

CONTRIBUTIONS OF SUNLIGHT TO GREENHOUSE ROSES

by

Edward L. Chandler

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
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Department of Horticulture

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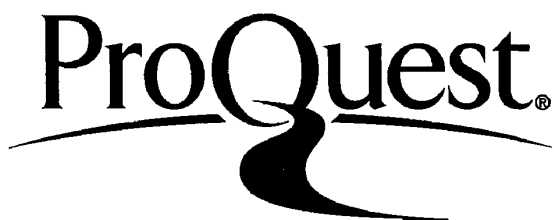
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AN ABSTRACT

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Donald C. Little

Three plantings of roses were made to study quantitative and qualitative effects of light intensity on the growth of Better Times roses. Growth measured by elongation and fresh weights of all plant material produced was correlated to light intensity by means of recording light intensity over plants growing in shade houses constructed of cloth and designed to allow 20, 35, and 58 percent incident radiation to be available. Total radiation as well as the reduced radiations was measured by means of a Speedomax recorder. Soil surface was covered with a highly reflective "frit", with a less reflective "frit", and with soil.

Carbohydrate analyses were made of tissue subjected to three levels of radiation. Sections of leaves were collected for an anatomical study of rose leaf development resulting from various quantities of light.

Total growth of the rose plants was reduced by decreases in light intensity. Reduction to 20 percent total solar radiation reduced growth to an extreme degree, and appeared to be near the minimum light intensity for growth. Light of the magnitude of 58 percent of full radiation allowed growth to be only slightly reduced. Judging from growth produced it appeared as if plants growing in 58 percent radiation had been supplied with almost as much light as was ideal for maximum growth. Any reduction of light below 58 percent of the total radiation resulted in rather sharp decrease in total growth.

Surface covers which increase the amount of reflected light seldom increased plant growth. Plant growth response from such indirect light was noted when radiation was extremely high and then only if plants were very small. This finding was thought to be related directly to the amount of shading of surfaces by plant foliage.

Carbohydrate analysis revealed a great increase in total sugars in leaf and stem tissue during periods of intense heat and extremely high radiation. Translocation, respiration or utilization of carbohydrates were found to occur in great quantities after periods of dark or cloudy weather.

Leaf structure was greatly modified by the intensity of light available to various plants. Heavy shading resulted in the development of very thin leaves with palisade cells of much less depth than those of leaves subjected to high radiation; total chlorophyll content appeared to be much greater in leaves obtained from these plants.

This paper is supplemented by eleven tables and nine figures.

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INTRODUCTION

Severe reduction in growth of greenhouse roses during periods of low solar radiation has been a perennial problem in the state of Michigan. Growers greatly concerned about this problem have given little thought to light needs in summer. The effects on the growth of greenhouse roses from radiation during the summer, especially during periods of high temperature, has not been investigated, but during periods of extremely high radiation it has been the commercial practice to apply external shade to glass in the greenhouse. This shading has reduced the impinging light and the temperatures within the greenhouse. The quantitative effect of this reduction of light on the total growth of roses has not been thoroughly studied. Data involving only number of flowers or shoots, as well as records of sunlight hours, are of limited value. Quantitative measurements of the solar radiation have rarely been accompanied by suitable quantitative growth measurements.

Modification of rose leaves and their carbohydrate status as a result of varying light intensities have not been thoroughly investigated and especially is this true for the high temperature period during the summer months. The effects of leaf shading and of diffused light on the growth of rose plants have received little study.

This investigation, therefore, was designed to permit:

- (1) the quantitative correlation of light intensity and growth,
- (2) the evaluation of varying amounts of diffused light on the growth of young and old rose plants,
- (3) the determination of thickness of leaves produced under various quantities of light, and
- (4) the analyses of the carbohydrate status of tissue from rose plants subjected to various quantities of solar radiation.

LITERATURE REVIEW

Investigations involving plant growth and light have been directed toward: light quality (Went, 1941), light intensity (Davis and Hoagland, 1928), and light duration (Hamner and Bonner, 1939). Many studies have been made on the effects of light on specific physiological processes. Some of the more significant results have been published by Blackmann and Matthaei, 1905; Sayre, 1928; Shull, 1936; and Emerson and Lewis, 1939. Much research has demonstrated the effect of light on plant growth (Shirley, 1929; Porter, 1936; Went, 1941).

Light Recording

Continuous attempts have been made to increase the accuracy of light recordings. Gourley and Nightingale (1921) employed photographic paper to indicate radiation values. Using a Macheth Illuminometer, Steinbauer in 1932 periodically adjusted intensities of artificial light. Attempts have been made to obtain a daily radiation value from a limited number of periodic readings (Muncie, 1917; Heinicke and Hoffman, 1933; Christopher, 1934; Gray, 1934). The necessity of having more accurate light readings has stimulated the development of various types of solar radiation recorders (Post and Nixon, 1939; Crabb, 1950; Hemphill and Murneek, 1950).

Complete works dealing with light measurement are available in English (Duggar, 1936; DeVore, 1938). Radiant energy nomenclature had been considerably standardized by Withrow (1943) and in 1950 a thorough compilation of the literature dealing with recording of solar radiation was made by Crabb.

The problems produced by the continuous variation of intensity and quality of solar radiation were recognized by Shirley in 1931.

Photoperiod and Quality of Light

Light quality has received much attention in recent years (Popp, 1926a; Emerson and Lewis, 1939; Went, 1941). Ultra-violet light has been found to have little effect on plant growth in general (Popp, 1926a; Pfeiffer, 1928; Funke, 1931; Laurens, 1933; Johnston, 1938). The visible spectrum was found to be necessary for normal growth, and the absence of light below 529 millimicrons reduced the growth of many species of plants (Popp, 1926a). Emerson and Lewis (1939) studied quantum efficiency of photosynthesis with segregated wave lengths of the visible spectrum. The quantity of chlorophyll developed in seedlings has been shown to vary in plants grown under light of various wave lengths (Sayre, 1928).

Information contributing to the effect of photoperiod is voluminous (Garner and Allard, 1920; Deats, 1929; Poesch, 1931; Hamner and Bonner, 1939). In 1927 a classical paper

by Scarth demonstrated the influence of light on the opening and closing of stomata in various plants.

Leaf temperature as influenced by light intensity has received considerable attention. Shull (1936) has made measurements of the speed of thermal adjustment in direct and diffused light. Wallace and Clum (1938) found the maximum heating above air temperature to be four, and the maximum cooling below air temperature to be seven degrees Centrigrade.

