative growth; and (2) the marked reduction in dry matter production through August in 1967 would place less stress on the soil nitrogen, and more vegetative growth would continue into the fall.

Leaf characteristics for the two years (Figures 5a and 5b) indicate that the decline in LAI during the latter part of the growing season was attributed more to the smaller size of leaves than to leaf number, since the latter actually increased while LAI decreased. Figure 5c shows the change in dry weight per leaf area during the season for 1966 and 1967; the ratio of leaf weight to leaf area increased rather steadily throughout the growing season for both years, indicating thicker leaves in the fall. Differences in leaf weight/leaf area ratios as the season progressed (Figure 5c) probably resulted from the increase in average age of the leaf.

The second major difference between years for the leaf area curves was the type of response to the application of nitrogen in July. The response to side-dress nitrogen in July was much greater in 1966 than in 1967 (Figures 2a and 3a). This probably was caused by differences in the nitrogen status of the plant in July. In 1966, early season growth was more rapid because of earlier planting and a better climate; thus there was greater need for nitrogen, and plants in the check plots were nitrogen-deficient by July 15. In 1967 planting was delayed and early season growth was slow; hence the nitrogen status of the plant was higher (Appendix Table 5) and

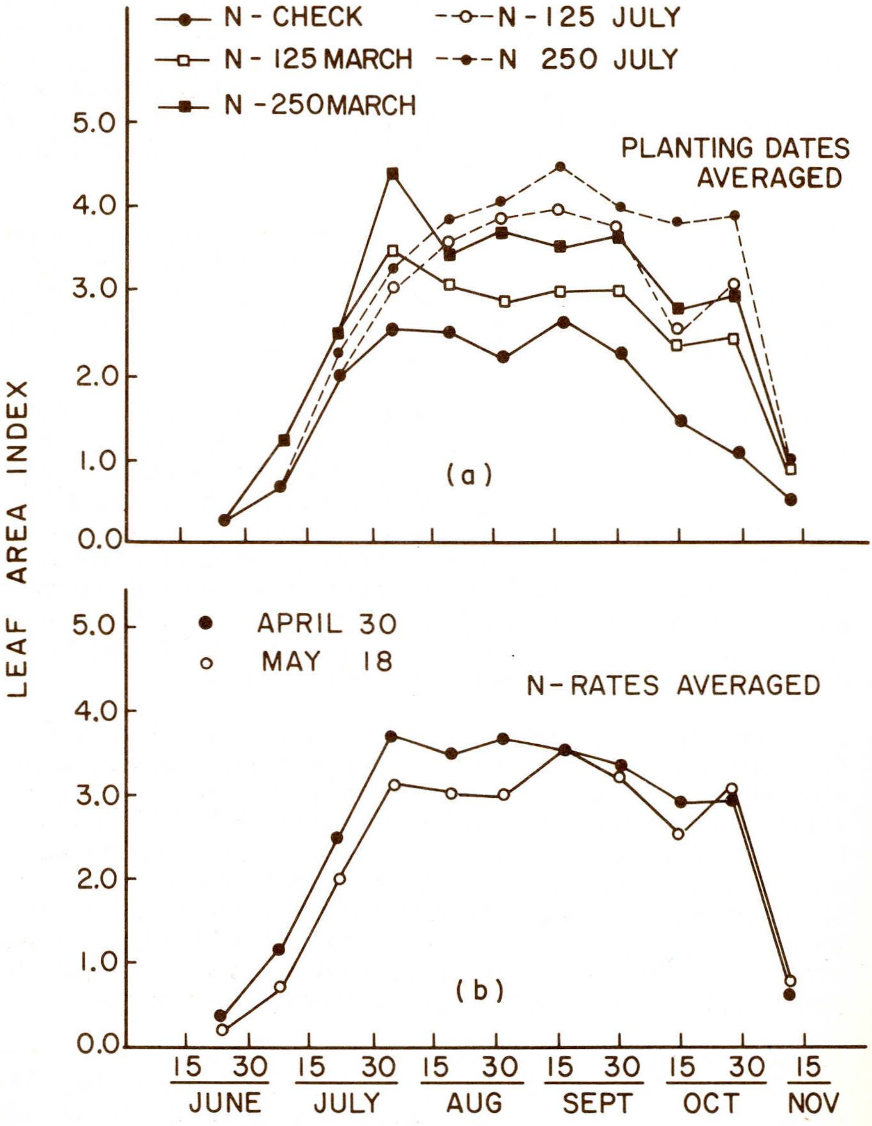


Figure 3. Effect of nitrogen fertilizer (a) and planting date (b) on leaf area growth curves, 1967.

growth was much less affected by the side-dress application of nitrogen fertilizer in July. The same reasoning helps to explain the significant yield response to nitrogen fertilizer in 1966 but not in 1967 (Tables 2 and 3). In 1966, preplant nitrogen induced larger leaf areas early in the season when solar radiation and air

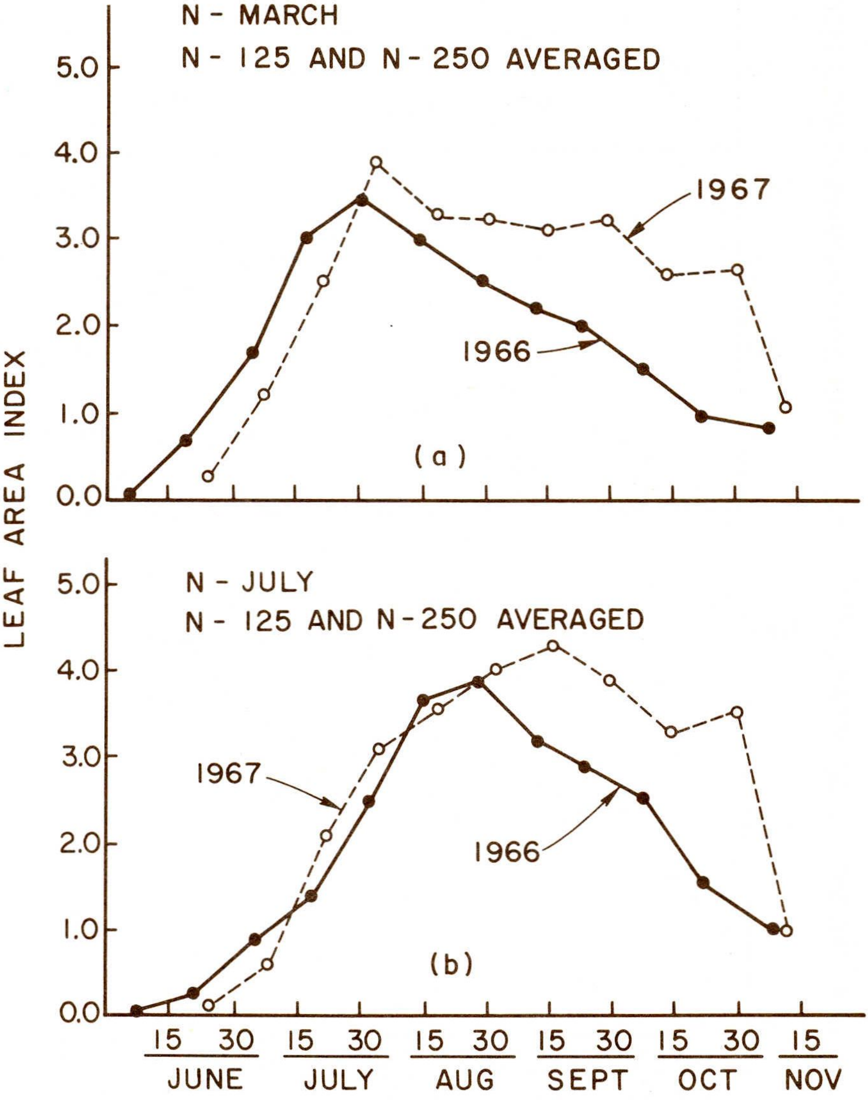


Figure 4. Leaf area response to nitrogen applied in March (a) and July (b); variety A56-3, March 31, 1966 and April 30, 1967 planting dates.

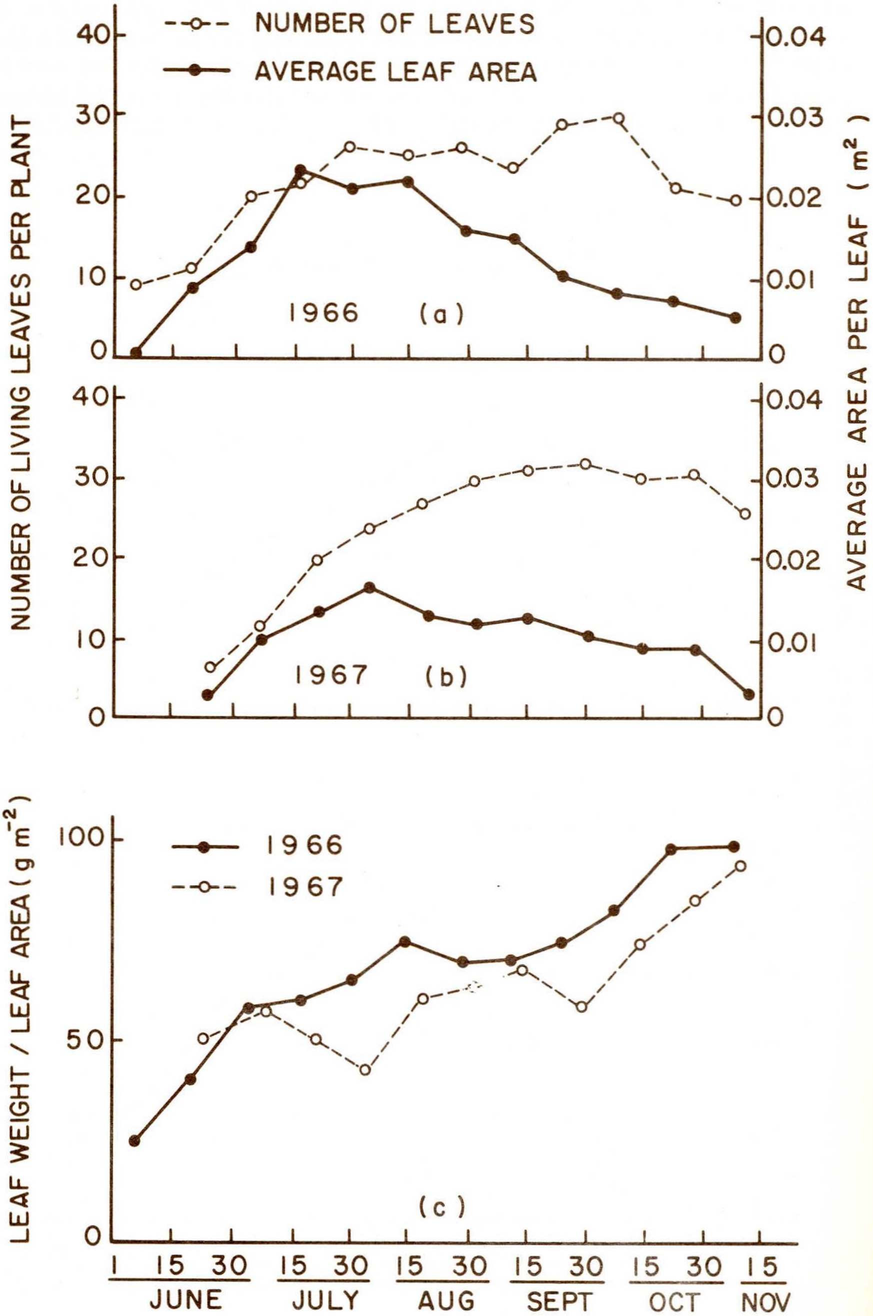


Figure 5. Several seasonal leaf characteristics for variety A56-3 in 1966 and 1967. Nitrogen was applied preplant and planting dates were March 31, 1966 and April 30, 1967.

temperatures were high, increasing the potential to produce photosynthate. In 1967, the nitrogen requirements were smaller for the plant of later planting and cool spring. The time of application of nitrogen made little difference on the resulting leaf area, explaining small differences in photosynthetic production.

Leaf area duration (LAD), represented by the area under LAI curves, often is used to evaluate the plants' ability to conduct photosynthesis because this parameter considers both the magnitude and persistence of leaf area (Watson 1958). The LAD for treatment effects for both years (Table 4) summarizes the data shown graphically in preceding LAI curves. One weakness with LAD is that it fails to show how leaf canopies are displayed during the season. An example of the importance of this is present in the 1966 experiment. LAD for treatments in March was less than those for the same rates of nitrogen in July (Table 4), but the resulting root and sucrose yields were greater (Tables 2 and 3) because of the earlier display of the leaf canopies during the season.

**Total dry matter—**Seasonal dry matter accumulation patterns for all treatments in 1966 and 1967 resembled the characteristic sigmoid curve for growth, so a logistic growth curve, $W = \frac{a}{1+be^{-ct}}$, was fitted to the data for each treatment by means of least squares. For any time t, dry weight of the plant is W; a, b, and c are parameters

Table 4. Average leaf area duration (LAD) for experimental treatments in 1966 and 1967.

| 1966 | | 1967 | |
|---|---|---|---|
| Treatment | LAD (weeks) | Treatment | LAD (weeks) |
| **Nitrogen†** | | **Nitrogen†** | |
| Check | 18.6 | Check | 35.9 |
| 125-March | 37.8 | 125-March | 51.7 |
| 250-March | 51.8 | 250-March | 58.5 |
| 125-July | 43.9 | 375-March | 59.0 |
| 250-July | 53.0 | 125-July | 55.3 |
| | | 250-July | 64.1 |
| **Variety** | | **Planting Date** | |
| A56-3 | 46.0 | April 30 | 57.2 |
| $F_1$ | 36.0 | May 18 | 51.3 |

*†lb nitrogen per acre, and time of application.*

which have to be estimated for each set of data. Some examples of the fit of the curves are illustrated in Figures 6 and 7. The parameters estimated for each growth curve are given in Appendix Table 7, and predicted dry matter yields in grams per square meter field area (g $m^{-2}$) for each treatment are summarized in Table 5. Calculated curves for all treatments fit the data very well until the end of the season when actual data showed a loss in weight.

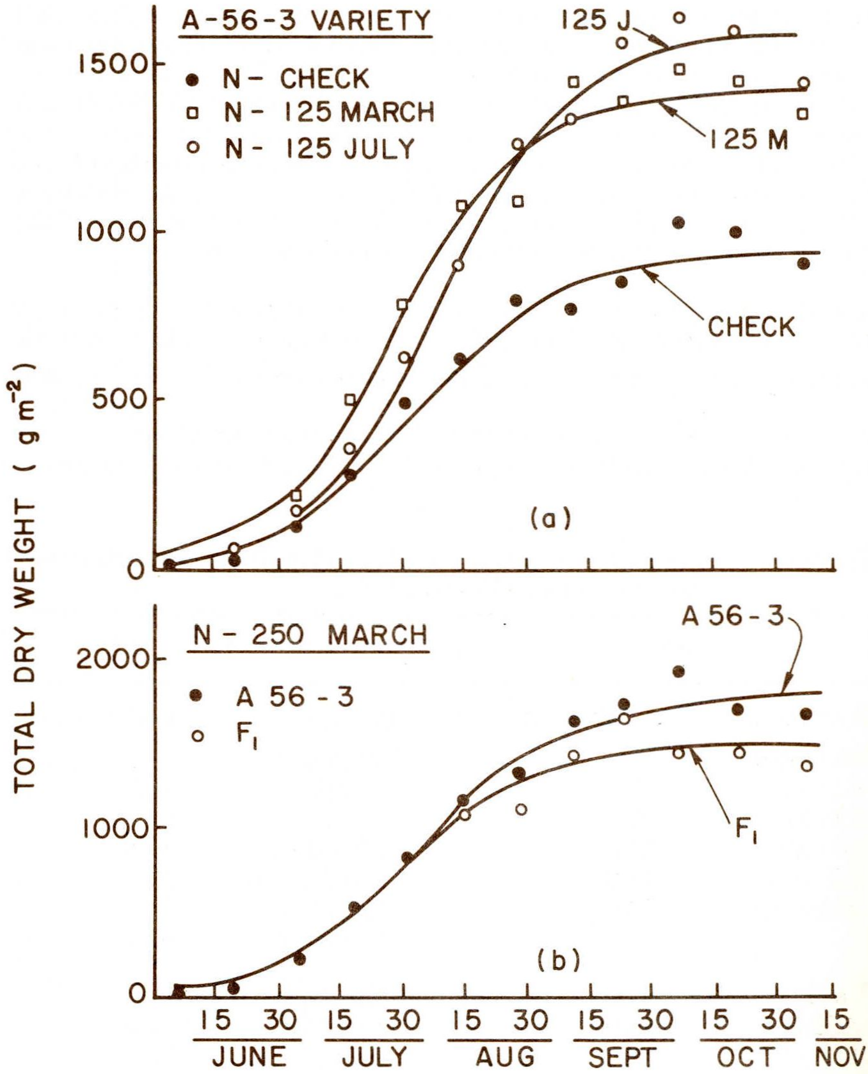


Figure 6. Effect of nitrogen fertilizer (a) and variety (b) on total dry matter yield, 1966.

