GROWTH AND DEVELOPMENT OF *LYCOPERSICUM ESCULENTUM* AS AFFECTED BY THERMO-PERIOD, PHOTOPERIOD, CHEMICAL GROWTH REGULATORS AND NUTRITIONAL SPRAYS

By

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I. INTRODUCTION

The State of Michigan is geographically located in an area having relatively short photoperiods of low intensity plus relatively low temperatures during the fall, winter and spring months. These climatic conditions are often conducive to poor yields of marketable fruit of greenhouse grown tomatoes (Lycopersicum esculentum) (22, 23, 57). The following series of experiments were conducted in an effort to develop economically-feasible solutions to several poignant environmental problems associated with the growth and development of greenhouse-grown tomatoes.

Investigations were carried on in an effort to increase the number of normal flowers conducive to normal fruit, the "per cent set," and the quality of the subsequent fruit which develop from the early flower clusters. The following methods were utilized in an attempt to accomplish these objectives: (a) artificially lengthening the photoperiod; (b) alteration of temperature in accordance with age and size of plants; (c) interaction of the supplementary photoperiod and the thermal variables; (d) foliar application of certain nutrient elements; (e) soil applications of selective growth-regulating chemicals; (f) and combinations of the above.

II. REVIEW OF LITERATURE

A. Supplementary Photoperiod

Variations of the length and intensity of the photoperiod have been widely employed by many investigators to induce or inhibit flowering in onions, china aster, stocks, and cosmos under a given set of conditions (1, 2, 20, 38, 40). These deviations from what is considered "normal" for a given plant have been extensively undertaken with many of the commercially-grown flowers. In 1922 Harvey (19) found that many plants could be successfully grown and induced to set seeds in a favorable light environment of from approximately 400 to 10,000 foot-candles. Naylor (35) found that 600 f.c. of fluorescent light for 16 hours duration per day produced excellent growth in red kidney bean plants.

Withrow and Withrow (58) have successfully grown tomato seedlings under a four-hour supplemental photoperiod of 500 f.c.; these being shorter, stockier, darker green in color, and of superior growth in comparison to those not receiving the additional fluorescent light. In like manner, Withrow (57) obtained definite increases in number of flowers formed and early fruit yields on the first clusters of a late winter or early spring greenhouse-grown tomato crop.

B. Supplementary Temperature

The temperature requirements of plants for reproductive development have for many years held the attention of investigators, and has resulted in the galaxy of fundamental information gained through the experiments of Lysenko, Gregory, Purvis, Whyte, Cholodny, Blaauw (32). However, only the post-emergence phases of the thermal requirements of the tomato plant were considered in the succeeding series of experiments. Responses from temperatures with many vegetable crops (20, 46, 48) are in many cases closely associated with the photoperiod. Whether the night or day temperature is most important and the respective optimums of each have not been determined for many species and varieties under greenhouse conditions. Post (38), however, considers 7° to 10° C. desirable night temperatures for growing carnations and snapdragons.

According to Went (51, 52), the cultivated tomato has optimal growing conditions, i.e., optimal "nyctotemperature," of 15^{o} to 20^{o} C. whereas during phototemperature it is closer to 26^{o} C. However, the "nyctotemperature" optimum during the seedling stage was approximately 30^{o} C.; which gradually fell to 18^{o} C. during the course of the plants' development. Dorland and Went (11) noted in an analysis of the temperature responses of the chili pepper (Capsicum annuum) essentially the same results. As was the case with the tomato, optimal growth was obtained at a phototemperature of 26^{o} C., and the optimal "nyctotemperature" dropped from 30^{o} C. for young plants to 8^{o} C. for full-grown plants.

C. Interaction of Supplemental Photoperiod and Thermoperiod

In 1923 Garner and Allard assumed that "temperature undoubtedly is the most important environmental factor in relation to the action of the light period on plant growth" (12). Roberts and Struckmeyer (40) demonstrated that poinsettia, a commonly considered short day plant, failed to bloom under short days when grown at a minimum temperature of 12.3^{o} C. In analyzing the photoperiodic and temperature reactions of soybeans obtained from different regions, Rudorf and Schrock

(41) noted that the higher temperatures given only in the early stages of exposure to short days hastened flowering.

Went in 1944 (51) maintained that the cultivated tomato, a photoperiodically-neutral plant, sets fruit abundantly only when night temperatures are between 15° and 20° C. and the day temperatures are about 25° C.; with lower or higher night temperatures fruiting is significantly reduced or absent. In 1948 Wittwer, et al. (61) made similar observations with outdoor tomatoes. According to Went these temperature optimums are also influenced by light intensity during the photoperiod, being lower for lower light intensities.

In addition, he concluded that the optimal for stem elongation is also optimal for fruit set and fruit growth. The afore-mentioned observations furnished much of the stimulus for the forthcoming investigations reported herein.

D. Foliar Application of Certain Nutrient Elements

The use of foliar application of the major nutrient elements (nitrogen, phosphorus, and potassium) to vegetable crops is not an established practice. Literature on this method of fertilization of vegetable crops is extremely limited. With few exceptions all previous nutrient element application studies were confined to the plant roots as organs of adsorption. More recently foliar applications of nutrients have merited investigation. Certain minor-element deficiencies of citrus (63) have been corrected by this method of application. The requirements for magnesium and nitrogen of apple trees has been met successfully by foliage application of Epsom salts and urea, respectively (4, 5). The reports of Went and colleagues (54, 56) suggests that sugar is absorbed through the leaves of several plants. The now general effective application of certain growth regulators as selective herbicides utilizes the ability of plant leaves for absorbing large organic molecules. The nutrient phosphorus has been reported as being readily absorbed through the leaves (43, 62). However, the lack of information on foliar applications of major nutrients is clearly indicated by recent reviews (25). The need for further investigation of the possibilities of leaf feeding with phosphorus, for example, is suggested by recent tests (45) on fertilizer uptake using radioactive phosphorus. Reports indicate that only 22 per cent of the phosphorus applied to the soil was recovered by the wheat plant. This suggests that the efficiency of utilization of some nutrients applied to the soil may be of low order.

