Sugarbeet Growth and Development under Controlled Climatic Conditions with Reference to Night Temperature

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Introduction

Sugarbeets have declined gradually in sucrose concentration in California from about 18.2% in 1937 to about 15% in 1959 (10,13).[2] Since then, the decline has stopped at about an average of 15%. Mineral nutrition, particularly with respect to nitrogen, has been found to have a large influence on sucrose content of the storage root (2,6). Sucrose concentrations, as a rule, are higher and beet yields are lower as the number of days of petiole nitrate-nitrogen below 1,000 ppm increases prior to harvest (6). The increase in sucrose concentration at the onset of nitrogen deficiency compensates for the tonnage loss and improves processing quality. However, a prolonged nitrogen deficiency results in an over-all loss of sugar produced. Top and storage root growth tends to be favored by an abundant supply of nitrogen, resulting in vigorous growth of tops and storage roots (2,4,8).

Climate has an important influence on sugar production. This was observed in a pot culture study with a common soil at two locations in California. The sugarbeets in the first year had a higher sucrose concentration in a cool cloudy climate than in a hot sunny climate. The following year the results were reversed (11). In a standardized pot culture study conducted in 17 major sugarbeet growing areas in the U.S. (12), sucrose concentrations in more than half of the locations were inversely related to minimum night temperature summed over 0°C for 4 weeks prior to harvest. Under comparable greenhouse conditions and ample mineral nutrition, including nitrogen, a low night temperature of 4°C increased sucrose concentration in comparison to the control plants at 17°C night temperature (8). Further increases in sucrose concentration were observed when nitrogen was withheld. In another study, sucrose concentration was inversely related to night temperature, with the greatest attained at 2°C and the least at 30°C (7).

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[2]Numbers in parentheses refer to literature cited.

Maximum sucrose yield was attained, however, in the night termperature range of 14 to 20°C. Essentially, sucrose concentration tends to reflect the climatic conditions prevailing before harvest, while root size reflects the climate from planting to harvest (5,9).

The objectives of the present study were to determine if sugarbeets could be grown successfully in plant growth chambers with improved lighting under completely controlled conditions of light, temperature, and nutrition, and to assess the effects of night temperature on sugarbeet growth and development with this technique.

Methods and Materials

Sugarbeet (*Beta vulgaris* L.) seeds of the variety F58-554H1 (MS of NBl x NB4) were treated with Phygon XL fungicide, 1% by weight, prior to planting. At planting, ten seedballs, equally spaced, were placed in a circle 12 cm in diameter, and planted to a depth of 2.0 cm in vermiculite No. 2 contained in 20-liter pots lined with 1.5-mil polyethylene liners. The vermiculite, prior to planting, had been tamped by jarring the pots lightly on the concrete floor after watering thoroughly; the pots then were refilled before planting with dry vermiculite. The seedlings as they grew were gradually thinned to two plants per pot. Drainage holes in the polyethylene liner and pot were provided at the bottom of each container for adequate flushing of water and nutrients. After planting, the seeds and plants were watered daily with one-half strength Hoagland solution (3) modified to include 0.5 m*M* NaC1. The nutrient solution was prepared with low salt tap water and commercial grade salts. Detailed cultural procedures used have been previously outlined (12).

Plants from the time of planting to harvest were grown in controlled environment chambers, with inside dimensions of 127 by 249 by 137 cm. Night temperatures of 2, 8, 14, 20, and 26°C for 8 hours and a common day temperature of 20°C for 16 hours were used. A temperature pattern for the 20/2°C (day/night) temperature cycle is given in Fig. 1. Air temperature was measured and controlled on the return air of the chamber and maintained at ± 0.5°C of the desired temperature.

Illumination consisted of thirty 244-cm cool-white VHO fluorescent lamps, interspaced equally with twenty-two 60-W extended life incandescent lamps. Fluorescent and incandescent lamps were replaced as needed to maintain illumination at either 3,000 ft-c or 3,400 ft-c.

A single growth chamber was used for each combination of day/night temperatures. Equal illumination was maintained among the chambers by adjusting plant distances from the lamps according to periodic readings taken with a Weston Model 756 sunlight illumination meter. At the early stages of growth, illumination was maintained at 3,000 ft-c at plant height, but as the plants developed and grew taller the illumination was increased to 3,400 ft-c.

