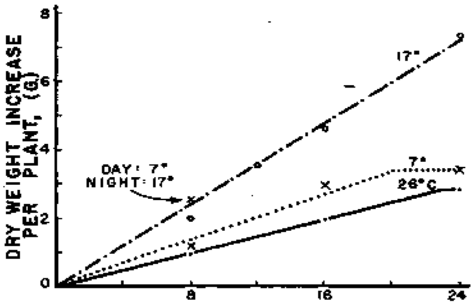

The Physiology of the Growth of Sugar Beets

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The sugar beet is, in many respects, an ideal experimental plant. We are primarily interested in its sugar content, and this sugar is the principal product of photosynthesis which does not seem to undergo transformation between its production in mesophyll cells and its storage in root cells. There are no complicating problems concerning the stem, since the leaves are implanted immediately upon the swollen root crown. The greatest disadvantage of beets for physiological experiments is their variability. Most commercial varieties are kept heterozygous to the greatest degree. This results in a degree of variability of both tops and roots, as far as size and form is concerned, which is unparalleled in any other major crop plant. The variability *in* size of root is not primarily the result of mutual shading and competition. In all other crop plants, heavy stands result in a more uni-form, though smaller, size of the individual plants. In young beet plants, long before they start to shade each other or compete for food or water, extreme differences in size occur.

PHOTOPERIOD (HRS.)

Figure 1.—Gain in dry weight of US 22/3 sugar beet plants in 30 days under different conditions of temperature and photoperiod.

In the experiment shown in Figure 1, plants were grown under a variety of temperature and light conditions. It was found that the greatest variability occurred in plants grown in an 8-hour photoperiod. In four separate groups, the lightest plants were 33, 33, 34, and 34 percent of the weight of the heaviest plants. In the 12- and 16-hour photoperiods, the lightest plants were 38, 50, 51, and 51 percent of the weight of the heaviest. In the plants grown in continuous light, the lightest plants were 55, 61, and 66 percent the weight of the heaviest. This shows that the more optimum the growing conditions, the less the variability. This result might be ex-

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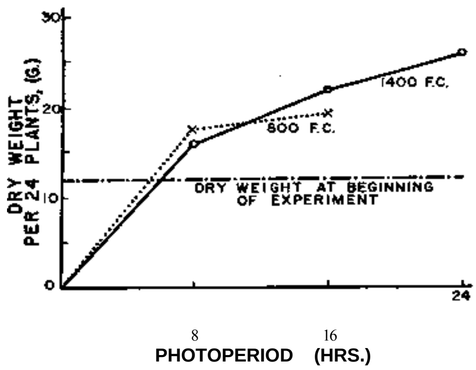

Figure 2.—Average **total dry weight of US 22/3 and US 35 sugar beet plants in 7 days at 14° C. under different conditions of light intensity and photoperiod.**

pected if the population was very heterogeneous and where, under poor growing conditions, the heterozygosity would become most clearly expressed in differences in growth.

In the experiment shown in Figure 2, the same phenomenon was ob-served. At the beginning, of the experiment, the plants in the two lightest groups weighed 50 percent of the heaviest. When these plants were grown for an additional 7 days at 14° C. in 8-, 16-, or 24-hour photoperiods, the variability slightly increased in the 8-hour, decreased in the 16-hour, and decreased appreciably in the 24-hour photoperiod. This was due to the fact, that in short photoperiods, the slowest growing (or lightest) plants continued to grow slowly. In the long photoperiods, the increase was ap-proximately the same for the light and the heavy plants. Table 1 shows this

Table 1.—Dry Weight of the Heaviest and the Lightest Beets (6 Plants per Container, 4 Containers Each) at the Beginning of the Experiment, and After 7 Days' Growth, for US 22 and US 35.

	Light Intensity	Photo-period	Dry Weight of 24 Beets Each		Increase Dry Weight in 7 Days		Weight Increase of Lightest in Percent of Heaviest
			Heaviest	Lightest	Heaviest	Lightest	
	ft.c.						
At beginning of experiment			15.98	8.05			50
After 7 days	800	8	23.24	11.06	7.26	3.01	41
	800	16	24.48	14.54	8.50	6.49	76
	1400	8	21.95	10.30	5.97	2.25	38
	1400	16	26.91	15.62	10.93	7.57	69
	1400	24	30.21	20.82	14.23	12.77	90

in some detail. The variability of these beets, therefore, depends largely upon sub-optimum growing conditions. Some plants are able to grow very well and make full use of light of short duration, whereas, others do this only during long photoperiods.

The over-all growth of the sugar beet has been studied in detail by Ulrich. The differences in response which he observed under different tem-perature and light conditions, must all find an explanation in the basic responses of beet plants to temperature and light. Their total growth is the sum total of all reactions going on in the plant. In this paper, an attempt is made to differentiate between the various physiological processes which contribute to the growth of the beet.