The relationship between light intensity and the potential for nutrient absorptions was investigated by Davis and Hoagland (1928). Alteration of chemical composition of plants by light intensity has been studied by Blackman and Matthaei (1905a), Kraybill (1923), Nightingale (1933), Street (1934), McCool (1935), Mitchell (1936), and Porter (1936).

The growth response of plants to varying nutrient levels in relation to different quantities of light has been reported by Gast (1937) who used conifer seedlings and found a direct correlation of growth response with increasing nitrogen when light intensity also increased. White (1905) using Lemna, found nitrate concentrations for optimum growth needed to be increased with increasing light intensity. This finding has been substantiated by Steinbauer (1932), and Post and Howland (1946).

Photosynthetic Efficiency

By measuring the increase in dry weight, the photosynthetic efficiency of Rosa sp. (Laurie and Witt, 1941), Lycopersicum esculentum (Porter, 1936), and Dianthus caryophyllus (Holley, 1942) has been correlated with various light intensities. Black and Matthaei (1905) have shown that with low light intensity the rate of photosynthesis is almost directly proportional to the light intensity. Many workers have reported that increased light intensities served to increase growth of higher plants (Rose, 1913; Shantz, 1913; Popp, 1926a; Garner and Allard, 1920). Shirley (1929) divided a large number of species into "shade" and "sun" plants. He found that at low light intensities the dry weight was almost proportional to the light intensity up to 20 percent of full summer radiation. At higher light intensities this correlation did not persist. "Shade" plants showed more rapid decrease in growth than "sun" plants as a result of their less efficient use of light at lower light intensities. Lubimenko (1908), Harder (1921), and Boysen-Jensen (1929) were in agreement with these results. Lubimenko, however, found the dry weight of Helianthus sp. to increase directly with the increase in light intensity up to full sunlight.

Combes (1910) found the optimum light intensity for the production of dry matter in plants to increase with increasing age of the plant. It is interesting to note that Heinicke

and Hoffman (1933) stressed the shading effect of leaves with increasing age of plants. The importance of diffused light as related to shaded leaves was observed by Gray (1934).

Fifty foot-candles of continuous light were found to be minimum for growth of Fraxinus pennsylvanica (Steinbauer, 1932). Shirley (1929) considered forty foot-candles of light as the minimum for existence with all species involved except Helianthus. Fragaria was found to produce flowers at 500 foot-candles of light but required 1500 foot-candles to produce fruit (Hedricks and Harvey, 1923).

Many observations have been recorded involving light intensities under varying conditions. Christopher (1934) used an Illuminometer to take periodic readings of light striking leaves in various locations on trees. No leaf on the north side of the tree was reported to receive over four percent of the total light of the day. Readings recorded during the summer months have been found to exceed 10,000 foot-candles (Boysen-Jensen, 1929). Light was suggested as a factor influencing the number of new lateral shoots produced by rose plants in varying locations in the greenhouse (Fischer and Kofranek, 1949). Light intensity controlled by position in the greenhouse bench was found to influence the yield and quality of roses (Rosa sp.) and Dianthus caryophyllus (Weinard and Decker, 1930). In a forest of deciduous trees light readings as low as 0.16 percent of total radiation have been recorded by Salisbury (1918).

Artificial reduction of light has been employed by many workers in an attempt to measure growth response of plants to varying light intensities (Shantz, 1913; Kraybill, 1923; Shirley, 1929; Clements and Long, 1934; Gray, 1934; Mitchell, 1936).

Maximum growth of many species was obtained with 35 and 58 percent transmission of light during June and July, but during August and September maximum growth was obtained with full radiation (Arthur and Stewart, 1931). Shading of plants was reported to have no effect on the number of non-flowering shoots produced by rose plants (Kamp, 1948). Hubbell (1934) found a decrease in both flowering and non-flowering shoot production of the rose with decreases in illumination. Lower flower production was obtained by shading Dahlia pinnata but no significant difference was obtained with shading of Callistephus (Batson, 1933).

Analysis of tissue collected from plants grown under different light intensities has been made for various constituents. Carbohydrate, nitrogen, and base element relationships of Pisum grown under various light exposures has been reported by Street (1934). Deats (1925) analyzed Capsicum frutescens and Solanum esculentum for starch content after different quantities of light had been supplied to the plants. Total nitrogen, sucrose, starch and dry matter were determined for peach and apple trees which had been shaded with cheesecloth (Kraybill, 1923). Total sugars were found to

decrease in rose tissue when shading was applied (Kamp, 1948).

The effect of light intensity on quality of growth of stems and leaves of various plants is of interest. Deats (1925) found the height and diameter of the stems of Lyopersicum esculentum and Capsicum frutescens plants to be directly proportional to the quantity of light. Shirley (1929) working with numerous species of plants correlated type of growth habit with quantities of light available. Fresh weight of tomato tissue has been shown to have a direct correlation with light intensity (Porter, 1936).

Gray (1934) related fruit set of sour cherry to light intensity. Maximum flowering and fruit set was found to be considerably delayed by reduced light. Many species failed to set fruit with 8 percent total radiation (Shirley, 1929). The number of roses produced were in direct relation to the number of sunlight hours (Muncie, 1917).

Modification of Leaf Structure

Variations in leaf structure caused by varying environmental factors have been reported by Clements (1904), Hanson (1917), Penfound (1932) and Pickett (1942).

Early work by Hanson (1917) showed difference in leaf structure of Acer and Quercus caused by different light intensities. Structural modifications throughout the plant in contrasting light intensities was observed by Penfound (1932). Pickett (1934) concluded that several factors enter

into and govern the rate of photosynthesis in green leaves and that probably one of them is the area of the surfaces of the exposed cell walls bordering the intercellular spaces. In 1938, Pickett published results of experiments designed to determine the amount of chlorophyll in Wealthy and York Imperial varieties of apples as well as the influence of the chlorophyll content and the extent of intercellular space on the amount of photosynthetic activity. Pickett and Kenworthy (1939) found that the depth of palisade mesophyll maintained a definite relationship to the ratio of the external and internal exposed cell surfaces.

EXPERIMENTAL PROCEDURE

First Experiment

Experimental Design

On May 5, 1950, four hundred "own-rooted" rose plants of the variety Better Times were planted in ground benches in the plant science greenhouse at Michigan State College. A six-inch depth of Brookston sandy loam, relatively low in organic matter, was placed in the bench and to this soil was added one-quarter well-rotted manure and four pounds of superphosphate. Nine plots of 24 plants per plot were replicated twice. Most buds had begun to expand on the plants since they had been cut back. Bouyoucos plaster blocks to be used as a guide for moisture content were placed in each plot.