E. Soil Application of Selective Growth-regulating Chemicals

As early as 1860 it was recognized by Julius Sachs that special substances are responsible for the formation and growth of different organs. However, only recently have growth-regulating chemicals been used successfully for increasing fruit set on many horticulturally-important species. Gustafson (13) in 1936 disclosed that several synthetic growth regulators will induce fruit development without pollination. By 1942 about 30 organic chemicals had been found effective in fruit setting (67). Murneek, Wittwer and Hemphill (31) had significantly improved fruit set and yields of greenhouse tomatoes with plant growth-regulator sprays when sunlight was deficient. In 1948 para-chlorophenoxy-acetic acid as used by Mullison and Mullison (30) improved fruit set of six tomato varieties grown under high temperatures. Wittwer (61) successfully overcame the poor fruit set on field-grown tomato plants which were grown at relatively cool night temperatures by using para-chlorophenoxyacetic acid at 25 parts per million. Wittwer and Murneek (60) have successfully used para-chlorophenoxy-acetic acid to improve total yields of green bush snap beans. Alpha-ortho-chlorophenoxy propionic acid was found to actively influence fruit set and leaf modification of tomato plants (62). Using 2,3,5-triiodobenzoic acid (TIB), Zimmerman and Hitchcock (68) and Waard and Roodenburg (50) induced increases in the number of flowers on treated plants and caused flowers to develop from vegetative tissue.

A number of different methods of application are being used for the treatment of plants with these growth-regulating chemicals. Gustafson (13) has reported on the use of lanolin preparation applied to the excised pistil of open flowers and water solutions or emulsions applied to open flowers with an atomizer. Zimmerman and Hitchcock introduced the vapor method, and the method of spraying the entire plant or the entire cluster at one time (64, 65). Randhawa and Thompson (39) have applied growth regulators to the soil in an effort to influence growth and fruiting of tomato plants.

Another phase of the utilization of these selective organic chemicals has recently been in the alteration of the plant's various constituent compounds. Recently, the vitamin

(31); the protein, and amino acid (15, 16); sugar content (35); and the mineral content (7) of several plants have been increased through the application of growth regulators to the stems and roots.

F. Interaction of Growth Regulators with Environmental Factors

It has long been known that many plants require a specific photoperiod for the induction of flowering. The exact mechanism by which the photoperiod or temperature controls blossoming or fruiting is not known. It is suggested, however, that something of the nature of a hormone is produced in the leaves of these plants in which the subsequent blossoming is controlled by the photoperiod according to Hamner and Bonner (17).

However, when alfalfa plants grown during long days were sprayed with 0.005% of 2,3,5-triiodobenzoic acid an increase in the yield of seed occurred (49). Cajlachjan and Zdanova (9) maintain that plants grown under short photoperiods possess lower auxin content than plants grown under long photoperiods. In their investigations with flower induction of Xanthium by auxins, Bonner and Thurlow (3) postulated that a possible role of the auxin is in photoperiodic induction. The exact mechanism responsible for flowering in the tomato plant is still obscure. Went (51) asserts that if tomato plants are grown at minimum night temperatures above or below their optimum 15° to 20° C. plus day temperature about 26° C. that fruiting is reduced or absent; suggesting a simulation of photoperiodicity by thermoperiodicity. Constant day and night temperatures of 26.5° C. were lethal to the California Spring annual Baeria chrysostoma, however, this effect could be counteracted by lengthening the photoperiod (27).

III. EXPERIMENTAL

Experiment A

Influence of Photoperiod and Growth Regulators on Seedling Growth of Flowering Response of Greenhouse Tomatoes

1. Objective. A preliminary experiment with foliar and soil applications of alpha-ortho-chlorophenoxy propionic acid (a-o-clpp) interacted with a 16-hour supplementary illumination of 300 foot-candles during the relatively light-deficient spring months failed to yield a significant difference in plant heights, dry weights and percentage of normal flowers.

It was suggested that an increased photoperiod may in the presence of a growth regulator (a-o-clpp) have a significant influence on floral development during those months when light is limiting. The objective of this study was then to determine whether the combination of photoperiod and chemical growth regulators might stimulate a more rapid expression of the reproductive cycle in tomato seedlings.

2. Methods and materials. John Baer and Rutgers tomatoes were planted in vermiculite.[1] Two days after emergence, they were watered with a 0.78 per cent nutrient solution of an all-soluble fertilizer containing the equivalent of 10 per cent nitrogen, 52 per cent P_2O_5 and 17 per cent K_2O. This procedure was followed every five days during the entire course of the experiment. One week after the differentiation of the first pair of true leaves, the seedlings were transplanted to 4-inch clay pots. Half of the number of pots contained a sandy-loam type of mineral soil and the other half contained a muck-type soil. All plants were grown in the greenhouse at 60° F. minimum night temperature. An interval of 14 days was allotted for the recovery from transplanting.

A split-plot type design was employed in this and all subsequent experiments with the exception of Experiment F, where a randomized-block type design was used. All variables were randomized and replicated. One-half of the total number of plants (336) were given 16 hours (7:00 a.m. to 11:00 p.m.)

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[1] An expanded mica purchased under the trade name of Terra-Lite.

of 300 foot-candles of supplementary light[2] in addition to the prevailing midwinter photoperiod which was an average of 10 hours per day during the course of the experiment. The light intensity in the greenhouse during the many cloudy days was too low to be measured by an ordinary General Electric galvic-cell type light meter. The intensity during sunny days of December, January and February was approximately 1,200 to 1,500 foot-candles. Seven weeks after emergence applications of alpha-ortho-chlorophenoxy propionic acid (a-o-clpp) were administered as follows, each treatment given to 96 seedlings:

Key to Treatment Symbols:

1. Controls (Not treated).
2. Single foliar spray of 5 parts per million.
3. Single foliar spray of 10 parts per million.
4. Single foliar spray of 20 parts per million.
5. Single soil application of 0.1 mg.
6. Single soil application of 0.3 mg.
7. Single soil application of 0.2 mg. (added nine weeks after emergence).