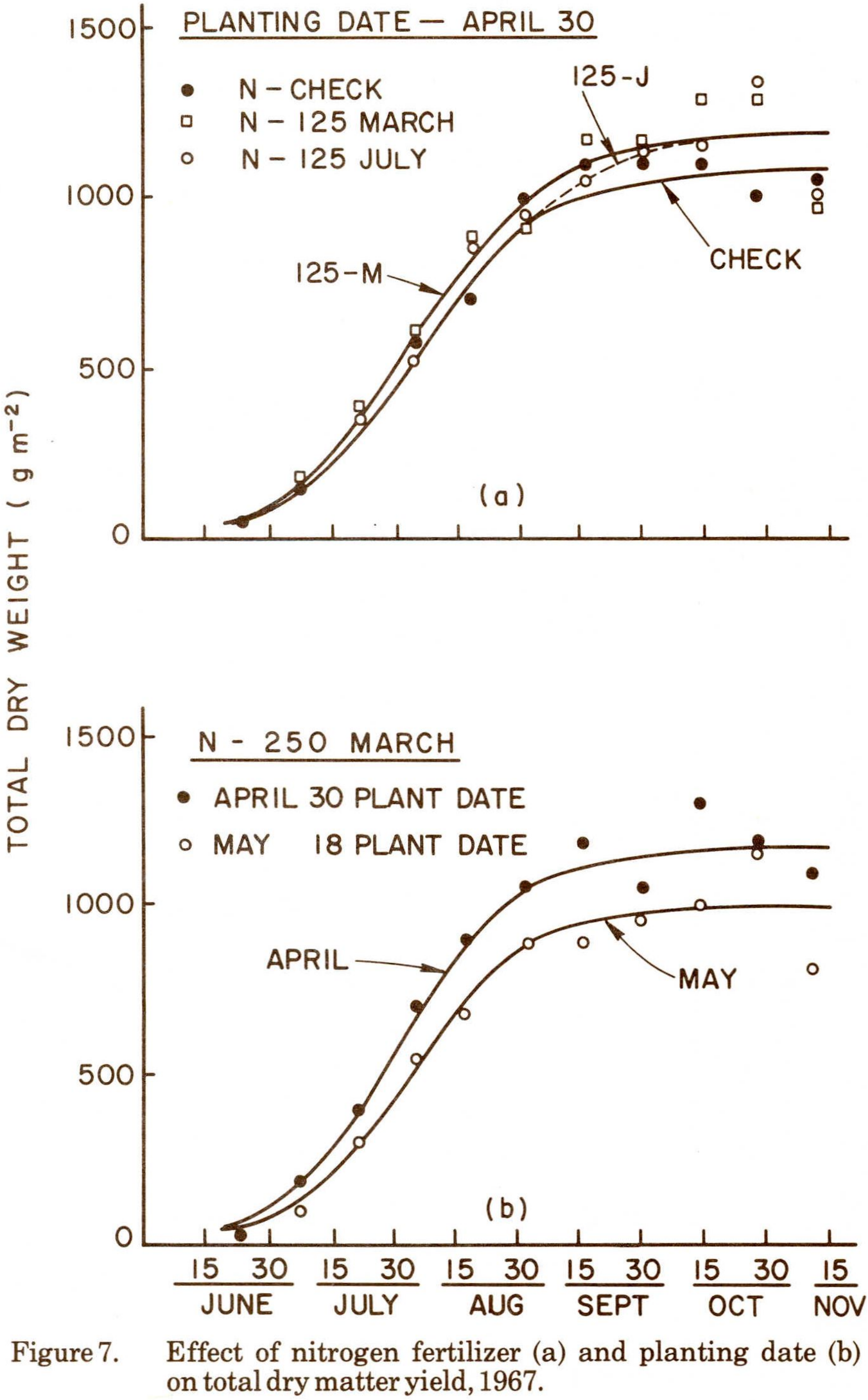


Figure 7. Effect of nitrogen fertilizer (a) and planting date (b) on total dry matter yield, 1967.

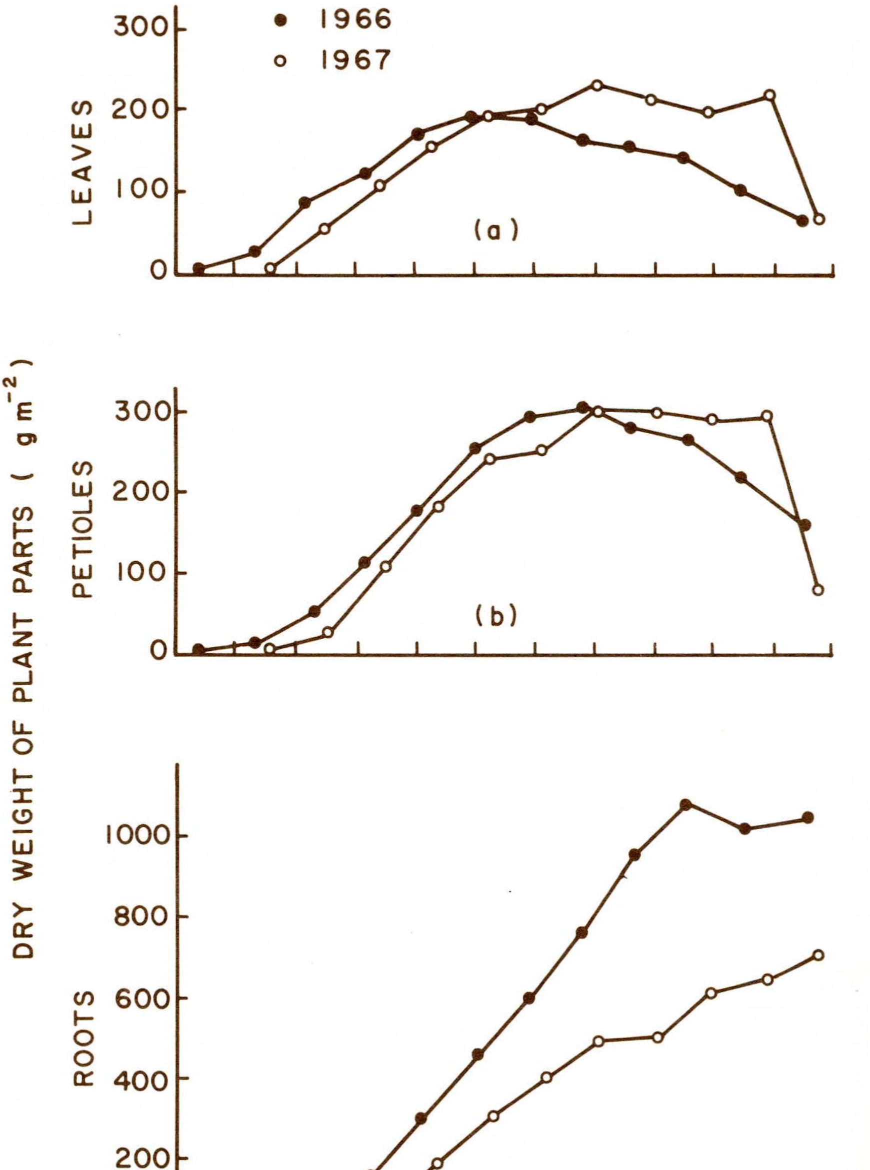


Figure 8. Effect of sampling date on dry matter yield of (a) leaves; (b) petioles + crowns; and (c) roots.

Sigmoid curves are unable to show this effect since they become asymptotic on both ends. Actual dry weight curves for the three plant parts for 1966 and 1967 indicate that this loss of total plant weight was caused by loss of tops (Figure 8) rather than by loss of root weight. Weight loss was more gradual in 1966 and began earlier, while leaf and petiole weight was fairly constant in 1967 until the last harvest when freezing weather (Appendix Table 3) killed a large portion of the top growth.

The logistic growth curve was fitted to the dry matter data to get a reliable continuous function from which the growth rate (GR) could be derived by taking the first differential of the original function,

$$GR = \frac{dW}{dt} = \frac{abce^{-ct}}{(1 + be^{-ct})^2}.$$

Any value of t may be used since it is a continuous function; thus growth rates can be obtained for any day in time without regard to harvest date. The second differential,

$$\frac{d^2W}{dt^2} = \frac{abc^2e^{-ct}\ (be^{-ct} - 1)}{(1 + be^{-ct})^3},$$

may be taken to find maximum growth rate ($GR_{max}$). Maximum growth rate is obtained when the second differential is equated to zero. In this experiment the first and second differentials were evalutated for all values of t from planting date to harvest, after the initial parameters were estimated. The area under the rate curves was determined to give the final dry matter yields in Table 5.

Growth-rate curves give more information when accompanied by corresponding leaf-area and net-assimilation-rate curves, since growth rate is the product of the two, GR = LAI x NAR. Leaf area is expressed by LAI, while NAR is the rate at which dry matter is produced per unit leaf area. Curves showing GR, NAR, and LAI for some specific treatments are given in Figures 9 through 12 to explain differences in final dry matter production. Leaf area curves were obtained by connecting actual data points for harvests. The NAR curves were constructed by connecting points calculated from the equation, $NAR = \frac{GR}{LAI}$. The GR values were derived from the calculated curves, but LAI values were measured for actual harvest dates since smooth curves were not derived for LAI.

The plotted data show, in general, that NAR decreased most rapidly to about the first week in July when the LAI was about 2. This was caused, apparently, by a rapid rate of increase in selfshading of the leaves, although $CO_2$ concentrations also could have become a limiting factor. During July and August NAR decreased less rapidly. The LAI increased to about 3½ to 4 but the rate of increase was less rapid. Solar radiation remained high (Figure 13). After September NAR decreased more rapidly again and approached zero by mid-October. Decreasing solar radiation and temperature probably were the cause for the low NAR in September and October. In most cases, however, NAR was not reduced sufficiently until after September 1 to overcome the positive effect of LAI; thus dry matter production was increased by treatments which increased LAI for that year. Leaf area duration accounted for 72 percent of the variability in final dry matter yields in 1966 ($r^2 = .72$,38df) and 74 percent in 1967 ($r^2 = .74$, 46df). In the 1966 experiment, nitrogen fertilizer increased dry matter (Table 5) because leaf area response was highly positive (Figure 2). Growth rate for the nitrogen check treatment, in spite of its high NAR, was reduced greatly throughout the season because of small leaf areas. Final dry matter production for plants given 125-lb rates were lower than 250-lb rates because of a lower growth rate after mid-July. The lower growth rate was associated with a marked decrease in LAI, caused apparently by nitrogen deficiency. This effect for early applied nitrogen treatments is illustrated in Figure 9.

Date of nitrogen application in 1966 had its main effect in altering the date at which maximum growth rate was obtained (Figure 10). Late nitrogen tended to delay maximum growth rate because of the delay in reaching maximum leaf area. In some cases, date of nitrogen application also affected final dry matter yields (Figure 6a), but this effect was related mainly to leaf area duration and was not consistent for variety or nitrogen rate (Table 5).

Varietal differences in dry matter yield were apparent in 1966, since the A56-3 variety produced greater dry matter yields for all nitrogen treatments. Figure 11 indicates that this effect appeared to be caused by a difference in leaf area, because the $F_1$ was not able to sustain leaf areas equal to the A56-3 late in the season. Part of this could be a variety effect, since the $F_1$ was known to have slightly lower top/root ratios. However, it also could have been related to more leaf spot on the $F_1$ since only green leaves were measured for leaf area. Net assimilation rate was slightly higher for the $F_1$ for the season, probably caused by lower leaf areas, although inheritance might control this factor to some degree.

Date of planting, in 1967, also exerted an effect on dry matter production by altering leaf areas for the season. Beets planted April 30 maintained higher leaf areas and growth rates than those planted in mid-May. If the A56-3 variety in 1966 is included with the 1967 data, a comparison of three planting dates with the same genetic material can be made (Figure 12). Growth rates in 1966 were greater early in the season because of greater leaf area. These 1966 rates also were as great late in the season, even with less leaf area, because NAR was higher (Figure 12). An examination of radiation data in Figure 13 indicates that 1966 provided more total radiation, especially early in the season. Air temperature was

Table 5. Total dry matter yields and maximum growth rates ($GR_{max}$) for 1966 and 1967 (data from calculated curves).

| Treatment | | Total* dry matter ($g\ m^{-2}$) | $GR_{max}$ ($g\ m^{-2}\ day^{-1}$) | $GR_{max}$ Date | Plant age at $GR_{max}$ (days)† |
|---|---|---|---|---|---|
| | | | 1966 | | |
| A56-3 | N-Check | 957.5 | 13.3 | Aug. 3 | 124 |
| | N-125 March | 1431.9 | 23.0 | July 31 | 120 |
| | N-250 March | 1775.0 | 26.5 | Aug. 5 | 126 |
| | N-125 July | 1601.6 | 25.1 | Aug. 9 | 130 |
| | N-250 July | 1640.5 | 24.5 | Aug. 12 | 133 |
| $F_1$ | N-Check | 989.0 | 11.3 | Aug. 8 | 129 |
| | N-125 March | 1408.7 | 23.9 | July 31 | 120 |
| | N-250 March | 1488.9 | 23.3 | July 30 | 119 |
| | N-125 July | 1468.0 | 23.8 | Aug. 9 | 130 |
| | N-250 July | 1501.7 | 24.4 | Aug. 9 | 130 |
| | | | 1967 | | |
| April 30 | N-Check | 1083.5 | 17.6 | Aug. 4 | 96 |
| | N-125 March | 1193.0 | 18.7 | Aug. 4 | 96 |
| | N-250 March | 1178.7 | 21.4 | Aug. 1 | 93 |
| | N-375 March | 1210.9 | 21.5 | Aug. 3 | 95 |
| | N-125 July | 1202.6 | 18.2 | Aug. 9 | 101 |
| | N-250 July | 1223.9 | 18.6 | Aug. 8 | 100 |
| May 18 | N-Check | 711.0 | 15.3 | July 27 | 75 |
| | N-125 March | 1017.3 | 15.8 | July 31 | 79 |
| | N-250 March | 997.5 | 17.6 | July 31 | 79 |
| | N-375 March | 961.0 | 16.4 | Aug. 1 | 80 |
| | N-125 July | 995.0 | 15.6 | Aug. 7 | 86 |
| | N-250 July | 1043.9 | 18.3 | Aug. 3 | 82 |

**Predicted final yield ($g\ m^{-2}$ x 0.00446 = tons/A).*

*†Days from planting.*

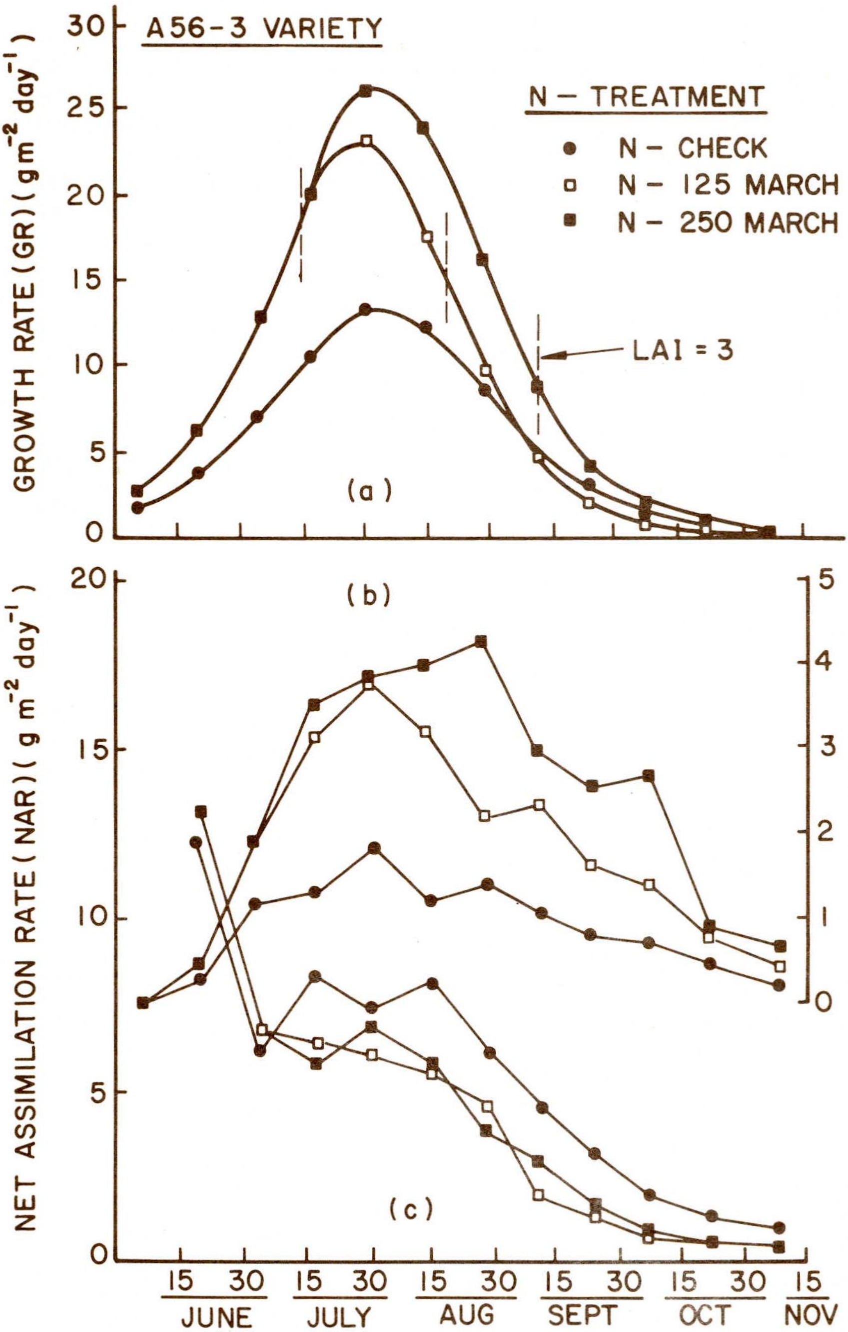


Figure 9. Effect of preplant nitrogen rates on (a) GR; (b) LAI; and (c) NAR, 1966.