Three types of surface cover were provided: inert white "Agricultural Frit"* which in bright sunlight reflected approximately 1100 foot-candles of light eight inches above its surface; black "Agricultural Frit" which reflected approximately 300 foot-candles; and a thin layer of Brookston sandy loam which reflected approximately 200 foot-candles of light (Figure I). A two-inch layer of glass wool was placed beneath each surface cover to minimize

*Agricultural Frit is the trade name of a fused silica product manufactured by the Ferro Enamel Company, Cleveland, Ohio.

Figure I. Greenhouse bench in foreground showing roses planted
in soil with a surface cover of:

a) white "frit"

b) soil

c) black "frit"



a

b

c

soil temperature variations (Figure II).

A shrimp netting and a camouflage netting were placed upon light wooden frames to form shade houses for reducing the amount of direct radiation. Light was reduced approximately 75 percent by the camouflage netting and approximately 55 percent by the shrimp netting.

The plants were grown in the usual commercial greenhouse manner (Figure III). Periodic applications of fertilizers were made to adjust the nitrate level of the soil to approximately 25 ppm, phosphate 5 ppm, and potassium 30 ppm, as measured by the Spurway method. Water was supplied by sub-irrigation when the level was found to be below 50 percent available moisture. Night temperature was maintained at 68° F. Roses were cut at the commercially recommended cutting stage (petals beginning to unfold), weighed and measured immediately (Figure IV).

Collection of Data

Flowers and attached stems were cut to the length required to leave two five-leaflet leaves on the branch. Length and weight of stems were recorded immediately after cutting. A measurement was made to total monthly increment of growth by each plant. After three and one-half months of growth, existing weights and lengths of the plants were obtained. Roots were washed free of soil and weighed separately. Light intensities, obtained by means of a

Figure III. Rose plants recently planted in ground bench with surface cover of soil.

Figure II. Rose plants recently planted in soil in ground bench showing

- a) planting soil
- b) layer of glass wool
- c) white "frit" cover



Figure IV. Method of measuring, weighing, and recording growth data showing how cards were clamped to stems and returned to file.



Weston light meter, were variable and supplied only relative values of direct and reflected light. Consequently, they were used merely as a guide for selecting suitable fabrics for shading the plants in the second experiment.

Second Experiment

Experimental Design

On September 16, 1950, four hundred dormant roses, which had been propagated by budding, were planted as in the previous experiment except that the soil cover of black frit was omitted. Six plots of 24 plants per plot were replicated twice with two rows of border plants between each plot. The plot arrangement was made as shown in the experimental design (Figure V).

Cheesecloth replaced camouflage netting used in the previous experiment to allow more light to reach the plants. Growth and production records were made for all treatments as before.

Collection of Data

In order to obtain growth measurements from older plants, this experiment was continued for two years. The plants were pruned severely in May, 1951, and all flower buds removed until September 1, 1951. Five and one-half months later all plants were removed for a comparison of weight produced over a period of 17 months.

EXPERIMENTAL DESIGN

WHITE FRIT 7		SOIL 1	HEAVY SHADE
SOIL 8		WHITE FRIT 2	
WHITE FRIT 9		SOIL 3	FULL RADIATION
SOIL 10		WHITE FRIT 4	
WHITE FRIT 11		SOIL 5	LIGHT SHADE
SOIL 12		WHITE FRIT 6	

Figure V.

Third Experiment

Experimental Design

On March 15, 1952, two hundred roses of the variety Better Times, propagated by budding, were planted as before. This provided six plots with 32 plants per plot. A previously calibrated and tested Speedomax recorder was installed using photovoltiac cells as receiving bodies for the solar radiation. In addition precision drop coils were used to allow calibration of the recorder. One cell was mounted in a horizontal upright position to measure the intensity of visible incident radiation in each of the three light intensities. Two additional cells were mounted in an inverted horizontal position to measure reflected light in full sunlight 12 inches above the soil covers.

Collection of Data

Leaf and stem tissues were collected before sunrise and after sunset on June 13, 14, and 15, 1952, for analyses of total sugars. All tissue was removed from flowering branches in the same stage of development. After having been dried in an oven at 100° F for three days the material was ground in a Wiley mill and stored in a desiccator. After re-drying the tissue, analyses were made by a modified Munson-Walker gravimetric method. The remaining tissue from the samples was dried and ashed by heating at 550° C for 12 hours.

During November one hundred mature five-leaflet leaves were collected from the top, middle, and base of plants in each of the six treatments. Tissues thus obtained were killed with F.A.A. (5 cc formalin, 5 cc acetic acid, 90 cc 95% alcohol) and embedded in paraffin. Cross-sections, 10 micro in thickness, were stained with Conant's quadruple stain. Leaf thickness and palisade depth of one hundred leaves collected from each treatment were measured by means of an ocular micrometer.

The terminal leaflets from mature leaves in the upper regions of the plant were found to be representative of the leaflets on the plants in a given treatment.

Fifty free-hand transverse sections were made from leaves collected during the month of May, 1952, from four treatments: full sun and heavy shade with frit and soil covers on each. Measurements were obtained as before.

On October 15, 1952, all plants were removed and final weight and elongation records were obtained as in the previous experiments.

EXPERIMENTAL RESULTS

Experiment One

Greenhouse temperatures higher than 100° F were recorded often during the summer months when light intensities within the unshaded greenhouse exceeded 10,000 foot-candles, the limits of a Weston light meter. All of the rose plants continued to grow and produce flowers in spite of these extreme conditions. Leaves of plants in 20 percent solar radiation were extremely thin and pale green. Many of the branches were weak and not held erect; flowers were small and pale in color. In comparison, plants which were grown in the 70 percent solar radiation were of better quality than those grown in the 20 percent, but not as good as those grown in the full radiation. Substantially more flowers were produced on plants growing in full radiation than on plants subjected to reduced light. No obvious differences were found between number of flowers produced on plants in the 20 percent and the 70 percent radiation (Table 1).

Surface cover appeared to have little influence on flower production in either of the reduced solar radiation treatments (Table 1). The number of flowers produced by young plants under full radiation was greater when the soil was covered by white "frit". No other apparent trends were

TABLE 1
 NUMBER OF FLOWERS PER TREATMENT
 (48 Better Times rose plants grown 105 days)

Treatment	Percent radiation		
	100	70	20
Soil cover	205	126	123
Black "Frit" cover	203	125	114
White "Frit" cover	290	130	112

established in relation to types of soil cover as an influence on plant weight.

Combined weight of flowers cut, final root weight, and final top weight (Table 2) substantiate observations of flower quality and total number of flowers produced. All weights were much higher for plants grown in full rather than in 20 percent solar radiation. No obvious differences in weight were attributed to the type of soil cover except a substantial increase in flower weight from plants grown in full radiation with a surface cover of white "frit".