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[2] Supplementary light source from a series of 40-watt white fluorescent bulbs in white enamel reflectors.

3. Results. A daily inspection of each plant was carried on at which time the number of days required for anthesis and the comparative normality or abnormality of first flower cluster was recorded. Neither the soil type nor the concentration, method or time of application of growth-regulating chemical had any significant influence on the dates of anthesis of first flowers. The usual varietal differences were observed. However, there was a highly-significant mean decrease of 3.2 days from the flowering time in the case of plants receiving the supplementary photoperiod (data summarized in Table I).

The ratio of normal to abnormally-formed primary flowers of the first cluster was perhaps significantly increased only in the case of plants receiving the additional illumination. No significant differences were obtained with respect to soil type, variety, chemical concentration or method of application.

The soil amendment of 20 parts per million of alpha-ortho-chlorophenoxy propionic acid resulted in significant increases in the dry weights of both foliage and roots. Significant increases were similarly obtained as a result of the increased photoperiod. Plants receiving 0.3 mg. of the chemical had the dry weight of both foliage and roots significantly decreased (data summarized in Table III). Two days after all plants receiving the additional illumination had flowered, each treatment was harvested by replications for fresh and dry weight comparisons. Weekly measurement of the seedling heights were made with final analysis being based on differences between initial and final heights. As a result of the soil applications of 0.2 mg. or 0.3 mg. of alpha-ortho-chlorophenoxy propionic acid (a-o-clpp) the heights of the plants receiving these treatments were on the average six centimeters less than all others. The plants exposed only to the normal photoperiod were a significant nine centimeters shorter than those given the 16-hour supplement (data in Table IV). Of special interest, as may be seen in Figure 1 are the comparative heights and stem thicknesses resulting from the soil application of a-o-clpp.

TABLE I

NUMBER OF DAYS TO THE FIRST ANTHESIS AS AFFECTED BY PHOTOPERIOD
(Mean of 24 plants)

Symbols	Treatments	
N.L.	Normal daily photoperiod	66.8
S.L.	Normal daily photoperiod plus 16 hours of 300 f.c. supplement	63.6
Difference necessary for significance:		
5% level		0.83
1% level		1.22

TABLE II

RATIO OF NORMAL TO ABNORMALLY FORMED PRIMARY FLOWERS OF THE FIRST CLUSTER IN RESPONSE TO PHOTOPERIOD
(ratio means of 24 plants)

Symbols	
N.L.	2.5:1
S.L.	6.1:1
Difference necessary for significance:	
5%	3.6:1
1%	5.7:1

TABLE III

THE EFFECT OF GROWTH REGULATOR AND PHOTOPERIOD TREATMENTS ON TOMATO SEEDLINGS WITH SPECIFIC REFERENCE TO DRY WEIGHTS OF PLANT MATERIAL
(mean grams of 12 plants per replication)

Treatment Symbols	Foliage		Roots	
	Growth Regulator	Photo-period	Growth Regulator	Photo-period
1.	40.6	N.L. 39.1	4.3	N.L. 4.3
2.	43.2	S.L. 41.6	4.5	S.L. 5.4
3.	39.2		4.5	
4.	44.4		5.0	
5.	43.1		4.7	
6.	27.0		3.5	
7.	48.8		7.3	
L.S.D. 5%	3.9	2.0	0.60	0.31
1%	5.2	2.6	0.91	0.41

TABLE IV

THE EFFECT OF GROWTH REGULATOR AND PHOTOPERIOD TREATMENTS ON TOMATO SEEDLINGS WITH SPECIFIC REFERENCE TO HEIGHTS OF TOMATO SEEDLINGS (mean cm. of 12 plants per replication)

Treatments	Growth Regulator	Photoperiod
1.	33.9	N.L. 26.9
2.	33.2	S.L. 35.9
3.	33.1	
4.	33.9	
5.	33.9	
6.	26.3	
7.	28.3	
L.S.D. at 5% level	2.4	1.2
1%	3.1	1.6

Figure 1. The response of tomato plants to soil applications of alpha-ortho-chlorophenoxy propionic acid. Left to right. control (non-treated), single soil application of 0.1 mg. (at seven weeks), single soil application of 0.3 mg. (at seven weeks), and single soil application of 0.2 mg. (at nine weeks).

Experiment B

The Interaction of Night Temperatures and Fruit Setting Hormones on the Yield of Tomato Plants

1. Objective. F. W. Went (51, 52) demonstrated certain optimum environmental factors for the growth and development of the tomato; however, this information was obtained under climatic conditions prevailing in five locals of southern California. It was suggested that a similar investigation be conducted in order to ascertain the optimum night temperature for fruit set under conditions common to Michigan. The objective therefore, was to determine specific optimal night temperatures for three tomato varieties and if necessary to supplement, by fruit-setting chemicals, the delayed fruit set resulting at nonoptimal temperatures.

2. Methods and materials. Early, mid and late season tomato varieties were selected; Early Chatham, John Baer, and Rutgers, respectively, thus enabling a comparative study encompassing divergent varieties. The plants were grown and "hardened" in accordance with standard procedures (47). Seven weeks after emergence the plants were divided into four main

groupings; each group was exposed to a different night temperature of either 40° F., 50° F., 60° F. or 70° F., respectively. The exposure was of 12 hours duration (6:30 p.m. to 6:30 a.m.) with all plants receiving the same outdoor photoperiod and temperature. These treatments were maintained continuously from May 7 until June 15. Each temperature group was interacted with each of the above varieties plus three methods of applying a growth-regulating chemical to promote fruit set. When mature flowers had developed on each variety at a given temperature treatment, an (a) entire foliar spray (20 parts per million) or (b) cluster spray (50 parts per million) or (c) soil amendment (0.75 mgs.) of alpha-ortho-chlorophenoxy propionic acid was administered.