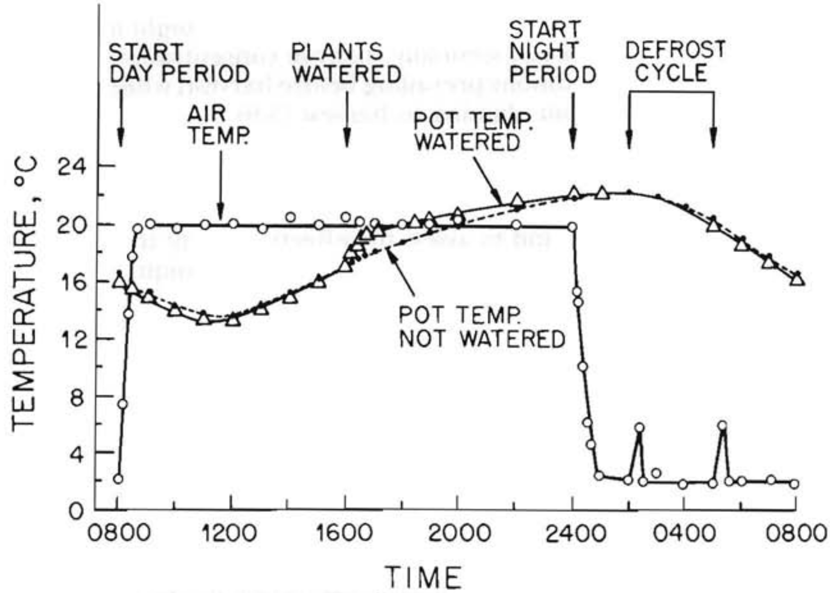

Figure 1.—Temperature pattern of ambient air and pot for the 20/2°C (day/night) temperature cycle.

In order to include five night temperature conditions with three available growth chambers, the experiment was conducted twice: first at 8, 14, and 20°C, and later at 2, 20, and 26°C. The 20°C condition served as the standardized control for comparing the results for the two trial runs.

At the start of an experiment each chamber contained thirty-two 20-liter pots placed on a platform in a 4-row by 8-column pattern. Pots were turned so that the plants were positioned diagonally to the column and row for maximum space utilization by the plant canopy.

Due to the light output characteristics of fluorescent lamps and the geometry of the chamber interior, less variation in plant growth was observed in a variability trial across the lamps than along their length. Therefore, column integrity across the width of the growing area was maintained. The experimental design used for the initial 5 weeks of growth was a 4 by 4 Latin Square replicated twice, with columns 1 to 4 and 5 to 8 forming the two squares. For each harvest, eight pots, one from each of the eight columns of the two Latin Squares in a chamber, were removed at random. The three pots remaining in a column after the first harvest were respaced within the column, forming three rows of eight pots, with equal canopy spacing per pot. After each harvest the eight pot rows had one less row for the following 4 weeks of growth. At the final harvest each chamber had a single row of eight pots along the center of the chamber.

Plants were harvested at 5, 9, 13, and 17 weeks after planting. Fresh weights of tops, blades, and storage root were taken on a pot basis. All fresh material from the tops was dried in a forced draft oven maintained at 70°C and weighed oven-dry. Old leaves were removed as required during the growing period and weighed after drying in the oven. These values were included in the total dry weight of tops. Pulp from the storage root was obtained with a Kiel rasp. Samples of pulp, 26.0 g each, were placed in small polyethylene bags, frozen immediately with dry ice, and analysed later for sucrose. Sucrose in the pulp was determined by the hot digestion procedure (1).

Results

Standardized environment

The results for the growth and development of sugarbeet plants under the standardized conditions of a plant growth chamber are presented in Table 1 for three trial runs. The degree of variability, as measured by the coefficient of variability (C.V.), depends on the measurement made and only slightly on the age of the plant. The lowest variability is associated with the sucrose determination and the highest with the sucrose stored, the calculated product of the sucrose percentage and root weight. Root weight has the next highest variability, followed by the total dry and fresh weights of the tops.

An inspection of the data in Table 1 indicates that growth differences related to plant age are relatively large and those between trials within an age category are, as expected, relatively small. The degree of variability from trial to trial is measured by the F-value, the ratio of the mean square among trials to that of error (Table 1). A small mean square for error or a large mean square among the trials will give a large F-value; the converse is true for a small F-value. For example, differences in sucrose percent among the treatments within a growth period are relatively small, and yet the observed F-values are quite large, mainly because of the very low mean square for error. Conversely, the F-values for sucrose stored are low and non-significant, mainly because of the high error term. Consequently, considerable caution must be exercised in the interpretation of results within an age group for different chambers operated simultaneously or for the same chamber operated at different times. Nevertheless, good reproducibility of results can be obtained over a 17-week period so that the effects of climate, *e.g.*, night temperature on beet root weight, percent sucrose, sucrose stored, and top growth, can be determined with confidence for sugarbeets growing rapidly in the completely controlled environments of plant growth chambers.