Experiment Two

The plants of this experiment were removed from the beds for final weights and measurements on April 15, 1952, 17 months after planting. Weight of plants indicated a direct relationship to intensity of light. This was consistent for root weight, wood removed in cut back, top weight, flower weight, and consequently, total plant material produced (Table 3).

The influence of direct solar radiation was much more pronounced than that of reflected light. Reductions in weight of roots, flowers, and top were greater as a result of reduced radiation than as a result of type of surface cover where reflected light was altered. Those increases in weight brought about by reflected light were greater in the full radiation plots than in the shaded plots (Table 3).

TABLE 2

FINAL WEIGHT OF PLANTS

(Weight in grams for 48 Better Times rose plants per treatment)

Light	Surface cover	Flower	Top	Root	Total
Full radiation	Black "Frit"	3156	2462	2658	8276
	White "Frit"	4019	2913	2920	9852
	Soil	2916	2174	2712	7802
20% radiation	Black "Frit"	1491	1375	1658	4524
	White "Frit"	1295	1469	2070	4834
	Soil	1886	1608	1598	5092

TABLE 3

TOTAL WEIGHT OF PLANT MATERIAL

(Grams per plant over a 17-month period)

Treatment	Surface cover	Top	Root	Flower cut		Cut back in summer	Total
				1951	1952		
Full radiation	Frit	144.9	91.7	89.9	95.09	59.5	481.2
	Soil	134.4	67.5	68.4	99.30	53.6	423.1
Light shade	Frit	112.9	57.1	58.8	66.38	52.6	347.8
	Soil	110.4	55.9	62.7	62.81	46.5	338.3
Heavy shade	Frit	103.0	52.8	41.8	65.07	42.9	305.5
	Soil	84.1	51.4	31.9	47.99	35.0	250.5

The total elongation of the plants during a comparable five-month period for 1951 and 1952 is contrasted in Table 4. Data obtained for 1951 are for three-year-old plants starting from dormancy, whereas data for 1952 are for the same plants which had been cut back and flower buds had been removed for approximately two months. Total growth as estimated by total terminal elongation for 1952 indicated three times the amount of growth obtained in 1951. Type of surface cover did not apparently greatly alter the total amount of elongation during this period. Values obtained for direct radiation and total elongation, however, indicate a direct correlation of growth with quantity of light.

Table 5 demonstrates the number of flowers produced, weight per flower, and the total flower weight produced on all of the plants in each treatment for a five-month period. Weight per flower and number of flowers were much greater in the second year and were substantially in the full radiation than when radiation was reduced. Differences as a result of soil cover were not consistently similar.

Experiment Three

As in experiment two, surface cover did not apparently influence total elongation but total weight of plant material produced was increased with increased light intensity (Figure VI). Reduction of light by 42 percent shading did not appreciably alter the total elongation or weight of material

TABLE 4

LINEAR GROWTH AS INFLUENCED BY LIGHT INTENSITY AND SURFACE COVER

(Centimeters for 32 Better Times rose plants per treatment over a period of five months)

Light	Surface cover	Vegetative linear growth		Reproductive linear growth		Total	
		1951	1952	1951	1952	1951	1952
Full radiation	White "Frit"	4046	11688	4157	11257	8203	22945
	Soil	4077	11174	3371	11666	7448	22840
Light shade	White "Frit"	3572	12050	3389	8977	6961	21027
	Soil	3830	11263	3279	8462	7109	19725
Heavy shade	White "Frit"	3918	10218	2476	9497	6394	19715
	Soil	3053	9636	1931	6737	4984	16373

TABLE 5

QUANTITY AND QUALITY OF FLOWERS

(32 Better Times rose plants per treatment for a period of five months)

Light	Surface cover	Number of flowers		Weight per flower in grams		Total weight cut in grams	
		1951	1952	1951	1952	1951	1952
Full radiation	White "Frit"	115	265	16.12	17.22	1854	4564
	Soil	94	273	15.48	17.46	1460	4766
Light shade	White "Frit"	96	207	13.94	15.39	1334	3186
	Soil	88	196	14.89	15.38	1308	3015
Heavy shade	White "Frit"	64	203	14.14	15.39	909	3123
	Soil	54	149	12.74	15.46	691	2304