3. Results. The results herein presented show no apparent significance existed when plant height, dry weight, and total yields of plants grown on the muck and upland soil types or method of chemical application were compared. As indicated in Table V and Figures 2 and 4, the 60° F. night temperature was responsible for most significant plant elongation, with the exception of Early Chatham, whereas 40° F. resulted in the least vertical growth of all the varieties. John Baer

and Rutgers however, were not significantly different from each other.

Using dry weights of the foliage of plants as an index of comparison, it will be noted in Table VI and Figure 3 that the 60° F. temperature resulted in the greatest increase in dry matter. Here the variety Rutgers made the greatest increase at all temperatures.

Table VII and Figures 5, 6 and 7 summarize the comparative yields of immature fruit which developed at the different temperature levels at termination of experiment on July 15. It will be noted that the 70° F. night temperature was most conducive to increasing the yield. While the Early Chatham variety yielded significantly more fruit than either of the other varieties regardless of temperature treatment.

TABLE V

HEIGHTS OF TOMATO PLANTS AS INFLUENCED BY NIGHT TEMPERATURE AND VARIETY
(centimeters per plant per 12 replications)

Varieties	40 F.	50 F.	60 F.	70 F.	Variety Mean
Early Chatham	33.9	38.5	36.3	35.8	36.1
John Baer	31.5	39.6	46.4	40.1	39.4
Rutgers	29.8	39.0	45.7	43.4	39.5
Temperature Mean	31.7	39.0	42.8	39.8	

Differences necessary for significance:	5% level	1%
Variety	1.7	2.6
Temperature	1.4	1.8
Variety x Temperature	2.4	3.2

TABLE VI

EFFECT OF NIGHT TEMPERATURE AND VARIETY ON THE DRY WEIGHTS OF THE FOLIAGE OF TOMATO PLANTS
(grams of dry matter per plant per 12 replications)

Varieties	40 F.	50 F.	60 F.	70 F.	Variety Mean
Early Chatham	10.7	11.9	12.1	10.4	11.2
John Baer	12.0	14.5	15.9	13.2	13.9
Rutgers	11.6	16.9	20.7	18.6	16.9
Temperature Mean	11.4	14.4	16.2	14.1	

Difference necessary for significance:	5% level	1%
Variety	1.3	2.0
Temperature	1.1	1.8
Variety x Temperature	2.3	3.1

TABLE VII

THE YIELD OF IMMATURE TOMATO FRUITS AS AFFECTED BY NIGHT TEMPERATURE AND VARIETY
(grams of fruit per plant per 12 replications)

Varieties	40 F.	50 F.	60 F.	70 F.	Variety Mean
Early Chatham	22.5	43.6	97.1	106.2	67.3
John Baer	3.1	9.9	51.2	84.7	37.2
Rutgers	0.2	0.9	16.6	57.1	18.7
Temperature Mean	8.6	18.1	54.9	82.6	

Difference necessary for significance:	5% level	1%
Variety	9.3	14.1
Temperature	9.1	13.3
Variety x Temperature	15.2	21.8