Night temperature

The effects of night temperature on the growth and development of sugarbeet plants cultured in plant growth chambers under

Table 1.—Variability of beet root weight, percent sucrose, sucrose stored, fresh weight of tops, and total dry weight of tops for three trials in growth chamber at 20/20°C day/night temperature.

	Growth period, weeks	Trial* 1	2	3	Mean	L.S.D., 5%	F value	C.V.
Beet root,	5	38	56	54	49	7	14.98	14.0
g	9	311	300	295	302	n.s.	0.19	18.0
	13	880	845	863	863	n.s.	0.16	14.1
	17	1610	1380	1600	1530	n.s.	2.16	16.4
Sucrose,	5	3.9	3.3	3.6	3.6	0.3	6.94	8.6
%	9	7.5	7.6	7.0	7.3	0.3	9.19	3.9
	13	9.9	9.0	9.3	9.4	0.3	18.33	3.4
	17	10.7	10.3	11.0	10.7	n.s.	2.43	5.0
Sucrose stored,	5	1.5	1.8	2.0	1.8	n.s.	3.40	20.8
g	9	23.3	22.8	20.7	22.3	n.s.	0.78	19.7
	13	88	76	80	81	n.s.	1.43	16.7
	17	174	143	176	164	n.s.	3.01	18.3
Fresh tops,	5	289	364	341	331	35	10.76	10.0
g	9	1210	1180	1200	1200	n.s.	0.16	8.3
	13	1400	1610	1740	1580	150	12.18	8.6
	17	1390	1670	1640	1570	160	8.12	9.5
Total dry tops,	5	17	20	20	19	n.s.	3.43	12.1
g	9	80	82	83	82	n.s.	0.33	11.0
	13	143	137	160	147	14	6.87	8.9
	17	180	187	205	183	n.s.	3.09	10.7

Required F values for the 5 and 1% levels are 3.74 and 6.51, respectively.
*Mean value of eight replications.

fluorescent-incandescent lighting of 3,400 ft-c for 16-hour photo periods at days of 20°C (Tables 2 and 3, Figure 2) are similar to those observed in the Phytotron for 8-hour photoperiods under glass with natural lighting from 8 a.m. to 4 p.m. Maximum fresh weight of tops in the present study occurred at night temperature of 20 to 26°C after 5 weeks of growth, at 14 to 20°C after 9 and 13 weeks of growth (Table 2), and at 14°C after 17 weeks of growth (Figure 2). On a dry weight basis, top growth was considerably lower at 2°C and only slightly lower at 26°C.

Table 2.—Effect of night temperature on top growth of sugar beets grown at 20°C day temperature.

Night temperature, °C	Fresh tops growth period, weeks				Total dry tops growth period, weeks			
	5	9	13	17	5	9	13	17
	g/2 plants							
2	151	1002	1291	1039	11	76	139	165
8	262	1102	1486	1451	18	84	137	180
14	270	1179	1621	1712	17	78	141	189
20	331	1198	1582	1565	19	82	147	191
26	330	1084	1338	1574	19	76	128	183
L.S.D., 5%	31	75	141	141	2	7	12	13

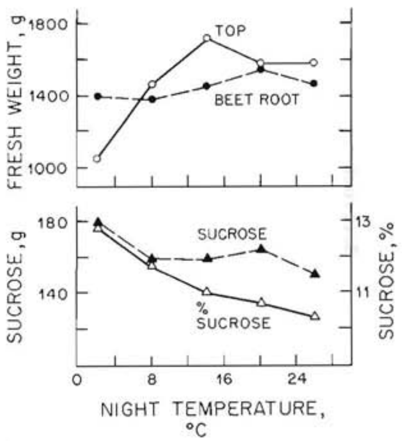

Figure 2.—Effect of night temperature on top and root growth and sucrose in sugar beets at the 17-week interval.

Beet root size was not affected significantly by night temperature at the 9- and 17-week harvests (Table 3), even though root size was smaller at 2°C at the 5- and 13-week harvests, and at 26°C for the

Table 3.—Effect of night temperature on beet root weight, sucrose percentage, and sucrose yield of sugarbeets grown at 20°C day temperature.

Night temperature, °C	Beet root growth period, weeks				Sucrose growth period, weeks				Sucrose growth period, weeks			
	5	9	13	17	5	9	13	17	5	9	13	17
	g/2 plants				%				g/2 plants			
2	19	252	645	1392	4.2	8.0	11.3	12.8	0.8	20.4	73	179
8	39	277	717	1367	4.5	8.0	10.3	11.7	1.8	22.2	74	159
14	42	256	743	1439	4.0	6.9	9.1	11.0	1.7	17.7	68	158
20	49	302	863	1527	3.6	7.3	9.4	10.7	1.8	22.3	81	164
26	49	244	651	1446	3.4	7.3	8.8	10.3	0.9	17.8	58	150
L.S.D., 5%	6	43*	85	112*	0.3	0.3	0.3	0.4	0.3	3.6	11	15

*F-test, not significant at the 5% level of significance.