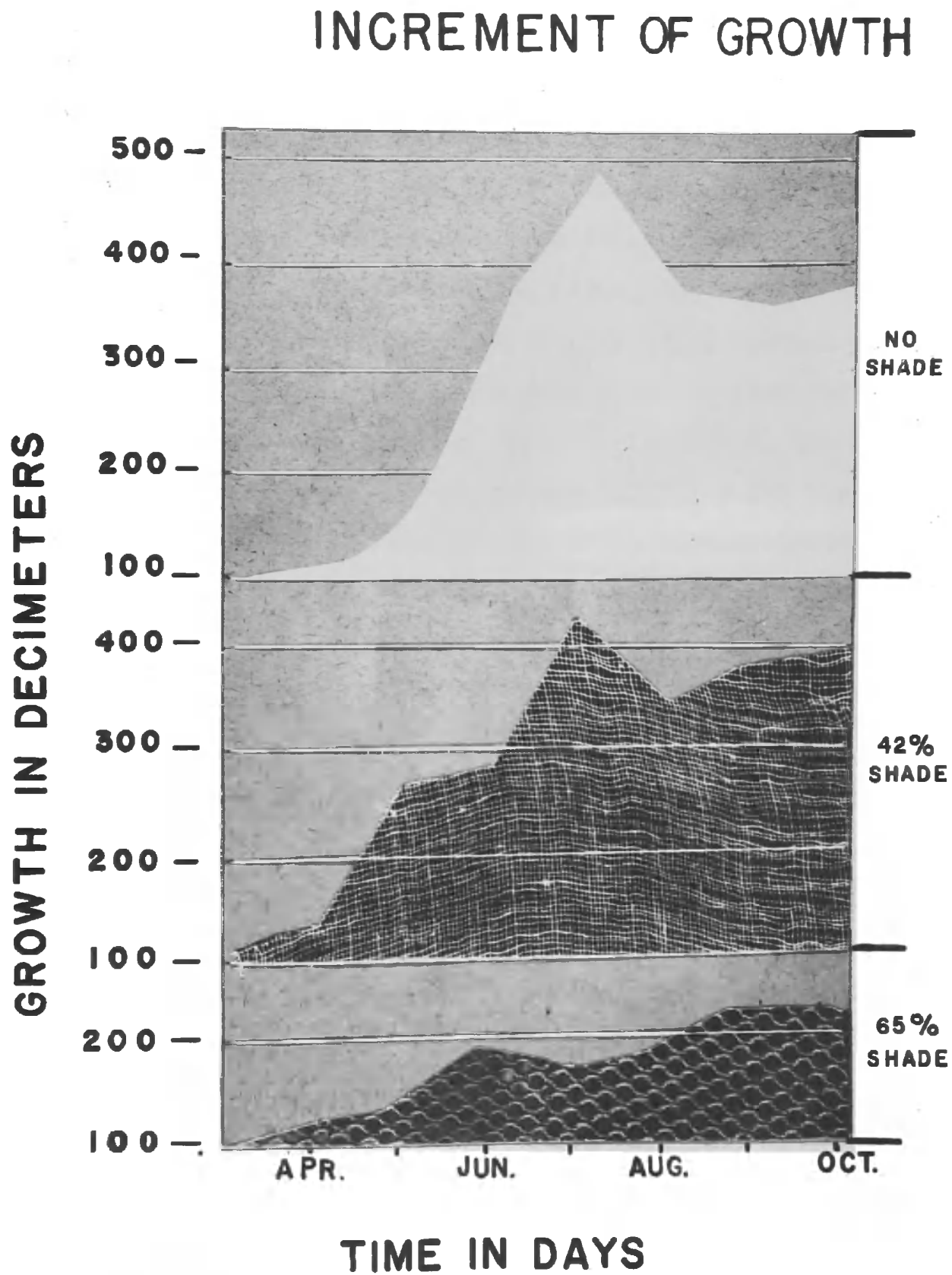


Figure VI.

produced but reduction by 65 percent greatly reduced total elongation (Figure VI, Table 6). Weights of roots, tops, and flowers were greatly reduced by the low level radiation (65 percent shade), whereas, very little reduction resulted from 42 percent shade (Table 7). Number of flowers produced increased with increased radiation (Table 8). Some of the highest light intensities during this summer period of growth occurred during June (Figure VII). Actual percentages of reduction of light were found to vary from month to month and from hour to hour; therefore, the 65 and 42 percent refer to the average reduction for the entire period of the experiment. Table 9 demonstrates the quantities of light available to the plants in the shade treatments as well as full radiation treatments.

Leaf thickness and the depth of the palisade layer indicate no relation between leaf structure and soil surface cover. Positive correlation of leaf thickness and light intensity was found to be highly significant for both full radiation and heavy shade treatments (Table 10). Depth of the palisade layer of cells in the leaf was found to vary positively with the light intensity to a significant degree. Average depth of upper palisade cells, lower palisade cells, and whole leaf were found to vary directly with light intensity.

Intercellular spaces, palisade cells, and spongy mesophyll cells were much smaller in the leaves exposed to

TABLE 6

GROWTH AS INFLUENCED BY LIGHT INTENSITY AND SURFACE COVER

(Centimeters of growth of 24 Better Times rose plants per treatment,
March 15 to October 15, 1952)

	Period ending					
	April 15	May 15	June 15	July 15	Aug. 15	Sept. 15 Oct. 15
<u>Full radiation</u>						
Frit surface	10500	27410	49189	75537	82171	95010 102461
Soil surface	10590	29630	66105	90121	97010	108420 115365
	21090	57040	115294	165658	179181	203430 217826
<u>Light shade</u>						
Frit surface	11370	30090	65468	85592	94191	104268 124020
Soil surface	11670	36420	62319	85994	89330	101364 112740
	23040	66510	127787	171586	183521	205632 236760
<u>Heavy shade</u>						
Frit surface	10625	21901	39528	44905	55934	66140 76350
Soil surface	11350	23645	42645	48996	54937	69638 71187
	21975	45541	82173	93891	110871	135778 147537

TABLE 7

WEIGHT IN GRAMS OF PLANT MATERIAL PRODUCED BY 24 BETTER TIMES ROSE PLANTS
GROWN MARCH 15 - OCTOBER 15, 1952

Light	Surface cover	Beginning	Top	Root	Flower	Total
Full radiation	Fertilizer	1444	2769	1594	4485	7404
	Soil	1512	3011	1958	5282	8739
		2956	5780	3552	9767	16143
Light shade	Fertilizer	1505	2693	1657	4824	7669
	Soil	1522	2877	1719	4407	7481
		3027	5570	3376	9231	15150
Heavy shade	Fertilizer	1522	1468	1020	2291	3257
	Soil	1532	1447	1238	2148	3301
		3054	2915	2258	4439	6558

TABLE 8

YIELD OF FLOWERS AS INFLUENCED BY LIGHT INTENSITY
AND SURFACE COVER(24 Better Times rose plants per treatment
over a seven-month period)

Treatment	Percent radiation		
	100	65	42
Soil cover	356	336	191
White "Frit" cover	379	328	176