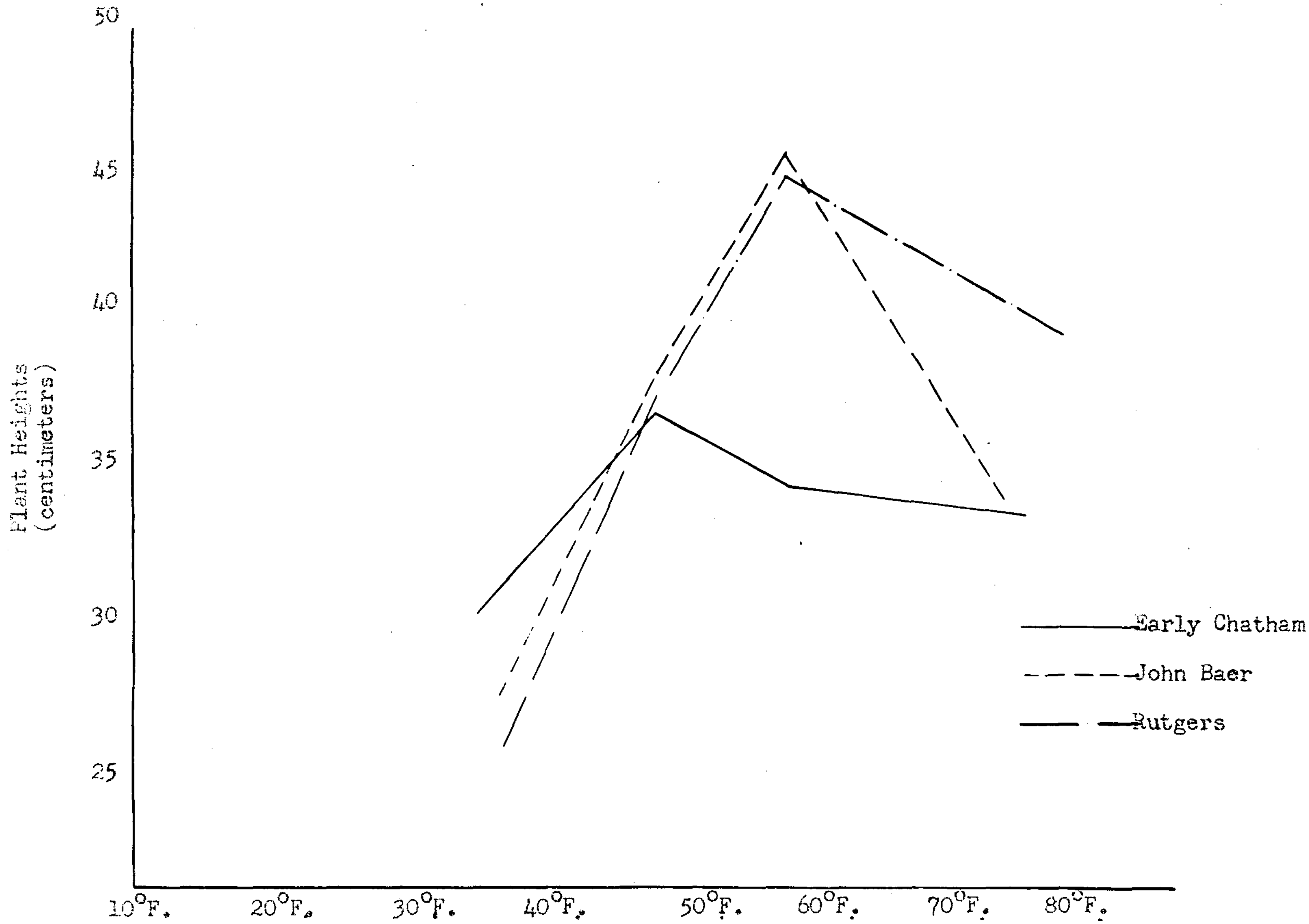

Figure 2

The Effect of Night Temperature on the Heights of Tomato Seedlings

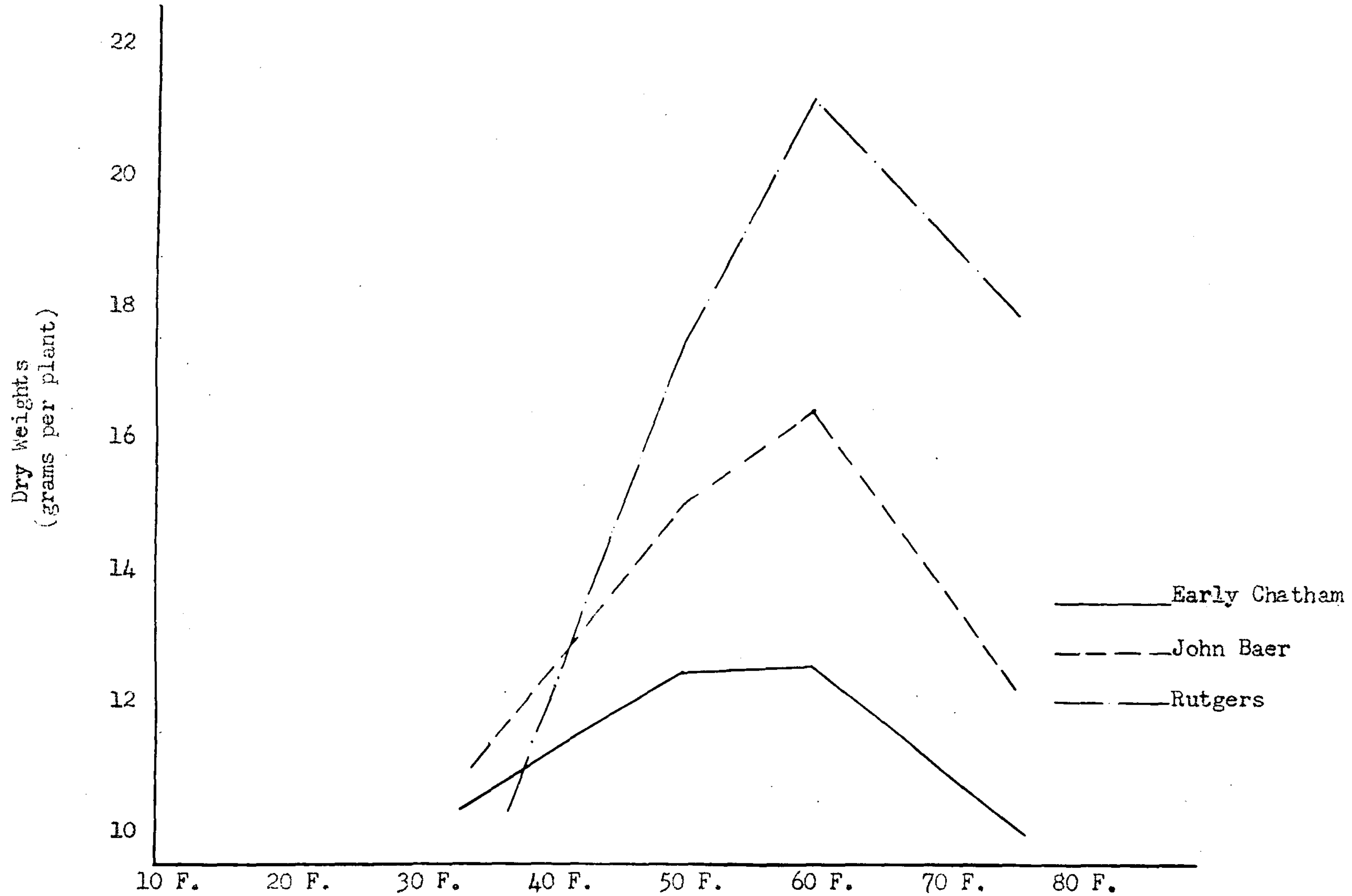

Figure 3
The Effects of Night Temperature on the Dry Weight Accumulation by Tomato Seedlings

Figure 4. The growth response of tomato plants as influenced by night temperatures.
Left set of three plants - 40°F. night temperature; daily outdoor temperature.
Right set of three plants - 60°F. night temperature; daily outdoor temperature.
Left to Right per Set: Early Chatham, John Baer, and Rutgers.