13-week harvest. These effects of night temperature did not carry over to the final 17-week harvest when the plants did not differ significantly in root size (Table 3).

Sucrose percentages of the beet roots for the four harvest periods increased with decreased night temperature. The increase in sucrose percentage at 2°C over that at 26°C was 0.8 and 0.7 percentage units for the 5- and 9-week harvests and 2.5 units for the 13- and 17-week harvests. Sucrose percentages also increased with plant age over the 17-week period, with the largest increase of 8.6 percentage units taking place at 2°C. Smaller increases of 7.2, 6.0, 7.1, and 6.9 percentage units took place at 8, 14, 20, and 26°C, respectively.

The increases in sucrose percentage due to low night temperatures compensated for the loss in root size that took place at 2°C in the 13-week harvest, and more than compensated for it at the 17-week harvest. These plants contained more sucrose than those at higher night temperatures. The combined loss in root size and lower sucrose percentage at 26°C resulted in lower sucrose yields for these plants at the harvest periods.

Discussion

The present results indicate that the slow growth and development of sugarbeet plants observed in the early Phytotron studies with fluorescent-incandescent lighting (7) was caused by the low intensity of light at 840 ft-c, rather than by its quality. In the Phytotron studies, a nearly full complement of leaves was produced in an 8-hour photo period but root size was very small and sucrose concentration was only about 3%. When the photo period was extended to 16 hours, a ten-fold increase in root size was observed, but it still fell short of that in sunlight, although sucrose concentrations were now equal. In the present study in plant growth chambers, with a similar kind of lighting and cultural technique, but with the light intensity increased to 3,400 ft-c, top growth, root size, and sucrose concentration equalled or exceeded earlier and subsequent studies in full sunlight and natural day length. Also, the present results at the 5-, 9-, 13-, and 17-week growth periods were found to be reasonably reproducible so that plants could be grown under standardized conditions and the results used as a convenient point of reference for comparative purposes. For example, with only three plant growth chambers available for use in the present study, a comparison of five night temperatures at a common day temperature of 20°C was made, with the first run of plants at 8, 14, and 20°C, followed by a second run at 2, 20, and 26°C. The results for 20°C served as a common reference point in the two runs, and later, in subsequent runs as well. A systematic study of climatic factors affecting plant growth can supply basic information for modelling sugarbeet growth either graphically by conventional methods or more elegantly with the aid of a computer.

The nature of the low night temperature effect is of special interest since the increase in sucrose concentration took place during the 8-hour dark period without a significant decrease in root size as observed earlier with 16-hour dark periods (7). Although natural daylight was used in the earlier study, relative comparisons indicate that short periods of low night temperature are adequate to initiate the sucrose accumulation process. Assuming that the foliage temperature is rapidly influenced by surrounding environmental conditions, and that the temperature-sensitive mechanism controlling sucrose accumulation is located in the foliage portion of the plant, then top temperature becomes an important environmental variable to consider for increasing the sugar content of the beet root. Here further research under controlled environmental conditions is needed for a better understanding of the night temperature effect on the accumulation of sucrose in beet roots.

Summary

Sugarbeets (*Beta vulgaris* L. var. MS NB1 x NB4) was grown under controlled climatic conditions to determine within-treatment variability and the effect of night temperature on sucrose concentration, sucrose yield, and vegetative growth. Night temperature covered the range of 2 to 26°C. Day temperature was set at 20°C and fluorescent-incandescent illumination at 3,400 ft-c for photo periods of 16 hours. Plants were grown in vermiculite, watered daily with one-half strength Hoagland solution modified to include 0.5 m*M* NaC1, and harvested after 5, 9, 13, and 17 weeks of growth. The plants grew exceedingly well under these conditions and served admirably as test plants.

Surcrose concentrations increased with decreasing night temperature, with a maximum sucrose concentration at 2°C for all growth periods and a maximum sucrose yield at 2°C at 17 weeks only. Beet root weight was depressed by a night temperature of 2°C at 5 weeks and at 26°C at 17 weeks. Maximum fresh weight of tops was obtained at 14°C night temperature, with greatly reduced weight at 2°C. These effects of night temperature are similar to those obtained earlier in sunlight, indicating that artificial light can substitute for sunlight in growth studies with sugarbeets. Since the plant growth chamber results are readily reproducible, basic knowledge about sugarbeets and climate can be developed rapidly for use in solving problems associated with beet sugar production.

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