Figure VII. LIGHT INTENSITY

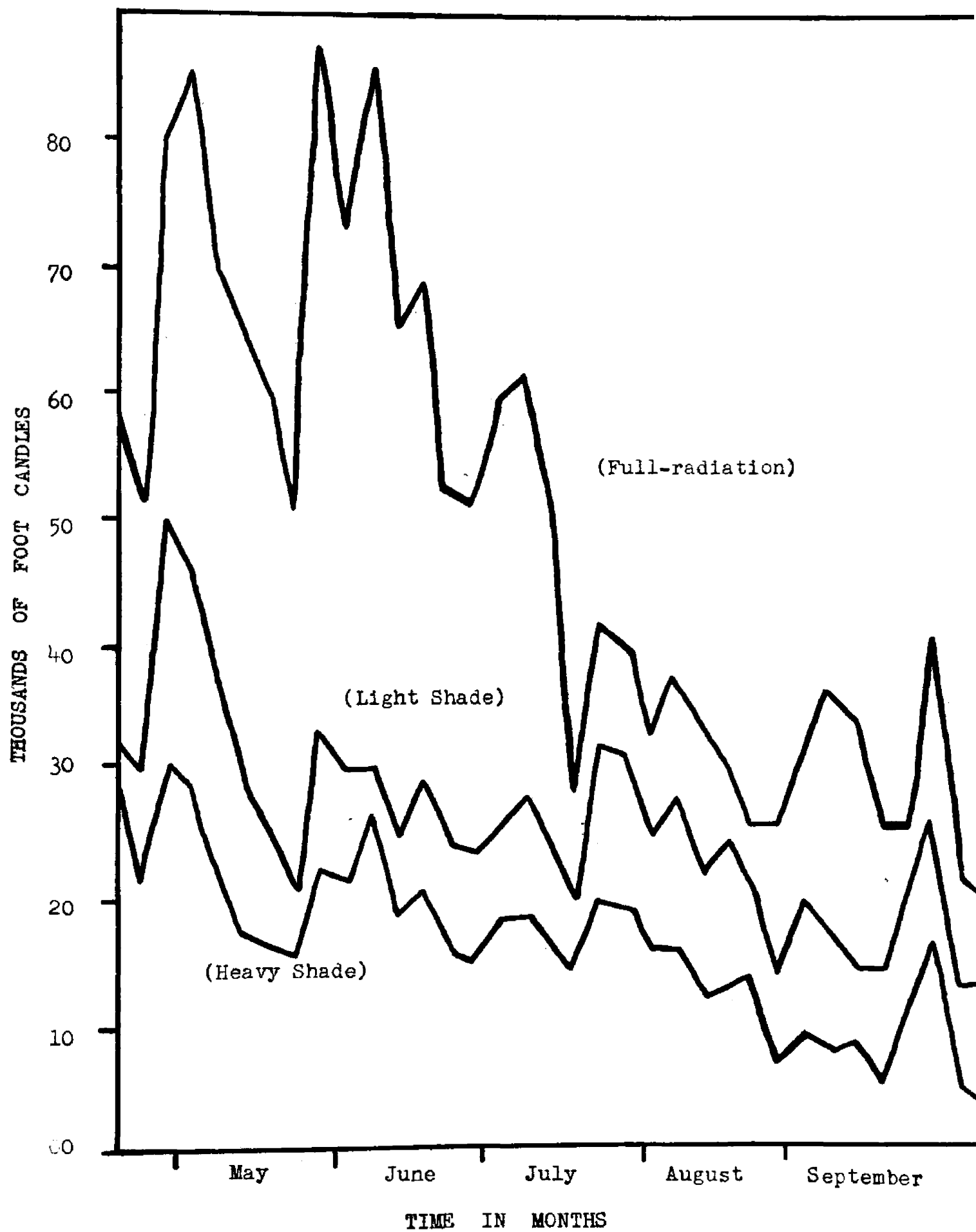


TABLE 9

LIGHT INTENSITY RECORDS IN FOOT-CANDLE HOURS

Light	April 15	May 15	June 15	July 15	Aug. 15	Sept. 15
	to May 15	to June 15	to July 15	to Aug. 15	to Sept. 15	to Oct. 15
Full radiation	2,137,000	2,173,000	1,765,000	1,096,000	888,000	792,000
Light shade	1,111,000	852,000	791,000	817,000	561,000	573,000
Heavy shade	790,000	621,000	536,000	477,000	299,000	283,000

TABLE 10
MEASUREMENTS OF LEAF SECTIONS

Light	Depth of palisade layer in micra		Total leaf thickness in micra
	Upper	Lower	
Full radiation	35.30	22.39	150.00
Light shade	31.03	18.83	138.67
Heavy shade	28.73	16.70	124.17

the reduced solar radiation than in leaves exposed to full radiation (Figure VIII). The difference in structure of leaves grown in full radiation and low solar radiation is illustrated in a camera lucida drawing (Figure VIII). Chlorophyll content was much more intense in the thicker leaves produced in the highest light intensity.

Total sugars were found to be higher in tissues obtained from plants grown in full radiation than from plants grown in light shade. The heavy shade further reduced the total sugars (Table 11). Sugars increased greatly on June 13 and during the following night rapidly decreased in leaf and stem tissues. During each daylight period total sugars continued to increase and to decrease during the dark period (Figure IX). At the end of the three-day period of high radiation, however, the tissues contained a much larger percentage of total sugars than at the beginning of the three-day period. The increments of increase of total sugars were nearly equal in the three light treatments. The percentage of ash on a dry weight basis decreased during the daylight and increased during the dark period.

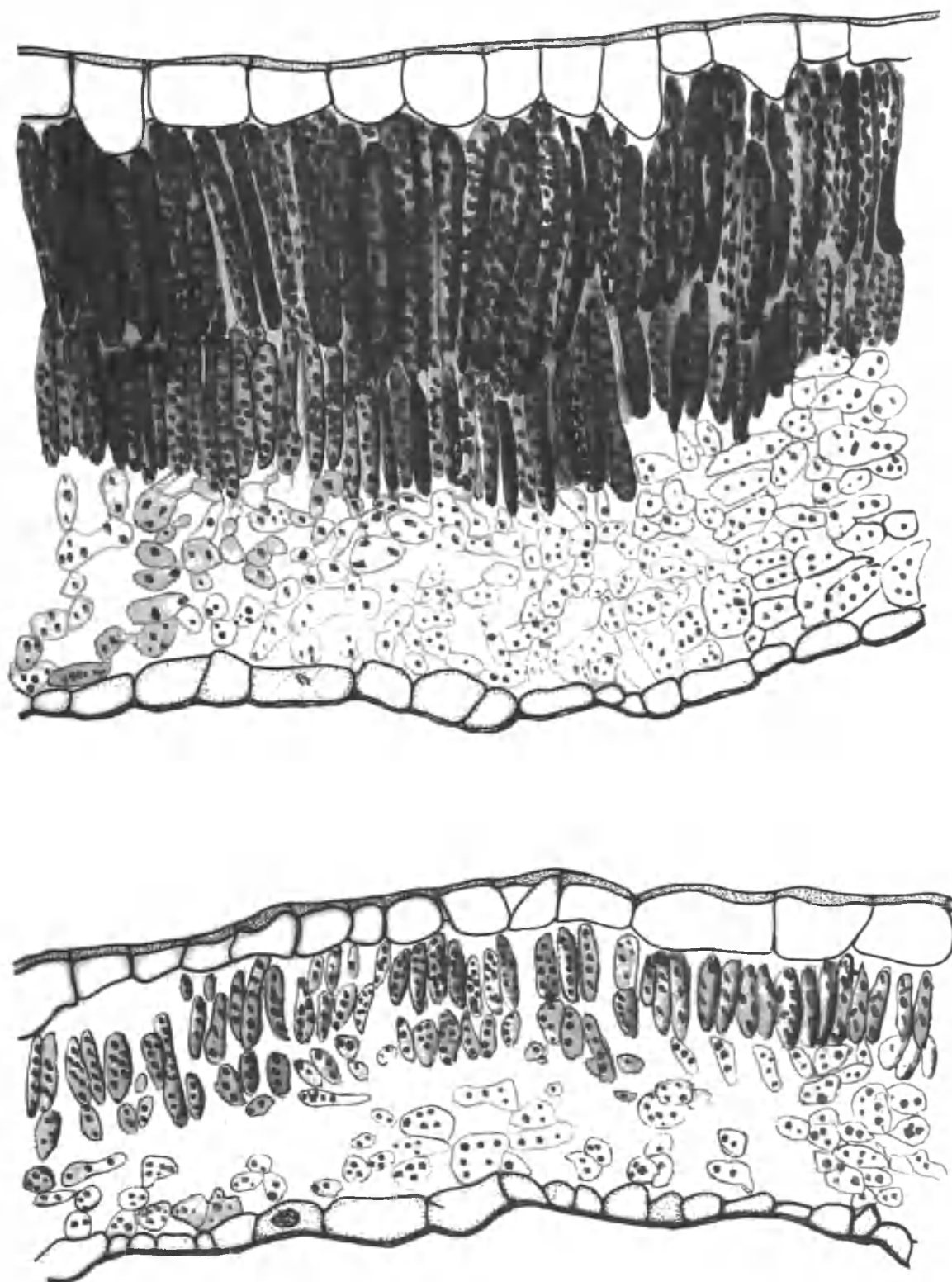


Figure VIII. Camera lucida drawings of cross-sections of leaves from plants grown in full sunlight (upper drawing) and 65 percent reduction of sunlight (lower drawing).