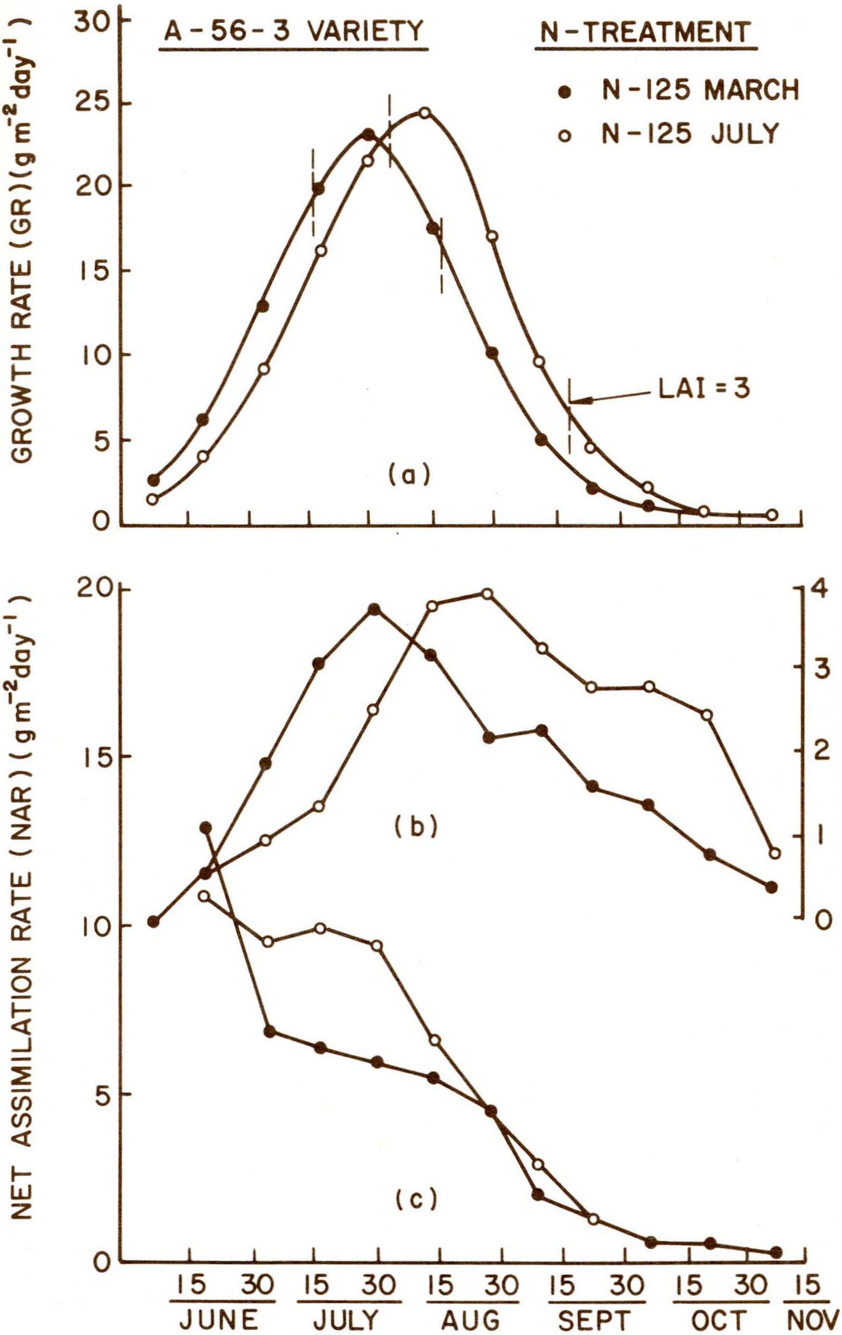


Figure 10. Effect of time of application of nitrogen on (a) GR; (b) LAI; and (c) NAR, 1966.

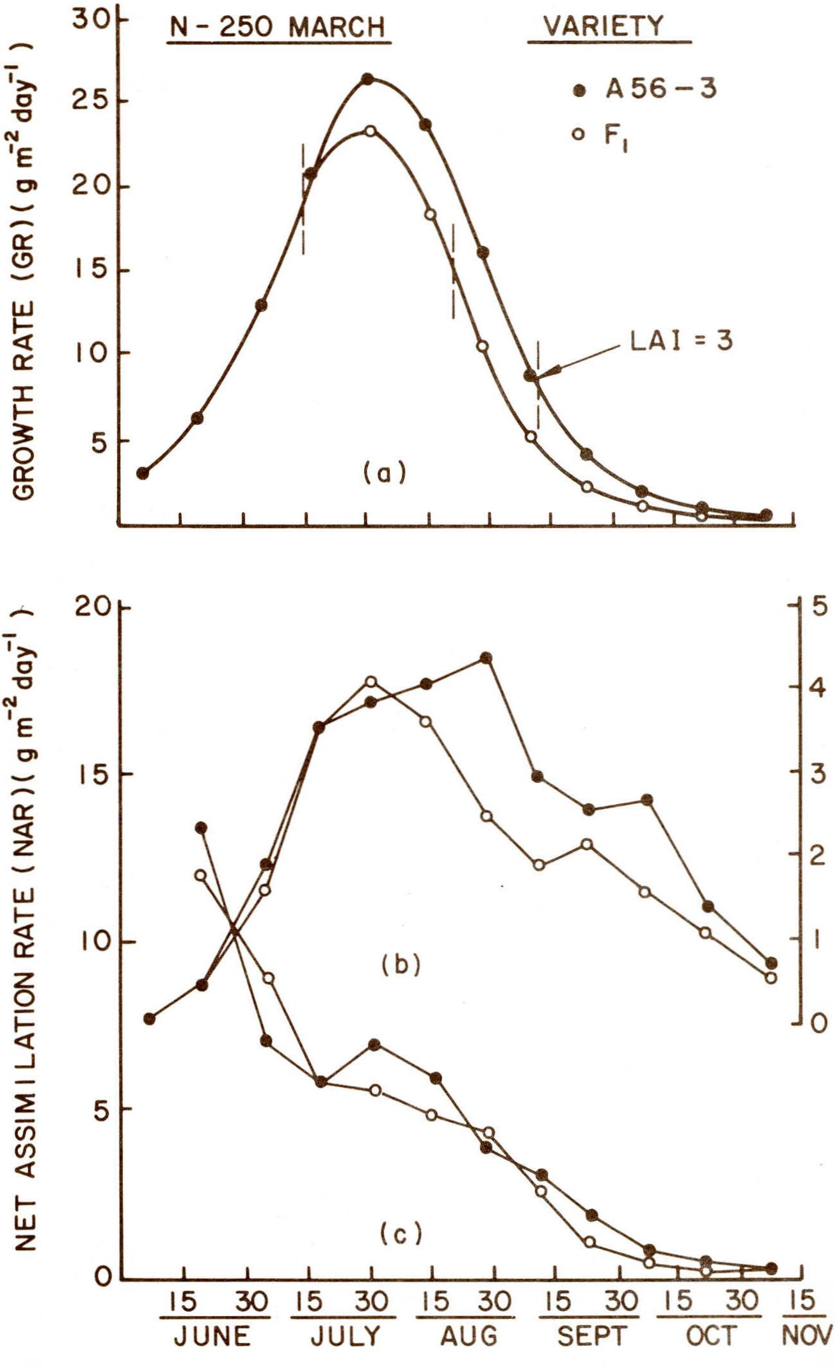


Figure 11. Effect of variety on (a) GR; (b) LAI; and (c) NAR, 1966.

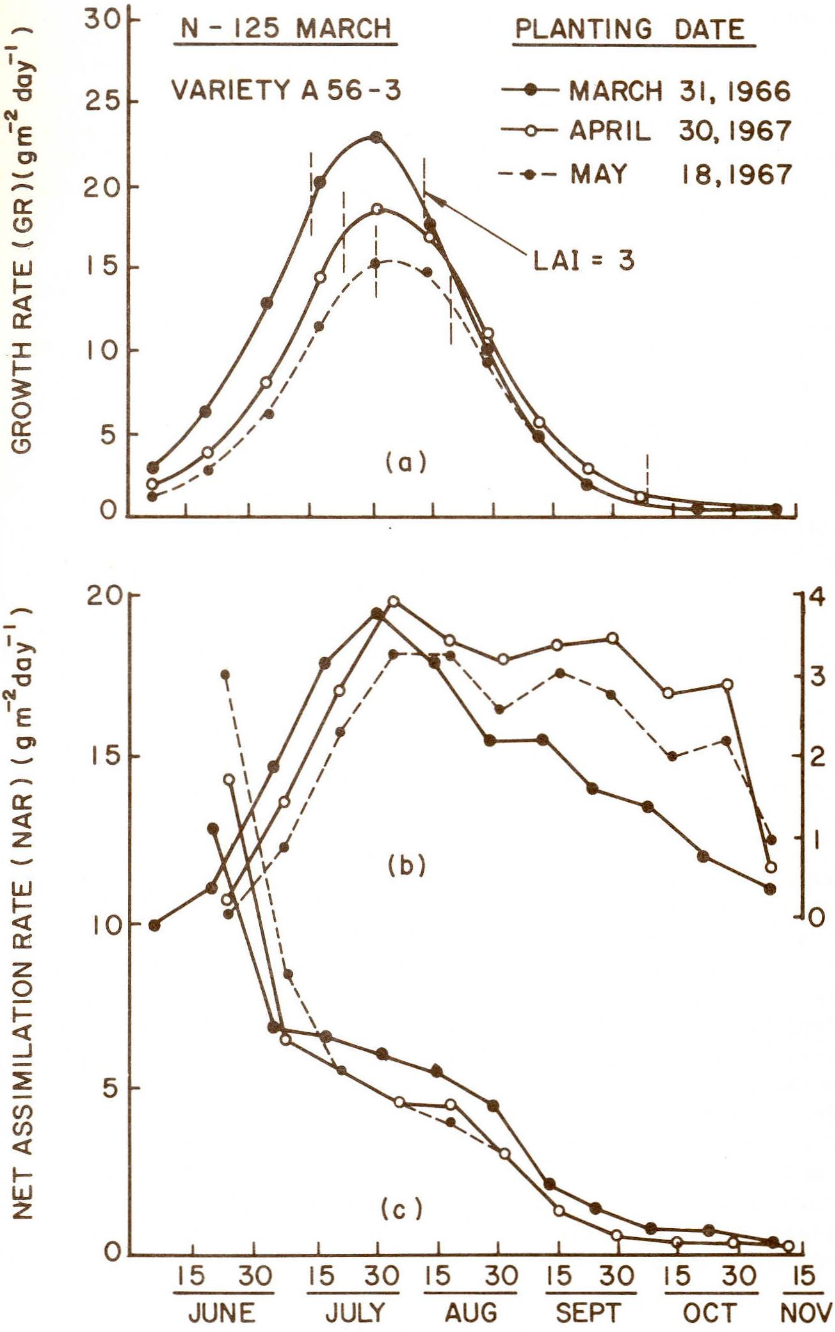


Figure 12. Effect of planting date and year on (a) GR; (b) LAI; and (c) NAR.

greater for the early part of the season in 1966, but lower than in 1967 late in the season. The lower average air temperature late in the 1966 season was caused by slightly lower night temperatures; radiation during the day was actually greater in 1966 for this same period. This could help explain the greater NAR for plants grown in 1966, since greater radiation during the day would accelerate photosynthesis, and lower night temperatures would decrease respiration.

The effect of radiation on plant growth was studied by selecting points on each growth-rate curve corresponding to a time at which the leaf area index was equal to 3 for that treatment. These points are shown in Figures 9 through 12 by the broken lines intersecting the growth-rate curves. It is obvious from these figures that the growth rate at constant leaf area generally decreased as the season progressed. This effect had to be caused by a decreasing NAR since LAI was constant. The NAR curves decreased as the season advanced and approached zero near the end of the season. Radiation values, corresponding to dates when leaf areas were constant, were taken from curves (Figure 13) and correlated with growth rates at that time in a polynomial regression analysis. Only the linear term was significant, however. The fit of the regression line is shown in Figure 14. Data for both 1966 and 1967 were included, but some treatments were omitted because they did not reach the required leaf area. At a constant LAI of 3, radiation accounted for 86% of the variability in growth rate. This could also be interpreted as accounting for 86% of the variability in NAR since leaf area was held constant. Points at which LAI = 2 also were analyzed with about the same results (Figure 14). In this case radiation accounted for 83% of the variability. The slope of the line for LAI = 3 was slightly steeper than for LAI = 2, which would seem logical since greater leaf areas would produce more dry weight under higher radiation and less under lower radiation if shading were a factor at the low radiation values. Plant age also could be a factor. There was no way to determine the age effect, but it is interesting to note in Table 5 that all treatments reached their maximum growth rates in 1966 and 1967 within a span of 13 days (between July 27 and August 9). However, plant age from planting to the time at which maximum growth rates were obtained varied as much as 58 days. The fact that all treatments reached a maximum growth rate at approximately the same time, regardless of plant age, might indicate age to be relatively unimportant in determining growth rates with sugarbeets.

**Root dry matter**—Dry matter yield of beet roots was not always affected in the same manner as total plant dry weight since some experimental treatments altered the root/top ratio. Some discussion of root growth will be presented here because it is the primary factor controlling sucrose yield.