Photosynthesis will be considered first. Under ideal conditions of light and temperature, the photosynthetic efficiency of beets is about 10 percent. This means that 10 percent of the incident light can be trans-formed by the beet leaf cells into chemical energy. In the field, not more than one or, at most, two percent of the light energy is transformed into harvestable plant material. This seems to indicate that it is not photo-synthesis, as such, which limits dry-weight production in the field. For closer analysis of the photosynthesis of beets, the effects of light on the increase in dry weight of young beets just before they are starting to thicken their tap roots were measured. To this end, young beets were germinated or transplanted in containers with vermiculite.

In the earlier experiments, five plants were grown together in a 10 x 10 centimeter plastic container. Since this technique tended to increase the individual variability, beets were grown singly in plastic cups 7 centimeters in diameter in later experiments.

Before the start of the experiment, all 100 or more containers with beets were lined up and visually divided into equal groups, each group containing the same proportions of heavy and light plants. One or two groups were harvested immediately, the other groups being kept for six or more days at different temperatures, different light intensities, or different photoperiods before being harvested. The increase in dry weights during that period of exposure can then be calculated by differences. Figures 1 and 2 show the gain in weight of different beet varieties over 7- and 30-day periods in 8-, 12-, 16-, and 24-hour photoperiods. It can be seen that there is a direct proportion between duration of illumination and dry-weight pro-duction probably indicating that photosynthesis is limiting. No increase in dry weight was noticed when light intensity was increased to above 1000 foot-candles, from which it can be concluded that the photosynthetic process cannot proceed faster than this rate. Only the rate of the process is limited, not the amount of dry weight which can be produced. By increasing the duration of illumination, more dry weight is produced in proportion to the length of photoperiod. It might be concluded, that at a 1000 foot-candle in-tensity, an equilibrium is reached between the rate of formation of photo-synthates and their translocation out of the leaf cells. This limited rate of translocation could either be due to the translocation system itself, or to the size of the receiving end of the translocation system. If there is not enough space to store the photosvnthates, the translocation system will be-come clogged and the rate will decrease.

In a cooperative experiment with Dr. John Spikes and Mr. Bruce Burn-ham of the University of Utah at Salt Lake City, beets were grown under several different growing conditions. After the plants had grown for four weeks, half were harvested and the material sent to Dr. Spikes for bio-chemical analysis. The remainder of the plants were divided into two groups and were subjected to light at intensities of 800 and 1400 foot-candles at 17° C. in a 24-hour photoperiod and harvested following one week's growth. From the increase in weight during the last weekly period, it was possible to get an idea of the growth potential of the beets which previously had been subjected to different temperatures and photoperiods.

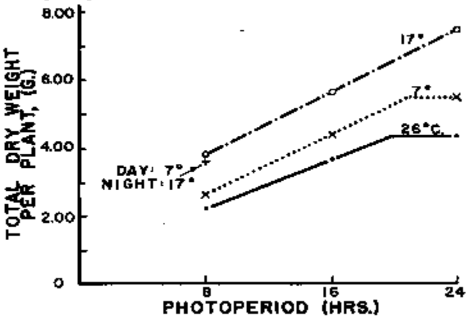

Figure 3. - Total dry weight of US 22/3 sugar beet plants after 7 additional days at 17° C. under a 24-hour photoperiod (temperature and photoperiod figures in graph refer to previous treatments).

Thus, correlations could be made between individual processes and previous or subsequent growth. Figure 1 shows the relationship between length of photoperiod and amount of dry weight produced. It can be seen that at 17° C, approximately twice as much growth and dry weight was produced than at either 7° C. or 26° C. The plants which had been grown at an 8-hour photoperiod had a greater growth potential than those at 16-or 24-hour photoperiods, as seen by comparing Figure 1 and Figure 3. Results seem to indicate that during short photoperiods, the plants had been held back in dry-weight production by the amount of photosynthates formed. As soon as more were formed in a 24-hour photoperiod the plants gained weight at an accelerated rate. The plants which previously had been at 26° C. photosynthesized better in a 1200 foot-candles than a 600 foot-candles intensity, whereas, the plants from 17° C. to 7° C. were more efficient in growth at the 600 foot-candles intensity.

Concerning correlations between individual processes and growth, Fig-ure 4a shows that the rate of the Hill reaction in beet leaves is positively correlated with length of photoperiod under which plants were grown. Con-versely, Figure 4b shows that there is a negative correlation with the growth potential of the beets. It could be concluded that the photochemical reduc-tion of water inside the chloroplasts is not the limiting process in the growth of beets. On the other hand, there is a slight positive correlation between the respiration rate of leaf discs and subsequent increase in weight. Plants with a high respiration rate were, in general, those which grew most rapidly when brought under the same conditions.