TABLE 11

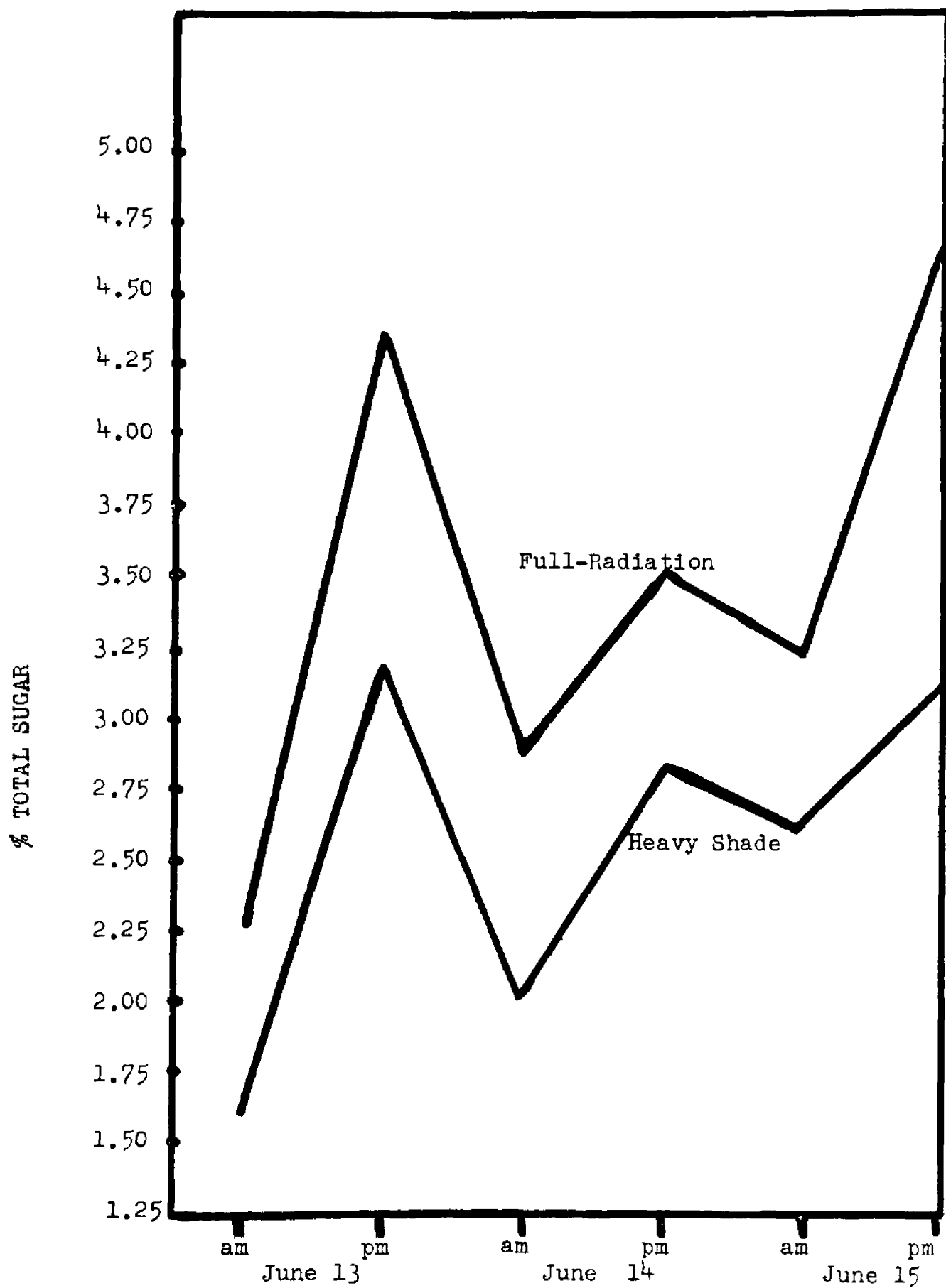
PERCENTAGE TOTAL SUGARS AND ASH IN RELATION TO LIGHT INTENSITY**

(Ten-gram samples of leaf and stem tissue)

Light		June 12		June 13		June 14		June 15	
		A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
Full radiation	Invert sugar	2.28	4.41	2.90	3.53	3.23	4.75		
	Ash	6.65	6.04	6.80	5.63	6.00	5.96		
	Ft.-Cd. Hrs.	48,600	61,600	78,200	74,200				
Light shade	Invert sugar	2.00	3.83	2.38	3.97	4.10	5.88		
	Ash	6.68	6.30	7.54	6.71				
	Ft.-Cd. Hrs.	19,500	23,400	27,600	27,100				
Heavy shade	Invert sugar	1.69	3.20	2.09	2.84	2.64	3.12		
	Ash	6.43	5.82	6.42	5.73	6.45	5.79		
	Ft.-Cd. Hrs.	12,300	17,200	22,400	21,200				

*Calculated as invert sugar and expressed on oven dry basis

Figure IX. VARIATION IN TOTAL SUGARS*



*Calculated as invert sugar.

DISCUSSION

Reduction of total plant weight and number and quality of flowers resulted from shading rose plants. These results are similar to the findings of Batson in 1933, who examined numerous plants grown in reduced light conditions. Shading of plants with cloth during the summer months without additional shading applied to greenhouse glass resulted in high air temperatures and low available solar radiation. An extreme reduction in light intensity combined with high temperature might be expected to greatly reduce carbohydrate synthesis and indirectly retard growth. Pronounced reduction in accumulated carbohydrates might occur in plants shaded by cloth during early morning hours, evening hours, and during cloudy periods. Kamp (1948) has reported a reduction in carbohydrate of plants as a result of shading and Weinard and Decker (1930) found the quality and yield of greenhouse roses to be reduced as a result of low light intensity available to certain plants in a greenhouse bench. A reduction of carbohydrates and consequently a reduction in growth might result during periods of high temperature and it would become severe under conditions of extremely low light intensity.