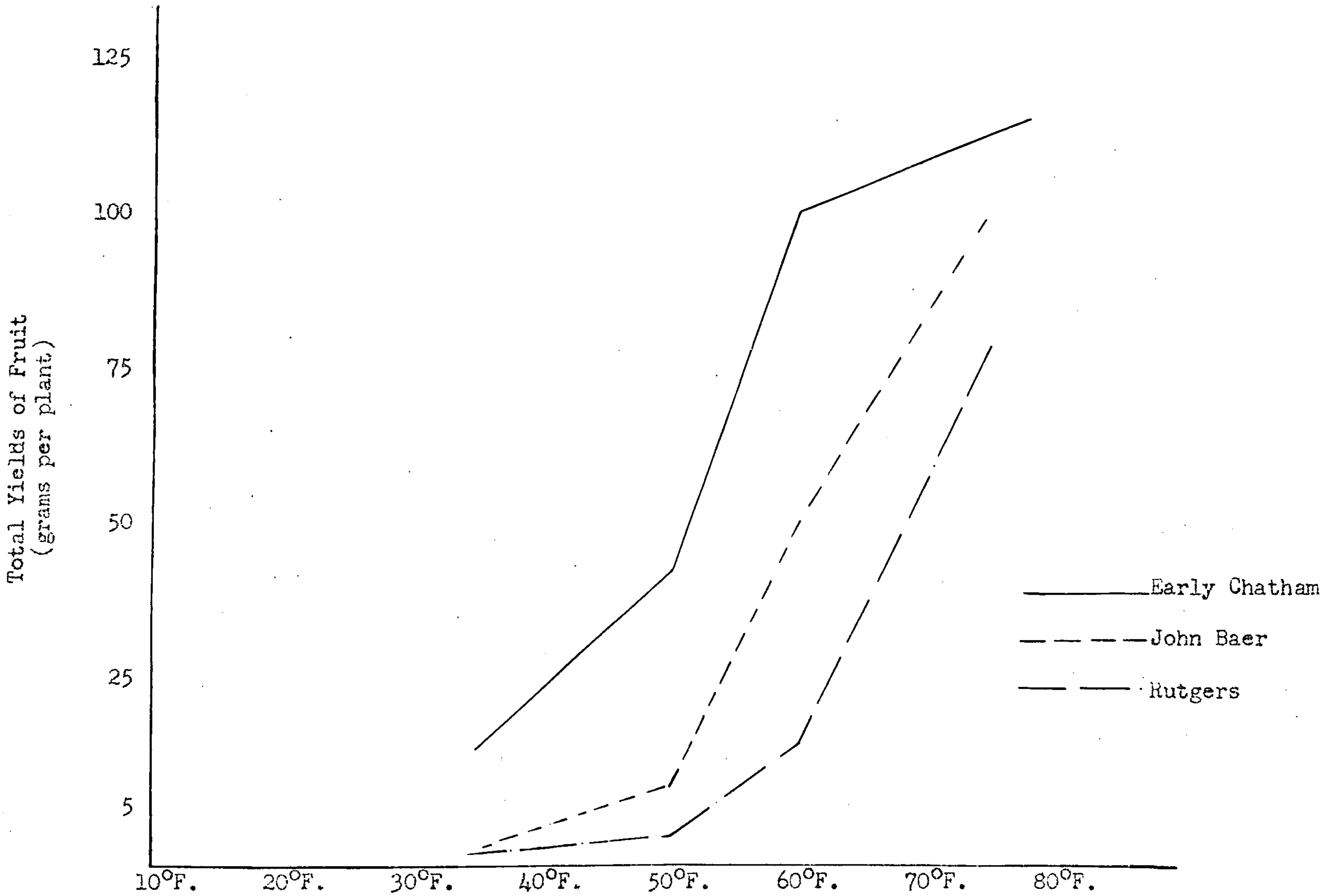

Figure 5
The Night Temperature Affects on the Yields of Immature Tomato Fruits

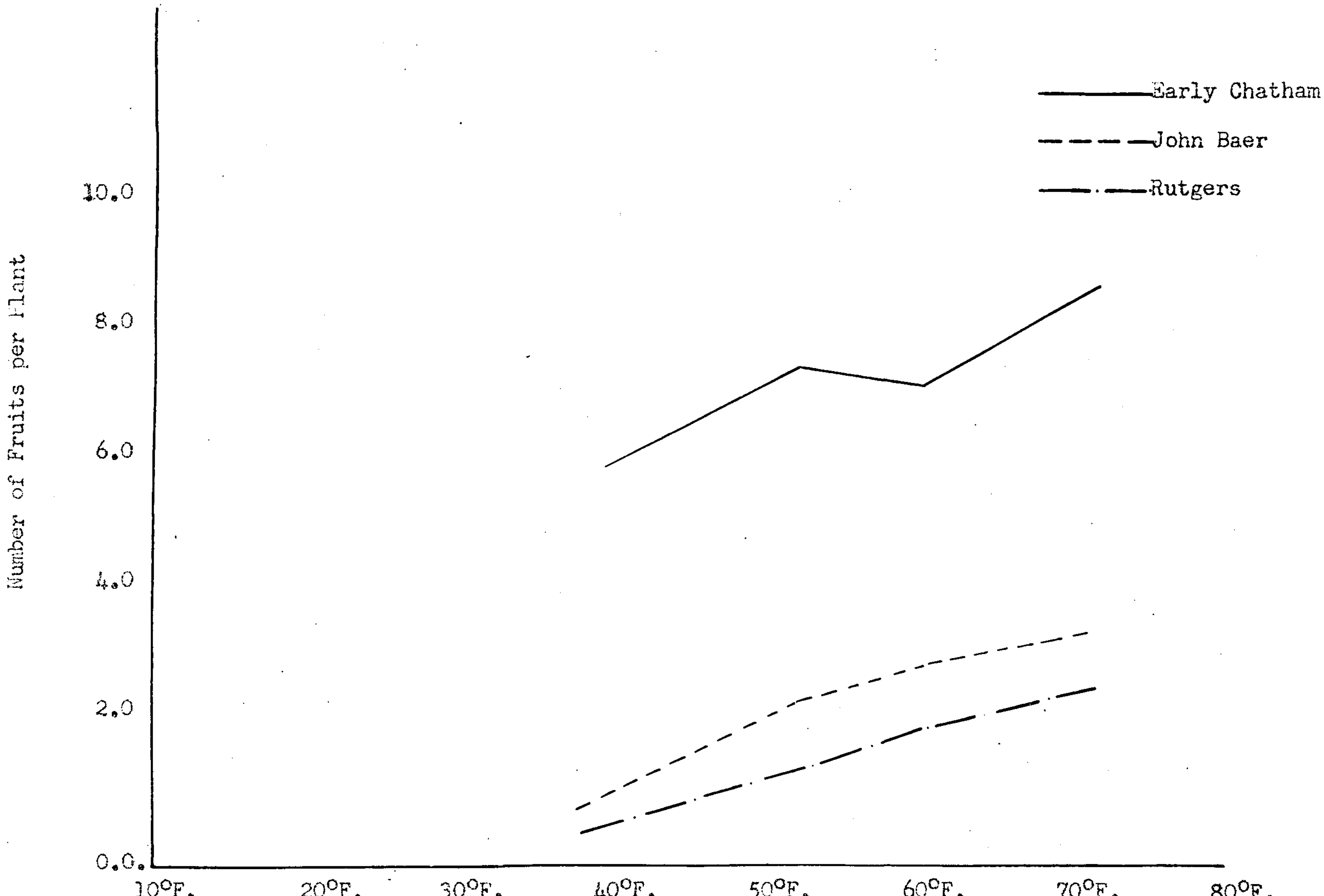

Figure 6
The Effect of Night Temperature on the Number of Developing Tomato Fruits

Figure 7. The influence of night temperature on the fruiting response of tomato plants.
Left set of three plants - 70oF. night temperature; daily outdoor temperature.
Right set of three plants - 60oF. night temperature; daily outdoor temperature.
Left to Right per Set: Early Chatham, John Baer, and Rutgers.

Experiment C

The Influence of Foliar Application of Certain Nutrient Elements and Sucrose on the Yield of Greenhouse Tomatoes

1. Objective. Previously-reported uses (4, 5, 25) of foliar-applied nutrient elements as supplementary fertilizer treatments have indicated some advantages in overcoming certain nutrient deficiencies plus the possibility of greater control over desired fruiting and vegetative response (44).

The limited photoperiod and intensity of light which are present during the winter and early spring months are the uncontrollable factors responsible for reduced photosynthetic activity. If sucrose is considered to be one of the first free sugars formed (10) and sucrose can be readily absorbed through intact tomato leaves (54) then one may speculate that part of the relatively low carbohydrate content which results from the limited photosynthetic activity may be partially supplemented by foliar applications of sucrose. Withrow (58) has found that plant roots can accumulate ions only in the presence of an adequate supply of oxidizable respiration substrates as carbohydrates. Thus ion accumulation by green tissue is indirectly accelerated by light through the photosynthetic process. Thus it was suggested that in addition to the use of sucrose, foliar application of nitrogen, phosphorus, and potassium be included as a possible supplement to root absorption in the nutritional needs of the plant.

2. Methods and materials. The seed of ten varieties of tomatoes were sown on July 5, 1950, and subsequently grown in accordance with established commercial practices of producing plants for a fall crop in the greenhouse. After eight weeks the seedlings were transplanted to productive soil in a ground bed and grown at 60° F. night temperature. Seven days were allotted for recovery from transplanting before spray treatments were applied. The open flowers of the first three clusters were sprayed twice weekly with 30 parts per million solution of para-chlorophenoxy propionic acid to insure relatively uniform fruit set. They were continued at weekly intervals until the termination of harvest on December 24, 1950. All foliar supplements were in aqueous solution containing 0.1 per cent Dreft[3] to facilitate wetting. A three-gallon