The logistic growth curve was fitted to the root dry matter data in the same manner as discussed for total dry matter so that root growth-rates (GR-r) throughout the season could be studied. The fit

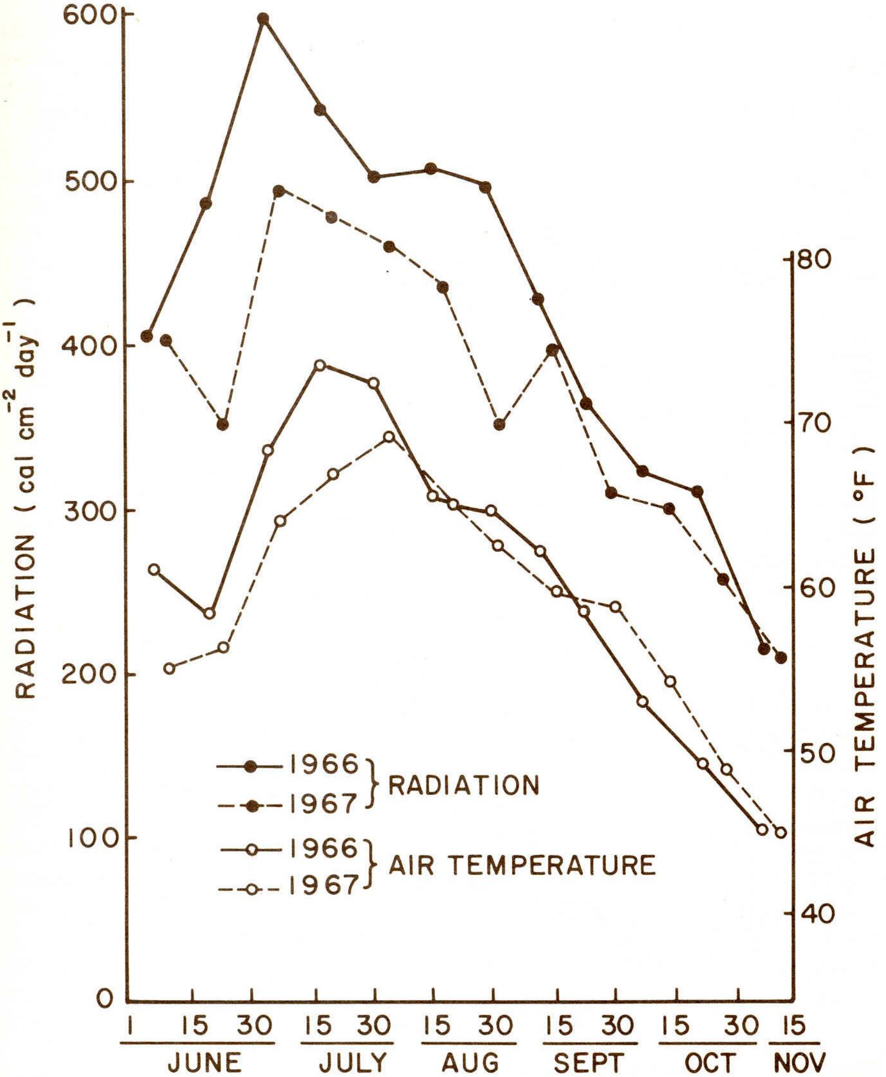


Figure 13. Average total solar radiation and air temperature for 1966 and 1967.

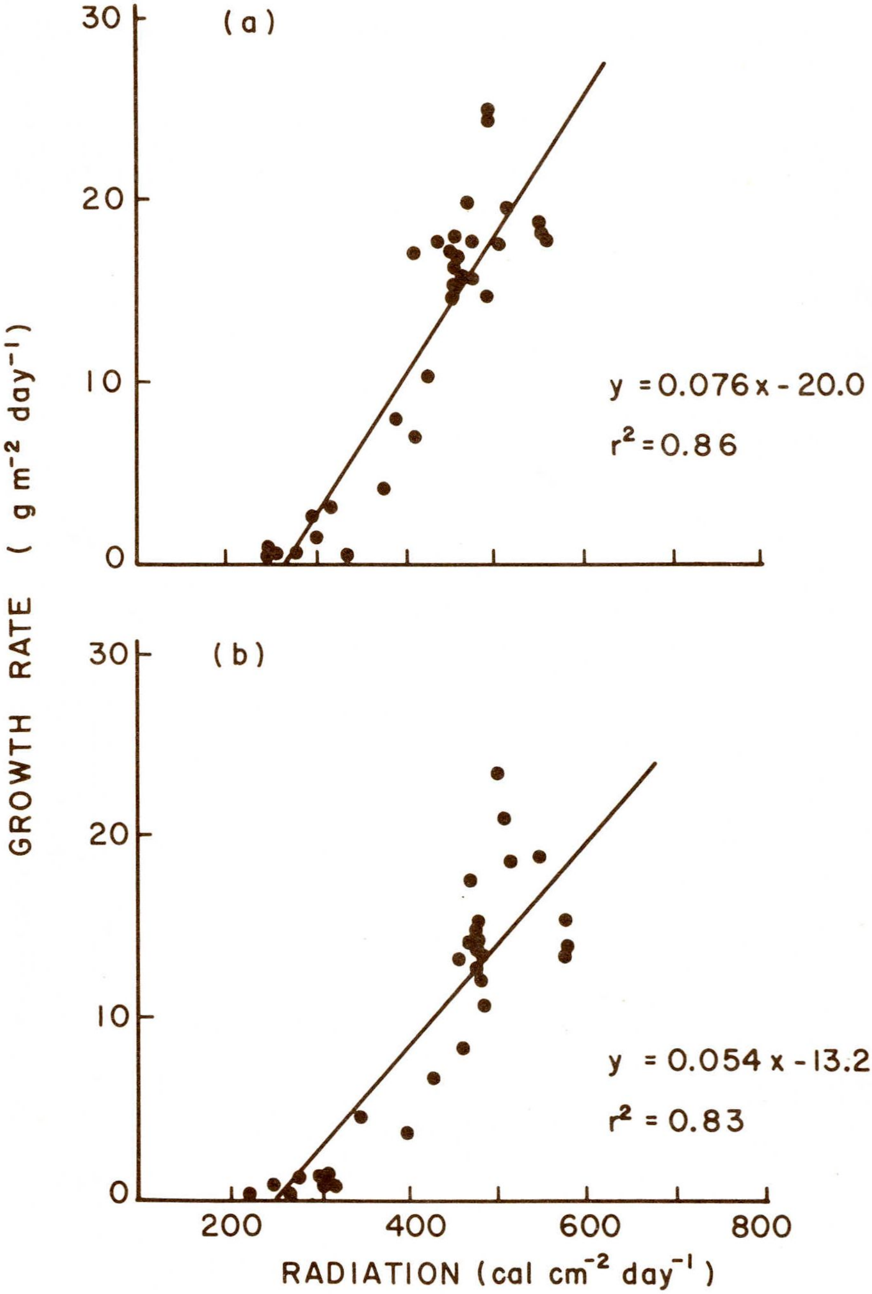


Figure 14. Effect of solar radiation on total growth rate at constant leaf area for (a) LAI = 3.0; and (b) LAI = 2.0 (years combined).

of the curves, as measured by the ratio of the sum of squares due to curvilinear regression versus the total sum of squares, were very good and about the same as those obtained for total dry matter. Estimates of the parameters for the equations are given in Appendix Table 8, and final predicted yields are given in Table 6. Several selected GR-r curves also are illustrated in Figure 15 to show seasonal differences caused by nitrogen, variety, and planting date.

In general, root growth rates responded to alterations in leaf area as did total growth rates. However, the relation between leaf area and GR-r was not consistent, and some exceptions occurred which are worthwhile discussing. Root growth rates for plants grown in 1966 and 1967 did not reach a peak until about 3 weeks after maximum total growth rate and leaf areas were obtained. A comparison of dates for maximum growth of individual treatments can be made from Tables 5 and 6. Leaves and petioles appeared to have first priority for metabolic products during the season as long as conditions were favorable for vegetative growth.

Treatments which prolonged or delayed maximum total growth until late in the season decreased root/total dry weight ratios. Seasonal deviations in root/total weight ratios for some treatments are presented graphically in Figure 16, and final root/total weight ratios for all treatments are given in Table 6. Nitrogen fertilizer, variety, and planting date all affected the proportion of total dry weight in the roots; this explains why all treatments having higher total dry matter yields did not necessarily produce higher root yields.

Nitrogen effects on root growth were much more pronounced in 1966 than in 1967, presumably for the same reasons as already discussed for leaf area and total dry matter. In 1966, plants receiving 125 lbs of nitrogen applied in March produced slightly higher growth rates and a greater total root yield than plants receiving 250 lbs N applied in July (Table 6), even though total dry matter production was less. This was a direct result of higher leaf areas early in the season when radiation was high, followed by a period in which the ratio of root to total growth was high. The proportion of total dry weight in roots was reduced by higher rates of nitrogen, but the degree of this effect was dependent upon the variety and the application date. If nitrogen was applied in March, the reduction in the root/total dry weight ratio was generally not great enough to cause reductions in final root yields.

Varieties also showed a response for the root/total dry weight ratio for 1966. The $F_1$ plants had higher root/total plant dry weight ratios for all nitrogen treatments (Table 6). However, a comparison

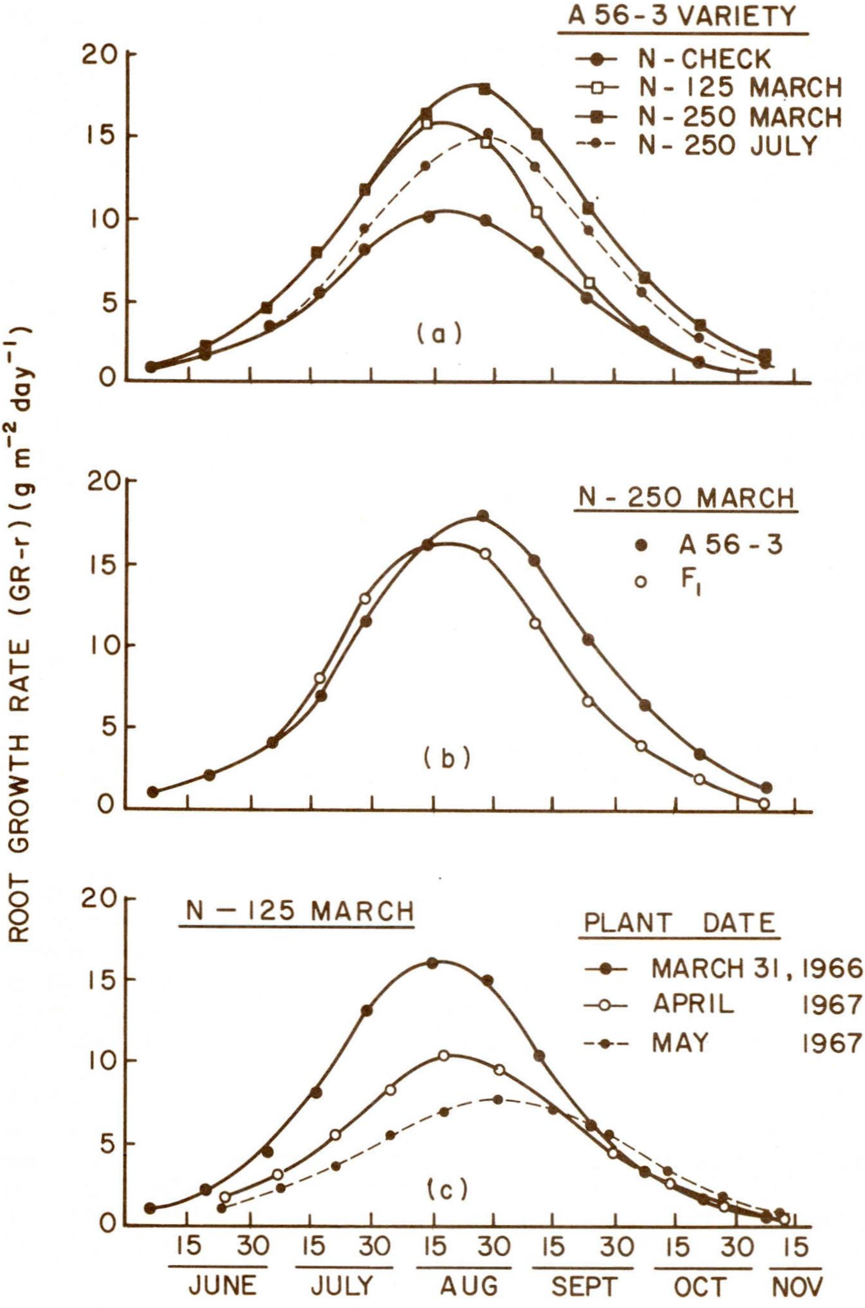


Figure 15. Root growth rate as affected by (a) nitrogen treatment (1966); (b) variety (1966); and (c) planting date (1966 and 1967).

of the two varieties in most cases showed that the A56-3 was able to maintain higher GR-r, even though a smaller proportion of the total weight was going into root weight. This is shown graphically for the 250-lb early nitrogen application in Figures 15b and 16b.

Table 6. Root dry matter yields and maximum root growth rates ($GR\text{-}r_{max}$) for 1966 and 1967 (data from calculated curves).

| Treatment | | Root dry* matter ($g\ m^{-2}$) | $GR\text{-}r_{max}$ ($g\ m^{-2}\ day^{-1}$) | Date of $GR\text{-}r_{max}$ | Final ratio root/total weight |
|---|---|---|---|---|---|
| | | | 1966 | | |
| A56-3 | N-Check | 817 | 10.3 | Aug. 23 | .84 |
| | N-125 March | 1146 | 16.1 | Aug. 20 | .80 |
| | N-250 March | 1362 | 17.7 | Aug. 28 | .77 |
| | N-125 July | 1190 | 16.3 | Aug. 28 | .74 |
| | N-250 July | 1106 | 14.7 | Aug. 30 | .67 |
| $F_1$ | N-Check | 892 | 9.0 | Aug. 26 | .91 |
| | N-125 March | 1201 | 17.5 | Aug. 17 | .86 |
| | N-250 March | 1179 | 16.4 | Aug. 27 | .79 |
| | N-125 July | 1000 | 13.8 | Aug. 23 | .75 |
| | N-250 July | 1066 | 13.5 | Aug. 26 | .70 |
| | | | 1967 | | |
| April 30 | N-Check | 798 | 10.1 | Aug. 25 | .73 |
| | N-125 March | 788 | 10.1 | Aug. 26 | .65 |
| | N-250 March | 786 | 8.4 | Aug. 29 | .66 |
| | N-375 March | 722 | 10.0 | Aug. 21 | .59 |
| | N-125 July | 827 | 8.4 | Sept. 10 | .68 |
| | N-250 July | 768 | 8.9 | Aug. 30 | .62 |
| May 18 | N-Check | 506 | 7.3 | Aug. 4 | .70 |
| | N-125 March | 671 | 7.6 | Aug. 17 | .66 |
| | N-250 March | 590 | 6.0 | Aug. 20 | .60 |
| | N-375 March | 566 | 6.4 | Aug. 18 | .58 |
| | N-125 July | 597 | 6.2 | Aug. 27 | .60 |
| | N-250 July | 579 | 5.8 | Aug. 19 | .55 |

**Predicted final yield ($g\ m^{-2} \times 0.00446$ = tons/A).*

Late planting also tended to delay top growth and depress GR-r late in the season. The roots accounted for about 66% of the total plant weight at the end of the season for all nitrogen treatments, when planted April 30, 1967. If planting was delayed until May 18,

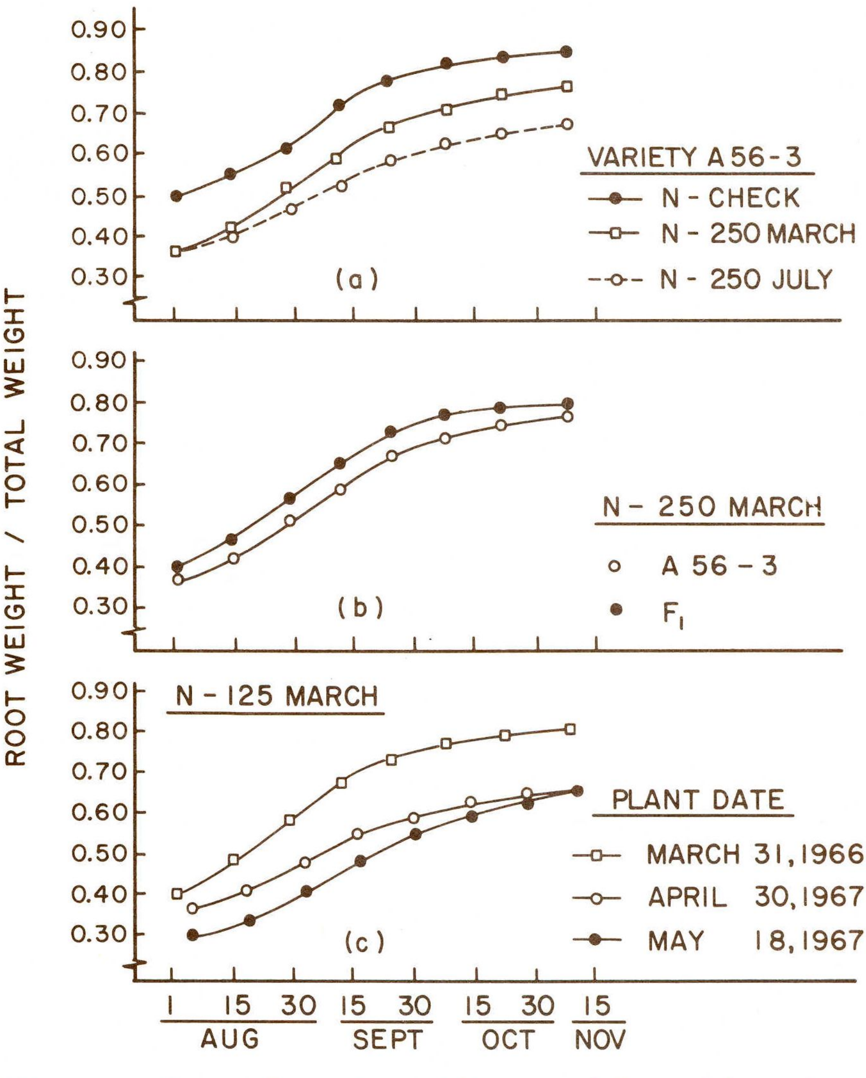


Figure 16. Seasonal root dry weight — total dry weight ratio as affected by (a) nitrogen treatment (1966); (b) variety (1966); and (c) planting date (1966 and 1967).

roots accounted for only 62% of the total plant weight. Beet roots, of the same genetic material planted March 31 in 1966, accounted for 76% of the total plant weight at the end of the season. A comparison of the three planting dates for the 125-lb early nitrogen application is given in Figures 15c and 16c.