Surface covers which increased the amount of reflected light yielded increases in growth of small plants only when

solar radiation was extremely high. Intensity of reflected light decreased rapidly as a result of decreased incident light and decreased progressively as surface cover became shaded by foliage of developing plants. Such measureable decreases in reflected light resulting from increase in plant size were noted immediately after the plants began to develop. Reflected light continued to decrease until the intensity was low and of limited physiological importance. Salisbury in 1918 recorded light intensity as low as 0.16 percent under lower leaves of woody plants. Combes (1910) reported the optimum light intensity for the production of dry matter in plants to increase with increasing age and consequent size of plants.

Increases in total weight of plant material with increased light intensity was consistent in all experiments. As plants grew larger and the density of foliage was greater, the magnitude of differences was increased by the additional months of growth. Increases as a result of reflected light were variable and of less magnitude in the shaded treatments than in those of full radiation. Light recordings revealed very low light intensities donated by reflected light as a result of shade treatments combined with the additional obstruction from heavier foliage.

Growth differences obtained as a result of different light intensities greatly exceed those differences in size

obtained as a result of alteration of surface cover. Very little light was available to be reflected, regardless of surface cover and did not greatly influence total growth over a long period of time.

The second year's growth was much greater than that of the first year as a result of removal of flower buds during the summer. Such removal was intended to conserve carbohydrates. Likewise the second year's growth was increased by further root development and greater leaf area. Number and quality of flowers were increased during the second year which suggested the difficulty of directly correlating growth of perennial plants with data of a physical nature unless age and previous treatment were well recorded and interpreted.

Reflected light did not appear to be influential in producing higher yields. It was possible that with woody plants or plants which greatly shade the soil surface, reflected light could not become available in intensities effective for increasing growth. Reduction of the total direct solar radiation to 58 percent did not greatly reduce growth or flower production. Reduction to 35 percent affected quality and quantity of plant material severely. Reduction to 58 percent was not as significant in its effect upon plant growth. Consequently, efficiency of utilization of solar radiation as indicated by bulk of growth during the

period of this experiment must have reached a critical point between 35 and 58 percent of full solar radiation, for the existing temperature. It was probable that radiation in excess of 58 percent of the total was beneficial but with limited efficacy. Reduction of light to the extent of approaching the 65 percent level, regardless of the greenhouse temperature, should result in sizeable reduction in total growth of the rose plants. Reduction of light to the 20 percent level resulted in very little growth of plants.

Light records were not compared with those available from the local weather bureau because different types of receiving bodies having variable linearity, range of sensitivity, and fatigue factors were used in this investigation. Greenhouse glass received an application of shading compound during the period of high radiation. Percentage reduction of light was found to vary constantly and, as reported by Gray (1934), various quantities of diffused light altered the amount of reduction resulting from shading. Cords and threads of textiles have depth and width which make possible great difference of amount of light passing through the openings depending on angles of incidence. Ends of greenhouses caused additional shading on some plants in early morning and in late evening. All of these factors allow for only relatively accurate solar radiation recordings in greenhouses regardless of the

quality of available equipment. Only averages of percentage reductions and totals of radiation were presented.

Studies of leaf anatomy verify findings of Pickett (1938), Hanson (1917), and Penfound (1931) in regard to modifications of leaves by varying light intensities. It is felt that increased vigor and rate of growth as a result of sufficient light produced leaves which were substantially thicker, layers of palisade cells which were deeper, and spongy mesophyll which was much more compact. Leaf structure, therefore appeared to offer some indication of the proximity of light intensity to the cardinal points. High radiation, in addition to facilitating the production of the greatest amount of plant material, facilitated the development of much thicker leaves than did a reduction to 35 percent of total radiation. Results obtained with less than 20 percent full solar radiation in which plants showed little suitable growth, indicated a light intensity near the minimum. It was often below this level that greenhouse rose plants during the winter months under heavy shading exhibited growth difficulties during cloudy days.

Percentage of total sugar increased measurably in leaves and stems of rose plants at high light intensities and temperatures. Maximum light intensity for photosynthesis and accumulation of carbohydrates were apparently not exceeded

for any length of time during periods of highest radiation during this investigation. Efficient utilization of light apparently decreased at extremely high light intensities but not to an extreme degree. Translocation, utilization in growth, or respiration of sugars appeared to take place rapidly after one daylight period of low solar radiation was followed by one of high solar radiation. Such variations in sugar content were not as obvious after one or two days of high radiation. On a percentage dry weight basis the ash content decreased as sugars content increased. Such analyses of tissue for invert sugar served as a useful technique for the study of growth and carbohydrate accumulation in plants.

SUMMARY

Three plantings of roses were made to study quantitative and qualitative effects of light intensity on the growth of Better Times roses. Growth measured by elongation and fresh weights of all plant material produced was correlated to light intensity by means of recording light intensity over plants growing in shade houses constructed of cloth and designed to allow 20, 35, and 58 percent incident radiation to be available. Total radiation as well as the reduced radiations was measured by means of a Speedomax recorder. Soil surface was covered with a highly reflective "frit", with a less reflective "frit", and with soil.

Carbohydrate analyses were made of tissue subjected to three levels of radiation. Sections of leaves were collected for an anatomical study of rose leaf development resulting from various quantities of light.

Total growth of the rose plants was reduced by decreases in light intensity. Reduction to 20 percent total solar radiation reduced growth to an extreme degree, and appeared to be near the minimum light intensity for growth. Light of the magnitude of 58 percent of full radiation allowed growth to be only slightly reduced.

Judging from growth produced it appeared as if plants growing in 58 percent radiation had been supplied with almost as much light as was ideal for maximum growth. Any reduction of light below 58 percent of the total radiation resulted in rather sharp decrease in total growth.

Surface covers which increase the amount of reflected light seldom increased plant growth. Plant growth response from such indirect light was noted when radiation was extremely high and then only if plants were very small. This finding was thought to be related directly to the amount of shading of surfaces by plant foliage.

Carbohydrate analysis revealed a great increase in total sugars in leaf and stem tissue during periods of intense heat and extremely high radiation. Translocation, respiration or utilization of carbohydrates were found to occur in great quantities after periods of dark or cloudy weather.

Leaf structure was greatly modified by the intensity of light available to various plants. Heavy shading resulted in the development of very thin leaves with palisade cells of much less depth than those of leaves subjected to high radiation; total chlorophyll content appeared to be much greater in leaves obtained from these plants.

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