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[3] A commercial detergent, sold under trade name of Dreft.

hand sprayer was used to apply these materials. In applying the spray, a special effort was made to wet both upper and lower surfaces of the tomato leaf. Each plant was sprayed individually, using a large corrugated paper-board screen to protect adjacent plants from possible drift of the chemical (tabular key to varieties and foliar treatments are enumerated in Tables VIII and XI).

3. Results. Approximately three weeks following the onset of the spray treatments a minor degree of marginal leaf burning occurred on those plants receiving treatment E (0.75% urea) was the only visible effects of the foliar applications. This slight injury, however, gave no apparent indications of reducing the plants' over-all efficiency.

Several interesting varietal responses can be noted in Tables VIII, IX, and X. There were no observed interactions between variety and nutrient application. The application of 0.3% phosphoric acid resulted in a significant decrease in total pounds of fruit produced (Table XI) and increased the days to first harvest (Table XII). However, the summarized data in Table XIII indicated a decrease in the per cent of green placental tissue in fruits developed on the plants receiving the phosphorus foliar sprays. Plants sprayed with urea produced fewer No. 1[4] fruit, and the fruit showed a greater percentage of green pulp (Tables XI and XIII). Perhaps the marginal burning resulting from the urea sprays were in part responsible for these results. The potassium and sucrose sprays had no apparent influence on the tomato plants used in this investigation.

The per cent of green placental tissue was based on arbitrarily selected standards. Values from one to five inclusive were awarded each fruit harvested, depending upon the proportion of observable placenta. Fruits which were externally red and internally devoid completely of any green pigmentation were given a value of five, whereas fruits having a red pericarp and placental tissue showing vivid green pigmentation were valued at one. There were three intermediate values, 2, 3 and 4, respectively. Thus, treatments with the highest values exhibited fruits with the lesser amount of green pulp. The same procedure was followed in those experiments using per cent of "green pulp" as a criteria for comparison.

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[4] No. 1 fruit refers to all red ripe fruit free of any type of external blemishes; globe shape; minimum diameter 2-1/2 inches, and weight range of 4 to 8 ounces per fruit.