The efficiency of different leaf areas for producing root material was studied by altering the total growth-rate equation. It was stated earlier that total growth rate is a product of leaf area index and net assimilation rate, i.e., GR = LAI x NAR. Not all dry matter produced by the leaves goes for root growth so NAR must be multiplied by a partition factor ($PF_1$) to indicate the relative amount of assimilate going to the root, i.e., GR-r = LAI x NAR x $PF_1$, or $\frac{dR}{dt} = A \times \frac{1}{A}\frac{dW}{dt} \times \frac{dR}{dW}$.

Growth rate of roots (GR-r) then becomes a product of leaf area index and net assimilation rate for roots (NAR-r), GR-r = LAI x NAR-r. Net assimilation rates for roots are given for certain treatments in Figure 17. NAR-r differed greatly between treatments, and were quite different from the NAR for total dry weight production given earlier. NAR for total growth decreased throughout the season and approached zero near the end of the season, whereas NAR-r reached a maximum during July and August. It is interesting to note that NAR-r did not reach a maximum until after maximum leaf area and maximum total growth were obtained. This substantiates the point made earlier, that top growth has priority for photosynthetic materials. Treatments which caused greater top growth, or delayed top growth, such as late nitrogen and late planting, decreased NAR-r considerably. At constant leaf areas, GR-r was not correlated as well with radiation as was GR, and it follows that NAR-r also was not correlated as well with radiation as was NAR. At a constant leaf area index of 3, only 25% of the variability in GR-r was accounted for by radiation, as opposed to the 86% accounted for with GR for total dry weight. This might be expected since it was shown in Figure 16 that nitrogen, variety, and planting date all affected the proportion of assimilate going to the roots.

It is apparent from this work that root growth is more specific in its requirement for leaf area than is total growth. Total plant weight was related quite closely to LAD for each season, as discussed in the previous section. However, root growth was not as well related to LAD since temporal development of leaf area in relation to the growing season became an increasingly important factor. LAD for the season could explain only 42% of the variability in final root dry matter yields in 1966 ($r^2 = 0.42$, 38df) and 33% in 1967 ($r^2 = 0.33$, 46df). Treatments such as early nitrogen and early planting date were more effective for root growth because plants presented their maximum leaf canopies earlier when radiation was greater, and because they increased the proportion of photosynthetic products going to the root later in the season.

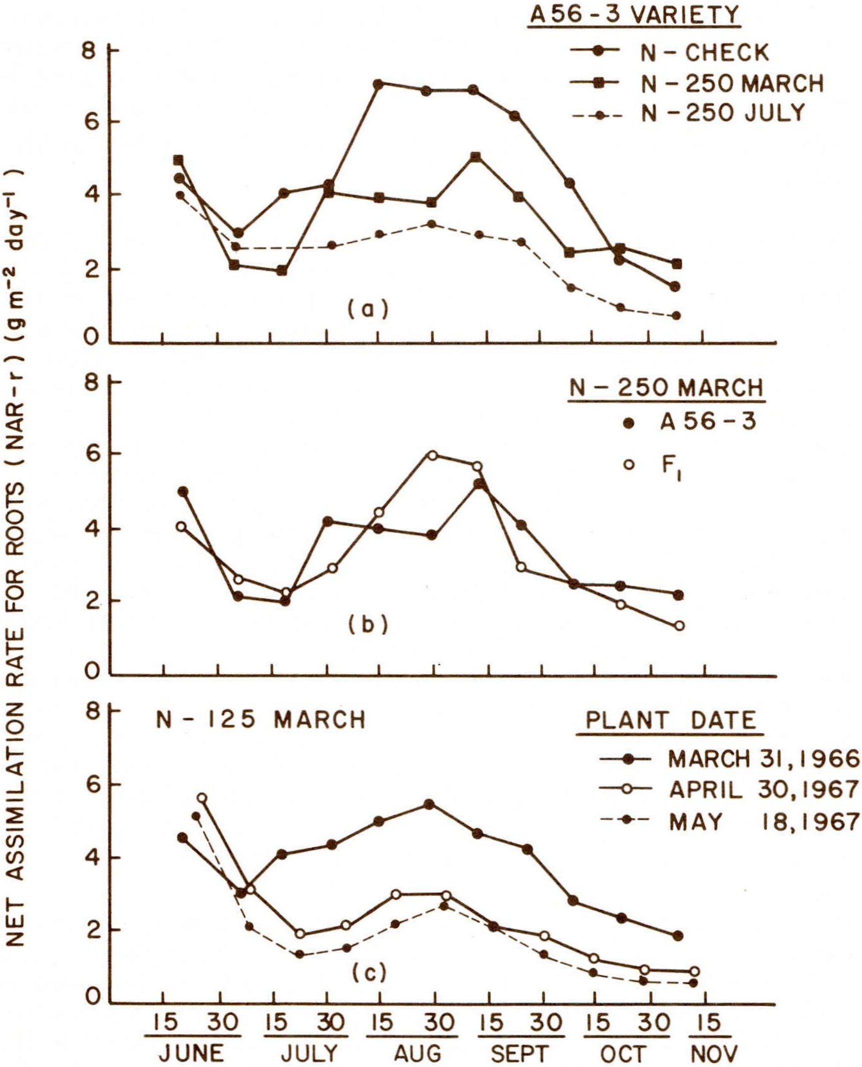


Figure 17. Net assimilation rate for root material (NAR-r) as affected by (a) nitrogen treatment (1966); (b) variety (1966); and (c) planting date (1966 and 1967).

**Sucrose accumulation**—In the previous section root dry matter, which is a portion of total dry matter, was discussed in relation to the treatment effects. In this section recoverable sucrose, a portion of root dry matter, will be studied. This fraction of total dry matter is of most interest since it is the final product of sugarbeet production.

Sucrose yield, in grams per square meter of field area (g $m^{-2}$) was determined at each harvest using recoverable sugar percentage and fresh root yield. Sucrose yield data followed the same sigmoid type of growth pattern as discussed for total dry matter and root dry matter; therefore, curves were fitted in the same manner as discussed before. Estimated parameters for each curve may be found in Appendix Table 9, and final predicted sucrose yields are given in Table 7. Actual data for final recoverable sugar yields were given in the first section in some detail; therefore, no discussion of final predicted recoverable sugar yields will be presented here. It might be worthwhile, however, to observe briefly some of the treatment effects on percentage sucrose during the growing season, because it was a major factor in determining final yield. Some of the more important occurrences follow: 1) increasing amounts of nitrogen applied during both March and July significantly decreased recoverable sucrose percentages of sugarbeet roots throughout the 1966 and 1967 season (Figures 18a and 18c); 2) nitrogen applied during July caused lower sucrose than March applications in 1966 (Figure 18a), but had little effect in 1967 (Figure 18c); 3) varietal differences in percentage sucrose in 1966 were not noticeable by the end of the season (Figure 18b); and 4) the influence of planting date (1967 only) on sucrose was not significant by the end of the season (Figure 18d).

Sucrose growth rates may be analyzed with respect to leaf area by the same approach used for root growth rates. Net assimilation rate for total dry matter may be multiplied by a partition factor ($PF_2$) to account for the portion of total leaf assimilate going to the root as sucrose, i.e., GR-s = LAI x NAR x $PF_2$ or

$$\frac{dS}{dt} = A \times \frac{1}{A}\frac{dW}{dt} \times \frac{dS}{dW}.$$

Growth rate of sucrose (GR-s) thus becomes the product of leaf area index and net assimilation rate for sucrose (NAR-s), GR-s = LAI x NAR-s.

Values for NAR-s throughout the season, for some treatments, are given in Figure 19. The curves resemble those for net assimilation rate of roots (NAR-r). This might be expected since about 65% of the root dry matter is sucrose. Treatments which provided greater LAI often decreased NAR-s. Maximum sucrose production resulted from the best combination of LAI and NAR-s values throughout the growing season. Sucrose growth rates (GR-s) were calculated and selected data are shown in Figures 20 and 21. The smaller growth rates were caused by low LAI, low NAR-s, or both.

Table 7. Sucrose yields and maximum sucrose accumulation rates (GR-s $_{max}$) for 1966 and 1967 (data from calculated curves).

| Treatment | | Recoverable* sucrose yield ($g\,m^{-2}$) | GR-s max ($g\,m^{-2}\,day^{-1}$) | GR-s$_{max}$ date | Plant age for GR-s$_{max}$ (days) |
|---|---|---|---|---|---|
| | | | 1966 | | |
| A56-3 | N-Check | 635 | 6.2 | Sept. 9 | 159 |
| | N-125 March | 721 | 11.3 | Aug. 20 | 140 |
| | N-250 March | 890 | 10.5 | Sept. 3 | 153 |
| | N-125 July | 685 | 8.7 | Aug. 29 | 149 |
| | N-250 July | 610 | 7.2 | Sept. 3 | 153 |
| $F_1$ | N-Check | 563 | 5.6 | Aug. 26 | 146 |
| | N-125 March | 755 | 12.0 | Aug. 15 | 135 |
| | N-250 March | 805 | 10.7 | Aug. 23 | 143 |
| | N-125 July | 616 | 8.6 | Aug. 21 | 141 |
| | N-250 July | 604 | 7.0 | Aug. 27 | 147 |
| | | | 1967 | | |
| April 30 | N-Check | 525 | 7.9 | Aug. 27 | 117 |
| | N-125 March | 510 | 7.1 | Aug. 29 | 119 |
| | N-250 March | 495 | 6.1 | Sept. 1 | 121 |
| | N-375 March | 450 | 5.3 | Sept. 1 | 121 |
| | N-125 July | 530 | 6.0 | Sept. 12 | 132 |
| | N-250 July | 480 | 5.8 | Sept. 5 | 125 |
| May 18 | N-Check | 342 | 5.5 | Aug. 8 | 98 |
| | N-125 March | 445 | 5.7 | Aug. 20 | 110 |
| | N-250 March | 330 | 4.3 | Aug. 17 | 107 |
| | N-375 March | 306 | 4.5 | Aug. 17 | 107 |
| | N-125 July | 390 | 4.6 | Aug. 27 | 117 |
| | N-250 July | 320 | 4.1 | Aug. 14 | 104 |

**Predicted final yield (g $m^{-2}$ x 8.92 = lbs/A).*

Treatment effects on sucrose growth rate will be discussed on this premise.

Discussion of nitrogen effects on GR-s will be limited to 1966 data (Figure 20) because there was no response to nitrogen in 1967. The reason for this will be discussed under planting date. In 1966, nitrogen applied in March produced a larger GR-s than nitrogen applied in July for two reasons. First, applications of nitrogen in March provided greater LAI early in the season (Figure 2a) with fairly high NAR-s (Figure 19a). Second, the greater LAI later in the season, as a result of nitrogen applied in July (Figure 2a), was accompanied by low NAR-s (Figure 19a). Efficiency of the leaves for sucrose production was reduced by the application of nitrogen in July because photosynthetic products were being used for vegetative growth rather than going into storage in the root.

Leaf area and sucrose production efficiency of the leaves were affected also by rate of nitrogen fertilization, therefore causing the GR-s to differ. Check nitrogen treatments caused plants to have a small GR-s (Figure 20a) because LAI was low throughout the season, in spite of high leaf efficiency (Figure 19a). Plants receiving the 125-lb rate of nitrogen had highest maximum GR-s (Figure 20) as the result of the combination of high LAI and high NAR-s early in the season. The 250-lb rate, however, provided greatest total sucrose yield because it maintained a higher average GR-s for the season. This was caused by a larger leaf area late in the season with an equally high NAR-s.

Much of the varietal difference in sucrose production appeared to be a leaf area effect. The A56-3 variety had a higher LAI throughout the season (Figure 2b) with approximately equal average NAR-s (Figure 19b). It has already been noted that the $F_1$ hybrid had more leaf spot, which may account for its poorer yield. It is possible that the performance of the $F_1$ could have been improved by slightly higher plant populations, since it had lower top/root ratios than the A56-3.

Planting date in 1967 had much the same effect as date of applying nitrogen in 1966. Earlier planting increased early LAI for all nitrogen treatments (Figure 3b), and a higher NAR-s (Figure 19c) was maintained until September. The late planting had a smaller leaf area early in the season and lower NAR-s until after early September. This resulted in more assimilate being channeled to vegetative growth.

Large differences were noted also in GR-s between years for the same variety and nitrogen treatment (Figure 21c). Part of the effect

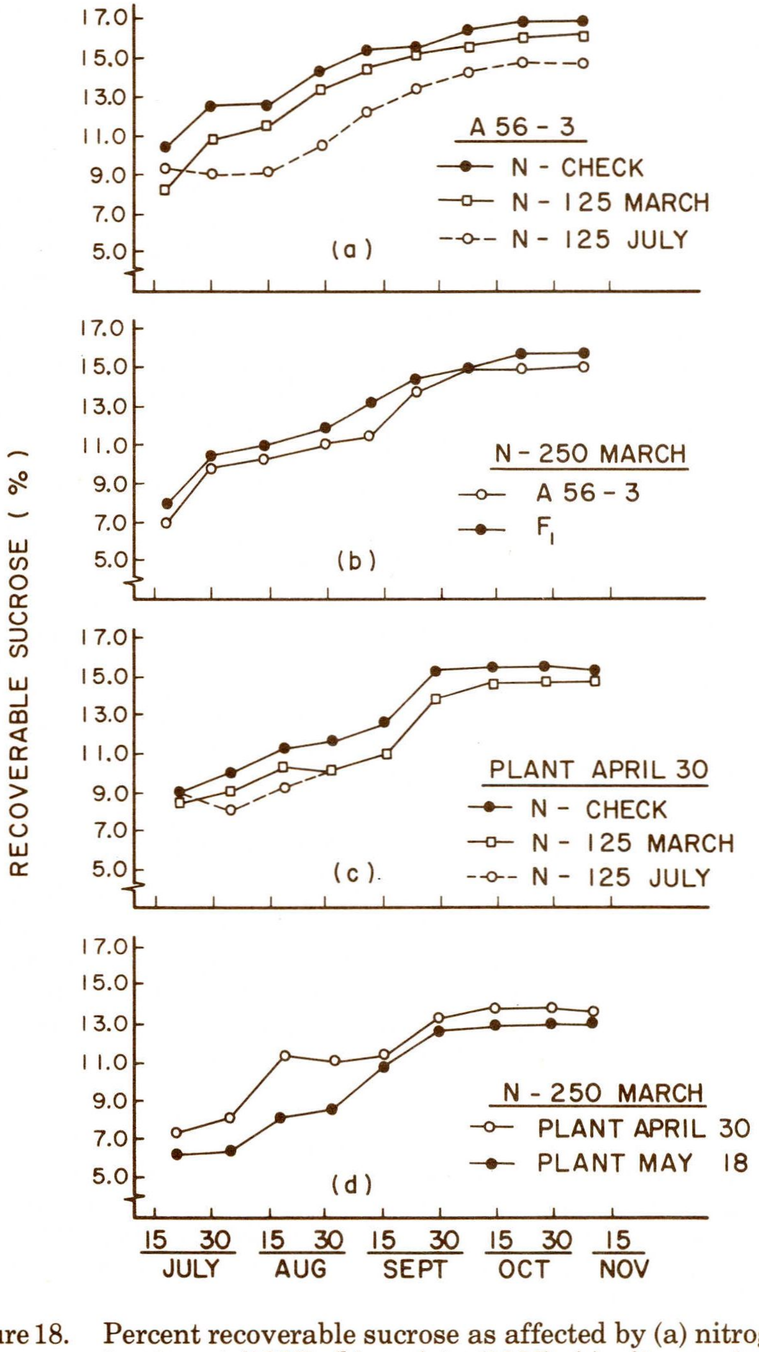


Figure 18. Percent recoverable sucrose as affected by (a) nitrogen treatment (1966); (b) variety (1966); (c) nitrogen treatment (1967); and (d) planting date (1967).