In another experiment, three different beet varieties were grown under different temperature conditions. Under optimum temperature conditions, slightly more growth was noticed in the 750 foot-candles light intensity. Figure 5 shows the results of this experiment in which the values for both 750 foot-candles and 1200 foot-candles have been plotted. From these figures it seems that GW 304A performed slightly better than US 22/3, especially at the lower temperatures. Variety 492 was less responsive than either of the other varieties.

The results of the experiment just described differ from those reported by Ulrich. He found that in artificial light intensities of 1000 to 15000 foot-candles, beets grew inferior to those grown in full daylight in the green-house. The basis for the difference in results probably lies in the fact that leaf development in older beets is so great that the leaves shade each other sufficiently to prevent each leaf from receiving the maximum light intensity, rather than the age of the plant. The majority of the older plants in a greenhouse get only one-fifth to one-tenth of the total amount of available light. Older beet plants, therefore, require a much higher light intensity for saturation, not because the saturation of the individual leaf is at a higher intensity but because the average light intensity at each leaf is so much lower. We could draw from this consideration, the conclusion that beyond a certain density of foliage, no advantage is gained by the beet plant from the development of a larger leaf area.

Some experiments on sugar translocation in the sugar beet have been carried out by Hull (1953). He found that at low temperatures, more

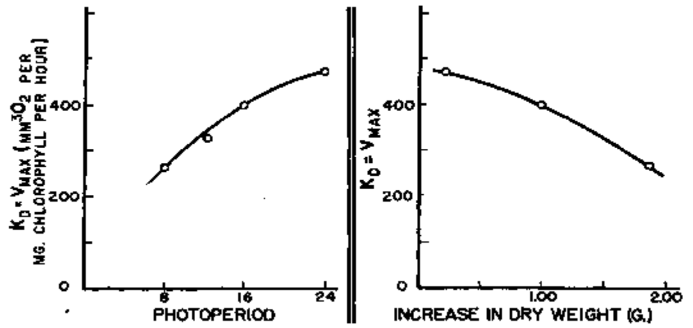

Figure 4a (left).—V_{rnax} of Hill reaction in leaves of US 22/3 sugar beets as a function of photoperiod. (after John D. Spikes).

Figure 4b (right).—V_{max} of Hill reaction as a function of increase in dry weight of the plants.

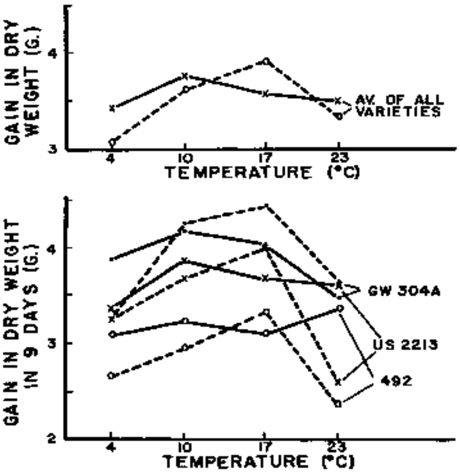

Figure 5. — Gain in dry weight per plant of 3 varieties of sugar beets under different conditions of temperature and light intensity (broken lines —650 to 700 foot-candles, solid lines—1200 to 1500 foot-candles.

(US 2213 in adjacent figure should be US 22/3)

sugar is translocated from the leaves to the root system. This probably ex-plains Ulrich's observation that at lower temperatures, the sugar percentage of beets increases. The lower the temperature, the more sugar is moved out of the leaves into the root. This leads to the conclusion that optimum sugar production can be obtained by first having the beets grow at a maxi-mum rate, so that as much storage space is produced as possible. This hap-pens at fairly high temperatures which normally occur during summer in the beet growing areas. Shortly before harvest, beets should be allowed to grow at lower temperatures so that the roots formed during summer can be filled with sugar.

In the previous discussion, we have seen how photosynthesis partially depends on the size of the root where the formed photosynthates can be stored. What do we know about the factors controlling this root growth? Unfortunately, the answer must be rather negative. We know very little about the physiology of the growth in size of the sugar beet root. It is obvious from Ulrich's determinations that root growth stops when both tempera-ture and nitrogen supply in the soil become low. There is currently no contrary evidence. Hormones coming from the leaves apparently do not control the size growth of young sugar beet roots. This suggestion is made as a result of experiments by Luis Gregory on potatoes. He found that tuber production of potatoes results from the influence of a factor pro-duced in the tops of the potato plant at night temperatures below 23° C. It is possible that a similar substance is formed in beet leaves which causes enlargement of the primary root. This substance apparently is formed only in older leaves. Grafting experiments should be used for this study. If it were possible to identify this factor with a chemical (which could be syn-thesized) , great new possibilities for increased sugar production would be available.