was caused by planting date, since the 1966 planting was a month earlier. In addition, the year effect could have been caused by the more favorable environmental conditions in 1966. Figure 13 indicates that both radiation and temperature were more

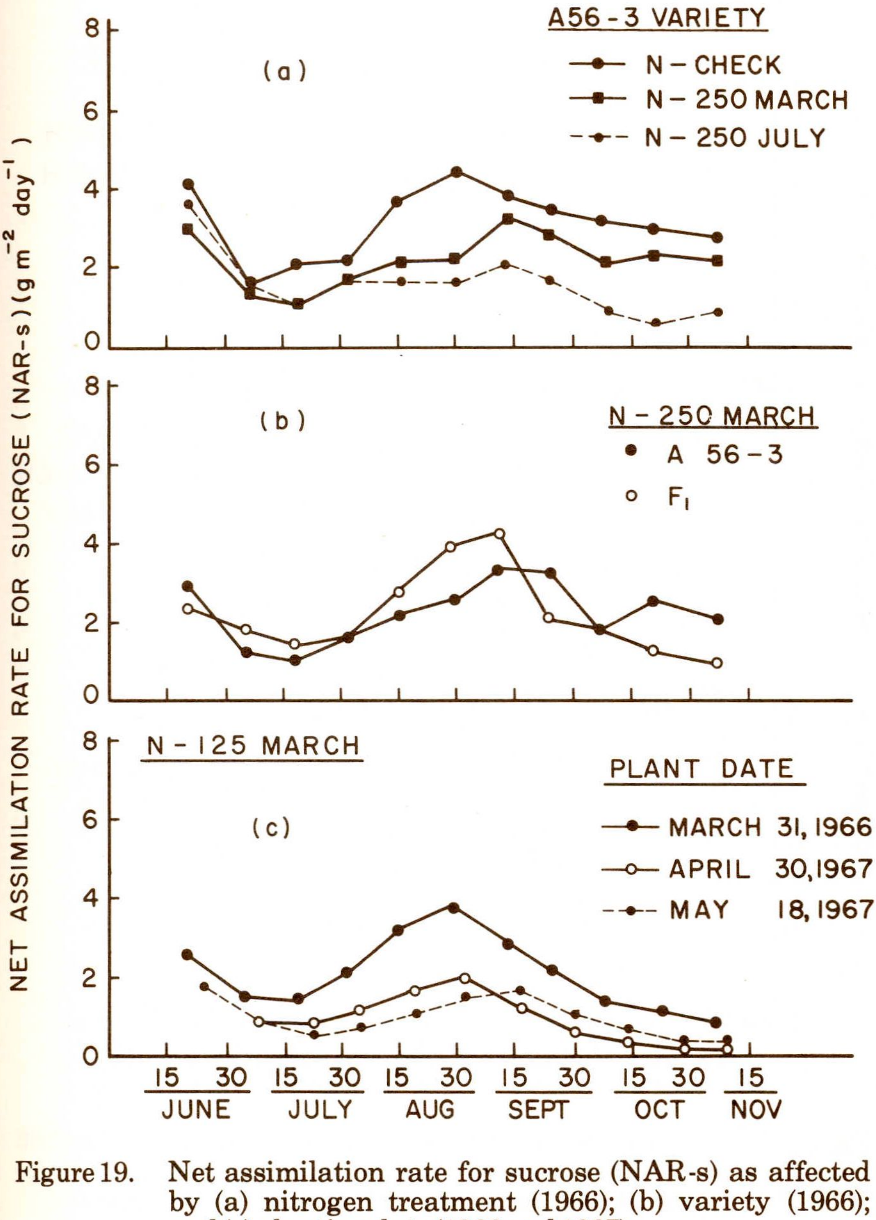


Figure 19. Net assimilation rate for sucrose (NAR-s) as affected by (a) nitrogen treatment (1966); (b) variety (1966); and (c) planting date (1966 and 1967).

conducive to higher NAR in 1966, and is supported by the greater NAR-s for 1966 (Figure 19c). Another noticeable difference between years was the differential response to nitrogen. Plants in the check treatment had higher maximum GR-s than the other nitrogen

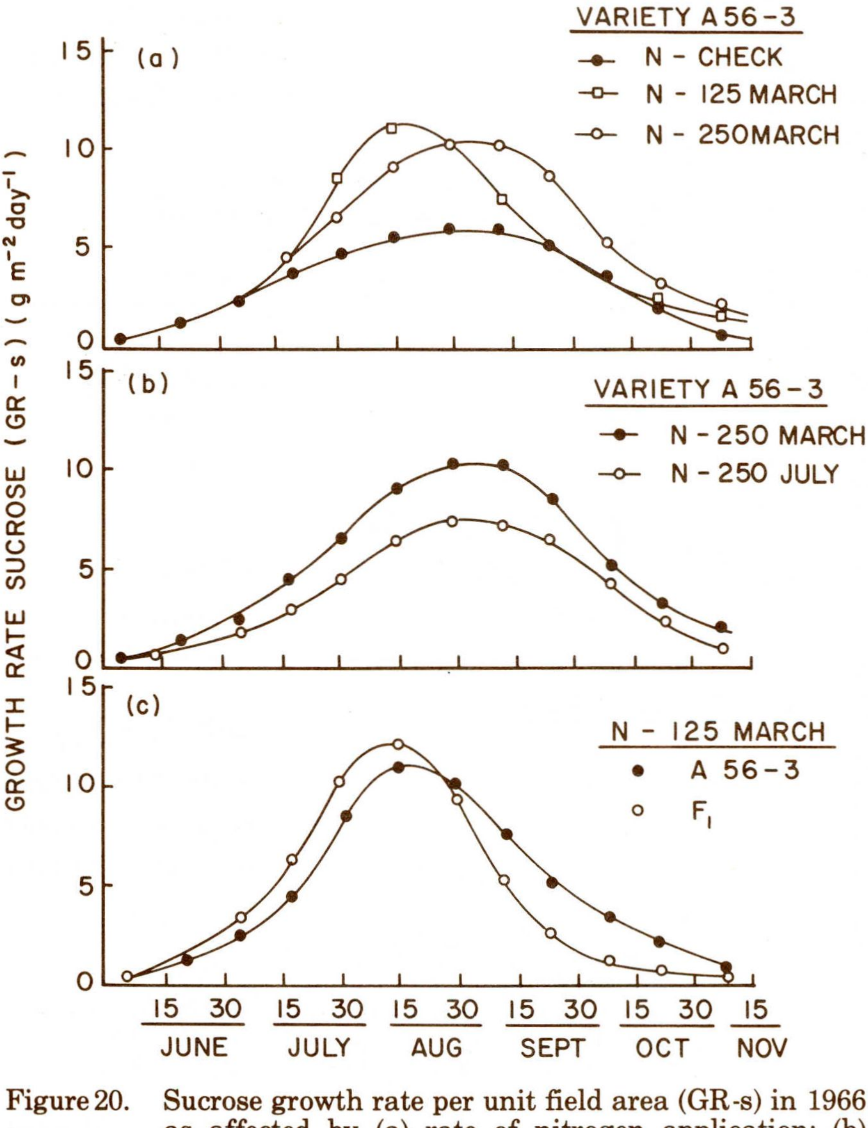


Figure 20. Sucrose growth rate per unit field area (GR-s) in 1966 as affected by (a) rate of nitrogen application; (b) date of nitrogen application; and (c) variety — ($g\ m^{-2} \times 0.00446 = tons/A$).

treatments in 1967 (Figure 21a), but in 1966 plants in the check treatment had the lowest values (Figure 20a). This was primarily a leaf area effect. Plants in the check treatment were deficient in leaf area in 1966, whereas the larger leaf areas in 1967 were nearer optimum for that season (Figures 2a and 3a).

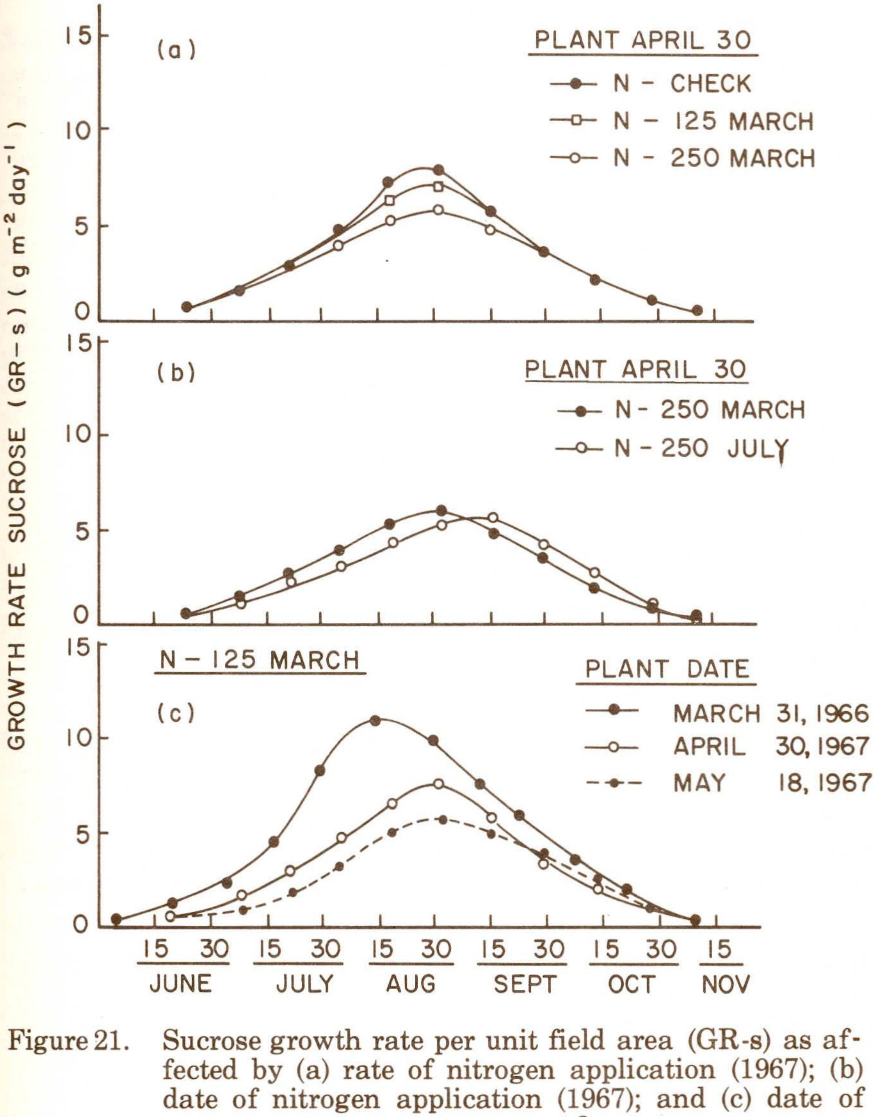


Figure 21. Sucrose growth rate per unit field area (GR-s) as affected by (a) rate of nitrogen application (1967); (b) date of nitrogen application (1967); and (c) date of planting (1966 and 1967) – (g m$^{-2}$ x 0.00446 = tons/A).

Late planting in 1967 had the same effect as late nitrogen in 1966. When growth was delayed until later in the season, additional nitrogen did not increase GR-s, since the increase in growth was principally vegetative. The small nitrogen effect in 1967 could also have resulted from unfavorable climate. A limiting climatic factor can reduce the benefit from nitrogen fertilization. Radiation and air temperature (Figure 13) and soil temperature (Appendix Tables 1 and 2) generally were lower for most of the season prior to September for 1967.

The effect of leaf area on the rate of increase of recoverable sucrose (GR-s) is rather easy to comprehend, since the leaves are responsible for intercepting the light for photosynthesis. Leaf area index may be controlled by treatment, thereby manipulating that portion of GR-s. The effect of the efficiency factor (NAR-s) is more difficult to visualize. It controls that portion of sucrose being sent to the roots that is not explained by leaf area. When years were combined, LAI could account for only about 49% of the variability in sucrose growth rates ($r^2 = 0.49$, 25df). This leaves much to be explained by NAR-s, which is affected by many interacting environmental factors. In the study of dry matter, it was found that by holding leaf area constant much of the variance in the efficiency factor could be explained by radiation; thus, total growth rate was dependent largely upon leaf area and radiation. This was not true, however, for GR-s.

The efficiency factor for sucrose growth-rate (NAR-s) was studied in the same manner as discussed for total growth of dry matter. Points were found on each GR-s curve corresponding to a time when leaf area index was approximately three. These sucrose growth-rates were then correlated with factors believed to affect NAR-s and GR-s. With LAI held constant, correlation values may pertain to either NAR-s or GR-s.

Radiation alone was found to correlate rather poorly with the sucrose productivity per unit leaf area. With the years combined, only 22% of the variability in NAR-s could be accounted for by radiation ($r^2 = 0.22$, 30df). This was much less than the 86% that was accounted for by radiation in total dry matter studies (Figure 14a).

Total nitrogen (% N) in the petiole + crown section (Appendix Table 6) also was used for correlation purposes, because nitrogen is known to have a definite negative effect on sucrose production. Total nitrogen alone was found to be a rather poor index of NAR-s, since only 16% of the variability could be associated with this variable ($r^2 = 0.16$, 30df). When both radiation and total nitrogen were combined in a multiple regression analysis, 59% of the variability in NAR-s could be assigned ($r^2 = 0.59$, 29df).

Best results were obtained when sink size (root weight) was included in the multiple regression analysis along with radiation and nitrogen concentration,

i.e., $Y = 8.30 + 0.29X_1 - 1.52X_2 + 0.77X_3^{**}$

$Y$ = GR-s ($g\ m^{-2} day^{-1}$)

$X_1$ =Radiation ($Cal\ cm^{-2}\ day^{-1}$)

$X_2$= % nitrogen in petioles + crowns

$X_3$= sink size ($g\ m^{-2}$) x $10^{-1}$

** = *all regression coefficients gave significant contributions at 1% level.*

Radiation, nitrogen percentage, and sink size combined to account for 88% of the variability in GR-s ($r^2 = 0.88$, 28df). The effect of radiation and nitrogen percentage on leaf efficiency for sucrose production has an obvious explanation. Higher radiation at constant leaf area has greater photosynthetic potential. This was shown in the investigation of total dry matter. The nitrogen concentration in the plant determines whether photosynthate is used for vegetative growth or sucrose storage. It is possible also that there is an interaction of radiation and percentage nitrogen, although this effect was not included in the model. It seems logical, however, that higher values of nitrogen would be tolerated at higher radiation values since more photosynthate would be present. The effect of sink size on sucrose growth rates is not as clear as the effects of radiation and nitrogen. Sink size may have its greatest effect in controlling the basal translocation rate for sucrose. If sucrose cannot be removed from the leaves after the photosynthetic reaction, it may be used for other purposes or stored in the leaves as starch.

It is entirely possible that a more complicated regression equation could be developed to better explain net assimilation for sucrose. Undoubtedly other factors such as $CO_2$ concentration and leaf temperature have important effects on leaf efficiency; however, measurement of these factors was beyond the scope of this study. No further refinement was made in this study because the logical causes were investigated and because a large portion of the variability in GR-s could be assigned.

The complexity of the factors controlling NAR-s make it difficult to describe optimum leaf areas quantitatively. There is no leaf area that would be optimum throughout a season, or optimum from year to year. Results from this study show that leaf area must decline with season. It would be ideal if the decline in leaf area was parallel to the decline in radiation. It appears doubtful that leaf areas for northeastern Colorado should exceed an index of 4 except possibly early in the season. Treatments which give a leaf area index above this may be excessive late in the season.

**Dry matter distribution—**Total growth rate, root growth rate, and sucrose growth rate have each been discussed separately in preceding sections. A clearer picture of plant growth is presented when all are compared simultaneously. In addition, growth rate of sugarbeet tops also may be studied.

Growth-rate curves for the tops (leaves and petioles plus crowns) (GR-lp) were found by subtracting root growth-rate values from corresponding total growth-rate values, i.e., GR-lp = GR - GR-r. It was explained earlier that both leaves and petioles plus crowns lost weight too early in the season to provide a good fit with the logistic growth curve when the whole season was considered (Figures 5a and 5b). Top growth rates, obtained by the above relationship, usually approached zero near the end of August. As expected, the duration and magnitude of the GR-lp curves were greatly affected by the experimental treatments.

Total growth rates and the partitioning of growth rates for the component parts are given in Figures 22a and 22b for two experimental treatments. These two treatments were selected to show the wide differences that may develop in assimilate distribution. Plants in all treatments had slightly different growth-rate relationships among the component plant parts, but certain treatment effects were obvious for all components.

Maximum top growth always preceded maximum root growth by about 3 weeks. Maximum rates of root growth usually were attained about the time top growth rates were approaching zero. Treatments which continued top growth late into the season slowed root growth and reduced root yields. Both late application of nitrogen and late planting date caused this effect (Figures 22a and 22b). The best root and sucrose yields were obtained from early plantings and early nitrogen applications. This allowed maximum top growth rates to be achieved earlier in the season and caused root growth rates and sucrose accumulation rates to be maintained at higher levels later in the season.

Rates of root growth and sucrose growth usually reached a maximum about the same time. Applications of nitrogen tended to increase maximum root growth rates and depress sucrose growth rates for any given time. It has already been shown, however, that this may be necessary to produce a large sink (root) for subsequent storage of sucrose.

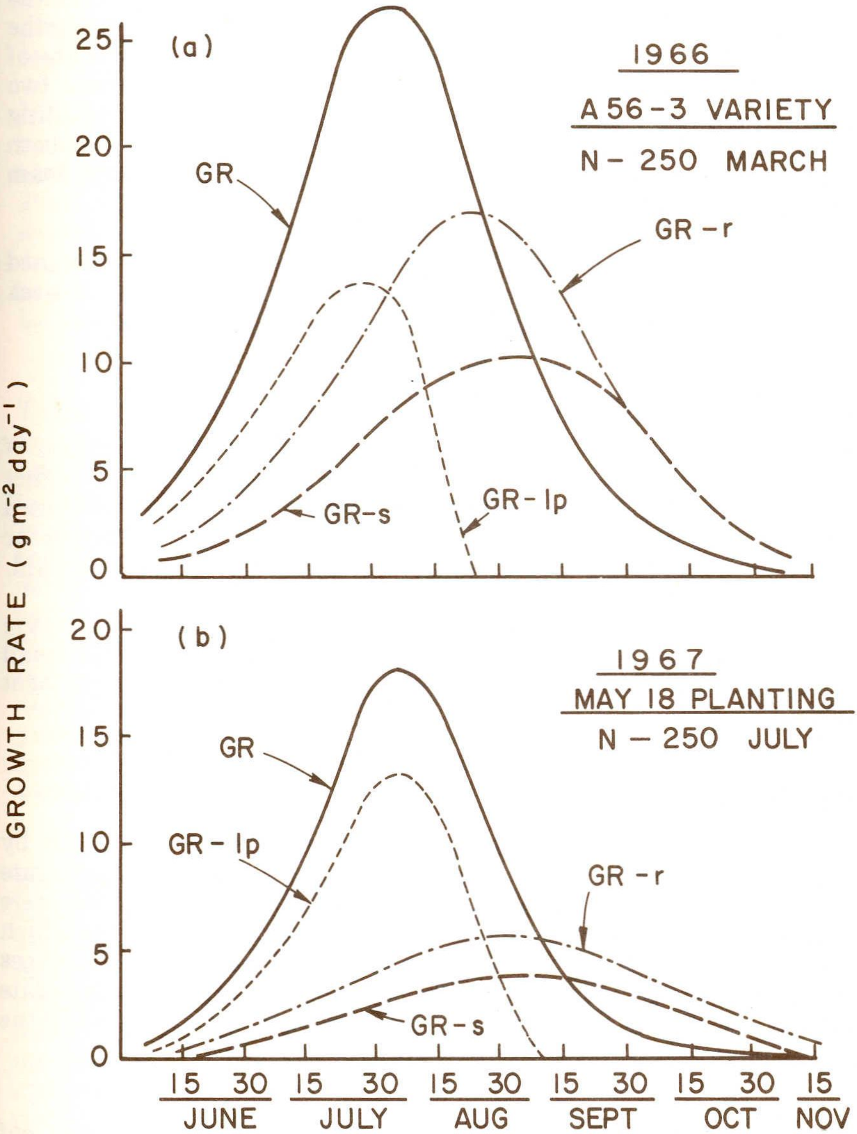


Figure 22. Partitioning of total growth rate (GR) into (a) growth rate of tops (GR-lp); (b) growth rate of roots (GR-r); and (c) growth rate of sucrose (GR-s) ——— (g m$^{-2}$ x 0.00446 = tons/A).

# SUMMARY AND CONCLUSIONS

Factorial experiments were conducted in 1966 and 1967 at the Agronomy Research Center near Fort Collins,Colorado to study the effects of genetic population, nitrogen fertilization, and date of planting on seasonal growth of sugarbeets. There were two varieties and five nitrogen treatments in 1966, and two planting dates and six nitrogen treatments in 1967. The soil for both experiments was a calcareous, nonsaline Nunn clay loam containing about 2% organic matter.

Leaf area, dry matter, and sucrose production were determined throughout the season on plant material samples at 2-week intervals. Seasonal plant growth was related to final yields.

## FINAL HARVEST YIELDS

There was a marked response to rate and time of application of nitrogen in 1966. Preplant nitrogen applications produced higher yields of roots and better quality beets than nitrogen side-dressed on July 15. Yields of roots and recoverable sucrose were larger for the A56-3 commercial variety than for a newly developed $F_1$ hybrid.

There was little response to nitrogen in 1967 and final yields were about 30% lower than those in 1966. The lower yields and small nitrogen response were attributed to a poor climatic environment in 1967.

## GROWTH ANALYSIS

A study of treatment effects on sugarbeet growth was made by comparing growth rates throughout the season. Growth-rate curves for total dry matter, root dry matter, and sucrose were obtained by the first differential of the logistic growth curve which was fitted to the accumulative data for each treatment. Differences in growth rates were then analyzed by studying the separate effects of leaf area index (LAI) and net assimilation rate (NAR), the component parts of growth rate (GR).

**Leaf area**—The commercial variety (A56-3) produced greater leaf areas than the $F_1$ hybrid throughout the season in 1966 for all nitrogen treatments. Leaf area duration for the genetic materials, expressed on a weekly basis, show the $F_1$ to have only 78% as much leaf area for the season as the A56-3.

Planting date had more effect on leaf area early in the season than late in the season. In 1967, beets planted April 30 had greater early leaf areas than beets planted May 18, but late season leaf areas were about the same. In 1966, beets planted March 30 had much greater leaf areas early in the season than beets planted on either planting date in 1967. However, late season leaf areas in 1966 were less than those in 1967.

Nitrogen fertilizer also had a significant effect on leaf area. Higher nitrogen rates increased leaf areas. This effect was observed for both preplant applications in March and side-dress applications in July. Preplant applications of nitrogen in March caused sugarbeets to reach maximum leaf areas earlier in the season than did side-dress applications in July. Nitrogen effects for both rate and date of nitrogen application were more pronounced in 1966 because of lower initial levels of this nutrient.

**Total dry matter**—Total dry matter production was affected greatly by leaf area. Larger LAI caused the net efficiency of the leaf (NAR) to decrease, but this decrease was not great enough to overcome the positive effect of increased leaf area on dry matter production. Greatest dry matter production within each year thus resulted from those treatments having the greatest leaf area duration. Leaves were more efficient for producing dry matter early in the season than late in the season. This was related directly to radiation. With LAI held constant, 86% of the variability in NAR was accounted for by radiation; thus, growth rates were dependent mostly upon leaf area and light. Maximum dry matter yields were obtained from largest leaf areas, but leaf areas were more productive if presented earlier in the season when radiation was highest.

**Root dry matter**—Leaf area duration for each season was not as highly correlated with root yields as with total dry matter. Treatments leading to greatest dry matter production did not necessarily produce greatest root yields. Root growth rates for most treatments did not reach their peak until nearly 3 weeks after the maximum rates for total dry matter production and indicated that top growth had priority for assimilate. Treatments such as late application of nitrogen and late planting delayed the time of reaching maximum leaf areas and maximum top growth, and reduced the proportion of net assimilate going to the roots. Highest root yields were obtained by those treatments which reached their maximum leaf area and top growth early in the season while radiation was high, so that a larger portion of assimilate formed later in the season could be used in root growth.

**Sucrose—**Sucrose growth rates (GR-s) at any point in time were determined by leaf area and the efficiency of that leaf area for sucrose production (NAR-s). Treatments which favored high root yields, such as early planting and early nitrogen, also increased the yield of sucrose because the photosynthetic potential was increased, and because a high proportion of late season assimilate went into sucrose storage rather than vegetative growth. Rate of nitrogen fertilizer was slightly more complicated to explain because it had a twofold effect. Higher rates increased LAI for the season, but decreased NAR-s for the season. Greater sucrose production for the season was attained only if the gain in leaf area more than compensated for the loss in efficiency (NAR-s). This was the case in 1966, but not in 1967. A study of the efficiency of the leaf for sucrose production proved to be more complex than that for total dry matter. With leaf area held constant, radiation accounted for only 22% of the variability in NAR-s or in GR-s. When radiation, percent nitrogen in the petiole and crown, and sink size all were considered in a multiple regression equation, 88% of the variability in NAR-s or in GR-s could be explained.

The interaction of the factors controlling NAR-s and the interrelationship between NAR-s and LAI make it impossible to give a specific leaf area which would be optimum for an entire season or for more than one season. In general, leaf areas must be greatest early in the year and decrease with season for maximum sucrose production. It is not likely that a LAI greater than 4 would be beneficial except early in the season in northeastern Colorado. Optimum leaf areas near the end of the season might be 3 or even less, depending upon the amount of solar radiation.

## APPLICATION OF RESULTS

Results from this study indicate that current cultural practices might be modified to increase crop production. By controlling plant growth more carefully at specific times during the season, especially leaf area and nitrogen concentration, a more favorable relationship with the environment may be achieved.

Rapid early-season growth of sugarbeets is essential to establish large leaf area and sink size necessary for high sucrose yield. Early planting date can help achieve this, but cold weather in the spring often limits this practice. Newer cultural methods such as transplanting, plastic coverings, or asphalt materials may provide frost protection and promote early-season growth. Such practices have worked with other crops and need to be considered for sugarbeets.

It appears also that there may be some benefit from a nitrogen fertilizer that would provide a slower rate of release. In this way leaf areas could be kept closer to the optimum values without a great loss in sucrose accumulation rates. Fertilizer residues would have to be depleted before harvest, however.

Eventually it may be possible to control the plant in advantageous ways by means of growth regulators. It would be ideal if substances could be applied early in the year to promote rapid vegetative growth. This could then be followed later in the season by growth inhibitors which would block vegetative growth and nitrogen utilization, therefore causing increased sucrose accumulation. To do this successfully, however, will require a better understanding of the action of growth regulators than we have at present.

# LITERATURE CITED


**Association of Official Agricultural Chemists.** 1965. Methods of analysis. 8th Edition. 1008 p.

**Blackman, V. H.** 1919. The compound interest law and plant growth. Ann. Bot. 33:353-360.

**Briggs, G. E., F. Kidd, and C. West.** 1920. A quantitative analysis of plant growth. Ann. Appl. Biol. 7:202-209.

**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. Jour. 59:349-354.

**Carruthers, A. and J. F. T. Oldfield.** 1961. Methods for the assessment of beet quality. I. Purity determinations using clarified extract from brei. International Sugar Jour. 63:72-74.

**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. Amer. Soc. Sugar Beet Tech. 14:433-454.

**Fisher, R. A.** 1920. Some remarks on the methods formulated in a recent article on the "Quantitative Analysis of Plant Growth." Ann. Appl. Biol. 7:367-372.

**Follett, R. H., W. R. Schmehl, Leroy Powers, and Merle G. Payne.** 1964. Effect of genetic population and soil fertility level on the chemical composition of sugar beet tops. Colo. Agr. Exp. Sta. Tech. Bull. 79. 65 p.

**Goodman, P. J.** 1963. Some effects of different soils on composition and growth of sugar beet. J. Sci. Fd. Agric. 14:196-203.

__________ 1967. What determines sugar beet yield? II. Plant population and leaf area index. British Sugar Beet Review 35: 171-172.

__________ 1968. Physiological analysis of the effects of different soils on sugar beet crops in different years. J. Appl. Ecol. 5:339-357.

**Gregory, F. G.** 1917. Physiological conditions in cucumber houses. Exp. and Res. Sta. Cheshunt. 3rd. Ann. Rep. 19 p.

**Husseini, K. K.** 1966. Influence of nitrogen, potassium, and sodium on sugar beet growth and quality. Ph.D. Thesis, Colorado State University, Fort Collins.

**Ivins, J. D. and P. M. Bremner.** 1966. Growth studies with the sugar beet crop. Agric. Progress 41:77-83.

**Johnson, C. M. and A. Ulrich.** 1959. Analytical methods for use in plant analysis. California Agr. Exp. Sta. Bull. 766:26-78.

**Last, P. J. and P. B. H. Tinker.** 1968. Nitrate nitrogen in leaves and petioles of sugar beet in relation to yield of sugar and juice purity. J. Agric. Sci. 71:383-392.

**Leach, G. J. and D. J. Watson.** 1968. Photosynthesis in crop profiles, measured by phytometers. J. Appl. Ecol. 5:381-408.

**LeClerg, E. L., W. H. Leonard, and A. G. Clark.** 1962. Field plot technique. Burgess Publishing Co., Minneapolis, Minn. 373 p.

**Morton, A. G. and D. J. Watson.** 1948. A physiological study of leaf growth. Ann. Bot. N. S. 12:281-310.

**Muramato, H., J. Hesketh, and M. El-Sharkawy.** 1965. Relationships among rate of leaf area development, photosynthetic rate, and rate of dry matter production among American cultivated cottons and other species. Crop. Sci. 5:163-166.

**Radford, P. J.** 1967. Growth analysis formulae — their use and abuse. Crop Sci. 7:171-175.

**Scott, R. K. and P. M. Bremner.** 1966. The effects on growth, development, and yield of sugar beet of extension of the growth period by transplantation. J. Agric. Sci. 66:379-388.

**Ulrich, A.** 1946. Plant analysis as a guide in the fertilization of sugar beets. Amer. Soc. Sugar Beet Tech. Proc. 4:88-95.

__________ 1950. Critical nitrate levels of sugar beets estimated from analysis of petioles and blades, with special reference to yields and sucrose concentrations. Soil Sci. 69:291-309.

**Watson, D. J.** 1947. Comparative physiological studies on the growth of field crops. I. Variations in NAR and leaf area between species and varieties and within and between years. Ann. Bot. N. S. 2:41-76.

__________ 1952. The physiological basis of variation in yield. Advances Agron. 4:101-145.

__________ 1956. Leaf growth in relation to crop yield. p. 178-191. *In* F. L. Milthrope (ed.) The growth of leaves. Butterworths Publications, London.

__________ 1958. The dependence of net assimilation rate on leaf area index. Ann. Bot. N. S. 22:37-54.

__________ 1963. Climate, weather, and plant yield. p. 338-349. *In* L. T. Evans, (ed.) Environmental control of plant growth. Academic Press, New York.

__________ 1968. A prospect of crop physiology. Ann. Appl. Biol. 62:1-9.

**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.

**Williams, W. A., R. S. Loomis, and C. R. Lepley.** 1965. Vegetative growth of corn as affected by population density. I. Productivity in relation to interception of solar radiation. Crop Sci. 5:211-215.

# GLOSSARY OF GROWTH ANALYSIS SYMBOLS, TERMS, AND EQUATIONS

## SYMBOLS

1. A = Leaf area.
2. W = Total dry weight of plant per unit ground area.
3. LP = Dry weight of tops (leaves plus petioles and crowns) per unit area.
4. R = Dry weight of roots per unit area.
5. S = Weight of recoverable sucrose per unit area.
6. t = Time.

## GROWTH ANALYSIS TERMS

1. GR = Growth rate for whole plant (dW/dt) per unit ground area.
2. GR-lp = Growth rate for tops (dLP/dt) per unit ground area.
3. GR-r = Growth rate for roots (dR/dt) per unit ground area.
4. GR-s = Sucrose accumulation rate (dS/dt) per unit ground area.
5. LAI = Leaf area index or leaf area per unit ground area.
6. LAD = Leaf area duration or integral of leaf area index curve.
7. NAR = Net assimilation rate or total growth rate per unit leaf area (1/A x dW/dt).
8. NAR-r = Net assimilation rate for roots or root growth rate per unit leaf area (1/A x dR/dt).
9. NAR-s = Net assimilation rate for sucrose or sucrose accumulation rate per unit leaf area (1/A x dS/dt).
10. $PF_1$ = First partition factor showing change in root weight with respect to change in total weight (dR/dW).
11. $PF_2$ = Second partition factor showing change in sucrose weight with respect to change in total weight (dS/dW).

## GROWTH ANALYSIS EQUATIONS

1. GR = LAI x NAR or $\frac{dW}{dt} = A \times \frac{1}{A} \frac{dW}{dt}$
2. GR-r = LAI x NAR-r or $\frac{dR}{dt} = A \times \frac{1}{A} \frac{dR}{dt}$
3. GR-s = LAI x NAR-s or $\frac{dS}{dt} = A \times \frac{1}{A} \frac{dS}{dt}$
4. GR-lp = GR - GR-r

# APPENDIX

Appendix Table 1. Radiation and temperature data for the 1966 crop season.

| Growth Period | Average Total Radiation (cal $cm^{-2}$ $day^{-1}$) | Average Air Temperature °F | Average Soil Temperature °F(6-inch depth) |
|---|---|---|---|
| May 23-June 6 | 415 | 63.0 | 70.0 |
| June 7-June 20 | 486 | 58.6 | 66.2 |
| June 21-July 5 | 590 | 69.5 | 73.5 |
| July 6-July 18 | 544 | 74.2 | 74.4 |
| July 19-Aug. 1 | 489 | 72.5 | 72.0 |
| Aug. 2-Aug. 15 | 507 | 66.3 | 64.0 |
| Aug. 16-Aug. 29 | 495 | 64.4 | 62.7 |
| Aug. 30-Sept. 12 | 428 | 63.0 | 62.6 |
| Sept. 13-Sept. 24 | 361 | 58.9 | 53.0 |
| Sept. 25-Oct. 8 | 312 | 53.1 | 53.2 |
| Oct. 9-Oct. 22 | 313 | 49.5 | 46.1 |
| Oct. 23-Nov. 8 | 214 | 45.0 | 43.3 |

Appendix Table 2. Radiation and temperature data for the 1967 crop season.

| Growth Period | Average Total Radiation (cal $cm^{-2}$ $day^{-1}$) | Average Air Temperature °F | Average Soil Temperature °F(6-inch depth) |
|---|---|---|---|
| May 28-June 10 | 414 | 56.7 | 58.1 |
| June 11-June 24 | 362 | 57.6 | 59.2 |
| June 25-July 8 | 494 | 64.4 | 65.5 |
| July 9-July 22 | 488 | 67.2 | 67.1 |
| July 23-Aug. 5 | 475 | 68.0 | 67.3 |
| Aug. 6-Aug. 19 | 445 | 65.8 | 62.9 |
| Aug. 20-Sept. 2 | 350 | 62.7 | 61.1 |
| Sept. 3-Sept. 16 | 403 | 59.2 | 58.9 |
| Sept. 17-Sept. 30 | 308 | 59.0 | 56.6 |
| Oct. 1-Oct. 14 | 301 | 54.0 | 54.2 |
| Oct. 15-Oct. 28 | 244 | 49.0 | 47.3 |
| Oct. 29-Nov. 11 | 203 | 45.0 | 40.8 |

Appendix Table 3. Days in which minimum temperatures were below 32°F during October and November, 1966 and 1967.

| 1966 | | 1967 | |
|---|---|---|---|
| October | Temperature | October | Temperature |
| 1, 4, 15, 16, 17, 19, 20, 22, 24, 25, 26, 30, 31 | 29, 28, 22, 26, 25, 24, 30, 29, 29, 29, 29, 26, 30 | 16, 20, 27 30, 31 | 27, 29, 22, 19, 18 |
| November | Temperature | November | Temperature |
| 1, 2, 3, 4, 5, 8 | 22, 19, 25, 28, 18, 19 | 2, 3, 4, 5, 6, 7, 8, 9 | 22, 8, 14, 9, 13, 18, 24, 27 |

Appendix Table 4. Available soil nitrogen and total soil nitrogen for experimental sites in 1966 and 1967.*

| Soil Depth Inches | Available Nitrogen (lbs N/acre) 1966 $NH_4$ | 1966 $NO_3$ | 1967 $NH_4$ | 1967 $NO_3$ | Total Soil Nitrogen (%N) 1966 | Total Soil Nitrogen (%N) 1967 |
|---|---|---|---|---|---|---|
| 1-6 | 9.5 | 14.3 | 11.2 | 12.4 | 0.103 | 0.097 |
| 6-12 | 4.0 | 13.8 | 9.6 | 10.8 | 0.114 | 0.093 |
| 12-18 | 4.2 | 16.5 | 7.2 | 12.2 | 0.065 | 0.079 |
| 18-24 | 7.0 | 10.7 | 8.2 | 10.6 | 0.045 | 0.057 |
| 24-30 | 6.1 | 12.0 | 7.2 | 10.2 | 0.036 | 0.047 |
| 30-36 | 2.8 | 10.9 | 8.0 | 10.4 | 0.032 | 0.039 |
| 36-42 | 3.0 | 6.1 | 8.2 | 9.6 | 0.029 | 0.036 |
| 42-48 | 3.2 | 6.3 | 7.6 | 9.6 | 0.027 | 0.034 |
| Total | 39.8 | 90.6 | 67.2 | 85.8 | | |

**Soils were sampled April 12, 1966 and March 18, 1967.*

Appendix Table 5. Nitrate-nitrogen concentration in petioles for 3 sampling dates, 1966 and 1967.

1966

| Treatment | | Sampling Date | | |
| --- | --- | --- | --- | --- |
| Variety | Nitrogen | July 28 | Sept. 6 | Oct. 3 |
| | | %N | | |
| A56-3 | Check | 0.11 | 0.03 | 0.03 |
| | 125 March | 0.22 | 0.04 | 0.03 |
| | 250 March | 0.58 | 0.12 | 0.08 |
| | 125 July | 0.80 | 0.17 | 0.07 |
| | 250 July | 0.94 | 0.44 | 0.32 |
| $F_1$ | Check | 0.09 | 0.04 | 0.03 |
| | 125 March | 0.18 | 0.05 | 0.03 |
| | 250 March | 0.58 | 0.08 | 0.05 |
| | 125 July | 0.84 | 0.08 | 0.06 |
| | 250 July | 0.96 | 0.46 | 0.30 |

1967

| Planting Date | Nitrogen | July 20 | Aug. 9 | Sept. 30 |
| --- | --- | --- | --- | --- |
| | | %N | | |
| April 30 | Check | 0.41 | 0.37 | 0.31 |
| | 125 March | 1.21 | 0.86 | 0.38 |
| | 250 March | 1.45 | 1.12 | 0.74 |
| | 375 March | 1.46 | 1.32 | 0.86 |
| | 125 July | 0.87 | 0.86 | 0.37 |
| | 250 July | 1.04 | 1.24 | 1.10 |
| May 18 | Check | 0.49 | 0.55 | 0.20 |
| | 125 March | 1.58 | 1.39 | 0.53 |
| | 250 March | 1.90 | 1.52 | 0.98 |
| | 375 March | 1.94 | 1.76 | 1.45 |
| | 125 July | 0.91 | 1.18 | 0.77 |
| | 250 July | 0.96 | 1.50 | 1.35 |

Appendix Table 6. Effect of nitrogen fertilizer and sampling date on nitrogen content of petioles plus crowns, 1966 and 1967.

| Sampling Date | Check | Nitrogen Treatment 125 lb March | 250 lb March | 125 lb July | 250 lb July |
|---|---|---|---|---|---|
| | %N | | | | |
| | | 1966 | | | |
| June 6 | 3.62 | 3.78 | 3.89 | 3.75 | 3.59 |
| June 20 | 3.89 | 3.51 | 3.89 | 4.20 | 4.74 |
| July 5 | 2.00 | 3.72 | 3.86 | 2.16 | 2.30 |
| July 18 | 1.35 | 2.25 | 3.00 | 2.15 | 2.22 |
| Aug. 1 | 1.41 | 1.53 | 2.46 | 2.63 | 2.61 |
| Aug. 15 | 1.28 | 1.56 | 2.00 | 2.26 | 3.04 |
| Aug. 29 | 1.16 | 1.32 | 1.98 | 1.79 | 2.45 |
| Sept. 12 | 1.29 | 1.28 | 1.94 | 1.63 | 2.43 |
| Sept. 24 | 1.11 | 1.30 | 1.65 | 1.44 | 2.28 |
| Oct. 8 | 1.27 | 1.53 | 1.66 | 1.44 | 2.05 |
| Oct. 22 | 1.27 | 1.46 | 1.59 | 1.42 | 2.10 |
| Nov. 8 | 1.25 | 1.41 | 1.63 | 1.51 | 1.95 |

| Sampling Date | Check | Nitrogen Treatment 125 lb March | 250 lb March | 375 lb March | 125 lb July | 250 lb July |
|---|---|---|---|---|---|---|
| | %N | | | | | |
| | | | 1967 | | | |
| June 24 | 3.42 | 3.63 | 3.80 | 3.91 | 3.33 | 3.36 |
| July 8 | 3.00 | 3.39 | 3.54 | 3.62 | 2.63 | 2.68 |
| July 22 | 1.75 | 2.96 | 3.20 | 3.58 | 2.25 | 2.45 |
| Aug. 5 | 1.37 | 2.00 | 2.62 | 2.91 | 2.10 | 2.68 |
| Aug. 19 | 1.05 | 1.58 | 2.00 | 2.25 | 1.83 | 2.38 |
| Sept. 2 | 1.18 | 1.63 | 2.13 | 2.15 | 2.00 | 2.61 |
| Sept. 16 | 1.35 | 1.62 | 2.00 | 2.15 | 1.82 | 2.00 |
| Sept. 30 | 1.25 | 1.89 | 2.18 | 2.63 | 2.00 | 2.48 |
| Oct. 14 | 1.49 | 1.91 | 1.87 | 2.21 | 1.75 | 2.10 |
| Oct. 28 | 1.36 | 1.62 | 2.15 | 2.52 | 1.72 | 2.20 |
| Nov. 11 | 1.30 | 2.01 | 2.36 | 2.55 | 1.79 | 2.66 |

Appendix Table 7. Calculated parameters for the logistic growth curve for total dry matter.†

| | | | | | |
|---|---|---|---|---|---|
| | | **1966** | | | |
| | | Parameter | | | |
| Treatment (lbs) | | a | b | c | $r^2$†† |
| A56-3 | N-Check | 962 | 192.6 | .055 | .83 |
| | N-125 March | 1434 | 313.1 | .064 | .93 |
| | N-250 March | 1781 | 295.6 | .059 | .95 |
| | N-125 July | 1606 | 518.5 | .062 | .94 |
| | N-250 July | 1648 | 442.8 | .059 | .94 |
| $F_1$ | N-Check | 1004 | 87.1 | .045 | .83 |
| | N-125 March | 1410 | 457.2 | .068 | .97 |
| | N-250 March | 1491 | 275.5 | .062 | .95 |
| | N-125 July | 1132 | 477.4 | .089 | .96 |
| | N-250 July | 1505 | 630.0 | .064 | .97 |
| | | **1967** | | | |
| Planted April 30 | N-Check | 1805 | 515.6 | .649 | .88 |
| | N-125 March | 1195 | 429.1 | .629 | .87 |
| | N-250 March | 1179 | 842.8 | .727 | .93 |
| | N-375 March | 1211 | 854.7 | .712 | .84 |
| | N-125 July | 1206 | 440.0 | .603 | .85 |
| | N-250 July | 1227 | 438.3 | .608 | .86 |
| Planted May 18 | N-Check | 717 | 714.0 | .865 | .84 |
| | N-125 March | 1019 | 138.5 | .620 | .87 |
| | N-250 March | 998 | 258.3 | .705 | .84 |
| | N-375 March | 962 | 246.9 | .684 | .87 |
| | N-125 July | 997 | 228.5 | .629 | .85 |
| | N-250 July | 1045 | 297.1 | .702 | .88 |

†*Total dry matter at any time "t" (days) is calculated by using parameters a, b, and c in the equation* $W = \frac{a}{1+be^{-ct}}$.

††*Ratio of sum of squares due to regression to total sum of squares.*

Appendix Table 8. Calculated parameters for logistic growth curve for root dry matter.†

| Treatment (lbs) | | Parameter a | b | c | $r^2$†† |
|---|---|---|---|---|---|
| **1966** | | | | | |
| A56-3 | N-Check | 834 | 256.2 | .049 | .87 |
| | N-125 March | 1158 | 448.8 | .055 | .94 |
| | N-250 March | 1395 | 409.1 | .050 | .97 |
| | N-125 July | 1213 | 575.9 | .053 | .94 |
| | N-250 July | 1133 | 503.3 | .052 | .94 |
| $F_1$ | N-Check | 941 | 84.5 | .038 | .85 |
| | N-125 March | 1210 | 482.4 | .057 | .96 |
| | N-250 March | 1193 | 458.8 | .055 | .96 |
| | N-125 July | 817 | 1040.8 | .068 | .89 |
| | N-250 July | 1092 | 306.5 | .049 | .95 |
| **1967** | | | | | |
| Planted April 30 | N-Check | 811 | 300.5 | .049 | .90 |
| | N-125 March | 801 | 344.9 | .050 | .89 |
| | N-250 March | 817 | 134.5 | .041 | .86 |
| | N-375 March | 728 | 465.6 | .055 | .87 |
| | N-125 July | 891 | 130.9 | .037 | .88 |
| | N-250 July | 791 | 221.9 | .045 | .91 |
| Planted May 18 | N-Check | 510 | 218.7 | .057 | .92 |
| | N-125 March | 699 | 109.7 | .043 | .91 |
| | N-250 March | 634 | 67.9 | .038 | .89 |
| | N-375 March | 592 | 106.3 | .043 | .89 |
| | N-125 July | 652 | 87.9 | .038 | .90 |
| | N-250 July | 620 | 58.9 | .037 | .89 |

†*Root dry matter at any time "t" (days) is calculated by using parameters a, b, and c in the equation* $W = \frac{a}{1+be^{-ct}}$.

††*Ratio of sum of squares due to regression to total sum of squares.*

Appendix Table 9. Calculated parameters for logistic growth curve for sucrose accumulation.†

1966

| Treatment (lbs) | | Parameter a | b | c | $r^2$†† |
|---|---|---|---|---|---|
| A56-3 | N-Check | 750 | 98.3 | .035 | .86 |
| | N-125 March | 867 | 567.8 | .057 | .92 |
| | N-250 March | 992 | 252.3 | .045 | .97 |
| | N-125 July | 810 | 355.0 | .049 | .96 |
| | N-250 July | 680 | 255.3 | .045 | .96 |
| $F_1$ | N-Check | 640 | 76.3 | .037 | .85 |
| | N-125 March | 815 | 899.2 | .065 | .97 |
| | N-250 March | 885 | 360.5 | .052 | .98 |
| | N-125 July | 675 | 443.4 | .055 | .92 |
| | N-250 July | 664 | 195.4 | .044 | .96 |

1967

| Treatment (lbs) | | a | b | c | $r^2$†† |
|---|---|---|---|---|---|
| Planted April 30 | N-Check | 565 | 1116.7 | .060 | .88 |
| | N-125 March | 552 | 714.7 | .055 | .88 |
| | N-250 March | 542 | 324.0 | .048 | .89 |
| | N-375 March | 370 | 164.3 | .043 | .91 |
| | N-125 July | 610 | 260.8 | .042 | .87 |
| | N-250 July | 534 | 345.8 | .047 | .91 |
| Planted May 18 | N-Check | 370 | 545.5 | .064 | .90 |
| | N-125 March | 500 | 230.1 | .049 | .92 |
| | N-250 March | 376 | 232.7 | .051 | .90 |
| | N-375 March | 332 | 469.0 | .057 | .90 |
| | N-125 July | 440 | 206.7 | .045 | .90 |
| | N-250 July | 366 | 165.1 | .049 | .91 |

† *Sucrose accumulation production at any time "t" (days) is calculated by using parameters a, b, and c in the equation* $W = \frac{a}{1+be^{-ct}}$.

†† *Ratio of sum of squares due to regression to total sum of squares.*