TABLE VIII

EXPLANATION OF VARIETAL SYMBOLS USED IN TABLES IX AND X

Symbols	Varieties
A	Uniform Globe S_4
B	Michigan State Forcing x Waltham 4th Generation
C	Northern Hybrid
D	Eureka Hybrid
E	Long Calyx Forcing
F	Michigan State Forcing Medium
G	Michigan State Forcing x Waltham 5th
H	Michigan State Forcing x Improved Pearson (F_9)
I	Spartan Hybrid
J	Washington State Forcing

TABLE IX

THE COMPARATIVE YIELDS OF TEN VARIETIES OF GREENHOUSE-GROWN TOMATOES

Variety Symbols	Treatment Averages of First Five Clusters		
	Total Yields, Lbs. of Fruit per Plant	Total Yields, Lbs. of No. 1 Fruit per Plant	Number of Days From Emergence to Anthesis
A	1.49	1.01	111.5
B	2.18	1.58	103.9
C	2.92	1.26	102.3
D	2.68	1.64	102.8
E	2.01	1.42	110.0
F	2.31	1.52	114.4
G	2.56	1.67	108.9
H	2.45	0.59	102.1
I	2.65	1.85	106.6
J	1.96	0.80	105.0
Difference necessary for significance:			
5% level	0.58	0.39	5.9
1% level	0.77	0.52	7.3

TABLE X

THE FRUIT QUALITY OF 10 VARIETIES OF GREENHOUSE-GROWN TOMATOES

Variety Symbols	Treatment Averages of:		
	Blotchiness of Fruit (%)	Green Placental Tissue (%)	Empty Locule (%)
A	1.4	7.4	1.2
B	3.0	11.8	4.3
C	4.1	13.6	3.1
D	2.2	14.1	1.3
E	8.0	8.4	5.2
F	2.4	9.3	1.7
G	2.6	13.2	2.2
H	3.2	15.6	7.9
I	3.7	11.8	2.2
J	2.8	11.9	3.8
Differences necessary for significance:			
5% level	1.4	2.3	1.6
1% level	1.9	3.1	2.1

TABLE XI

THE EFFECTS OF FOLIAR APPLIED SUCROSE AND MAJOR NUTRIENT ELEMENTS ON THE YIELDS OF GREENHOUSE TOMATOES

Treatments	Total Yields, Lbs. of Fruit per Plant	Lbs. of No. 1 Fruit per Plant
I. Control - No treatment after setting in ground bed	2.57	1.36
II. 0.3 per cent potassium chloride foliage spray weekly	2.35	1.44
III. 0.3 per cent ortho-phosphoric acid foliage spray weekly	1.87	1.31
IV. 0.75 per cent urea spray weekly	2.42	1.17
V. 10 per cent sucrose foliage spray weekly	2.41	1.38
Differences necessary for significance:		
5% level	0.31	0.27
1% level	0.39	0.35

TABLE XII

DAYS TO HARVEST AS INFLUENCED BY FOLIAR SPRAYS OF SUCROSE AND CERTAIN MAJOR NUTRIENT ELEMENTS

Treatments	Number of Days Required for First Harvest
I. Control - No treatment after setting in ground bed	107.5
II. 0.3 per cent potassium chloride foliage spray weekly	107.6
III. 0.3 per cent ortho-phosphoric acid foliage spray weekly	109.6
IV. 0.75 per cent urea spray weekly	104.7
V. 10 per cent sucrose foliage spray weekly	104.3
Differences necessary for significance:	
5% level	4.0
1% level	5.3

TABLE XIII

EXTERNAL AND INTERNAL QUALITY OF TOMATO FRUIT AS AFFECTED BY FOLIAR SPRAYS

Treatments	Blotchiness of Fruit (%)	Green Placental Tissue in Fruit (%)
I. Control - No treatment after setting in ground bed	3.7	12.2
II. 0.3 per cent potassium chloride foliage spray weekly	3.2	11.0
III. 0.3 per cent ortho-phosphoric acid foliage spray weekly	2.6	10.3
IV. 0.75 per cent urea spray weekly	2.9	12.5
V. 10 per cent sucrose foliage spray weekly	3.8	12.0
Differences necessary for significance:		
5% level	1.0	1.6
1% level	1.3	2.1

Experiment D

Yield of Three Greenhouse-grown Tomato Varieties as Influenced by Photoperiod

1. Objective. Preliminary experiments with supplemental light to extend the normal day length to 16 hours using a light intensity of 300 foot-candles applied to the foliage of tomato plants prior to transplanting to the ground bed, provided evidence that yields of fruit subsequently harvested from these plants were significantly increased. Also, it has been previously indicated that the addition of a supplemental illumination to young tomato plants during the winter and early spring months of the year when light is the limiting factor has significantly increased the percentage of fruit set. Further evidence of this has been given by Howlett (23) who maintained that tomato plants with a relatively low carbohydrate and high nitrogen content, which resulted when light was limiting, set submarginal percentages of fruit. This condition was attributed to the elongated pistils resulting from a decrease in the photosynthetic products which thus successfully prevented normal self-fertilization.

It was thereby suggested that tomato seedlings grown during the winter months be subjected to a supplemental illumination to determine what influence the added light would exert on subsequent yields.

2. Methods and materials. Three varieties of tomato, considered to be of the forcing type (two selections of Spartan Hybrid and Washington State Forcing) were germinated in vermiculite in January of 1949. The minimum night temperature throughout this investigation was 60° F. At emergence one flat containing an equivalent number of seedlings of each variety was exposed to a 16-hour photoperiod by which the normal day length was extended by the use of white fluorescent bulbs giving an intensity of 300 foot-candles at the tips of the plants. A similar seeding was exposed only to the normal daily photoperiod during that period. These different illuminations were continued until all the plants matured to "pricking-off"[5] stage. All plants were then transplanted to standard 4-inch clay pots and cultured according to standard commercial greenhouse

[5] A term referring to the physiological age of a tomato plant when the first pair of true leaves have visibly formed.

procedures. During this stage of development and until transplanted to the ground bed an equal number of plants of each variety were exposed to one of the following photoperiodic treatments: (a) naturally-occurring photoperiod maintained during entire life cycle; (b) naturally-occurring photoperiod plus additional light of 300 foot-candles to extend the day length to 16 hours from "pricking-off" until transplanted to ground bed; (c) naturally-occurring photoperiod plus 16 hours of 300 foot-candles supplement, maintained from emergence until transplanted to ground bed.

3. Results. In terms of total yields of "red-ripe" fruit the results obtained were of negative economic importance. Data in Table XIV and Figure 9 indicate a trend toward increasing total yields with increasing photoperiod, however, the results of this phase of the experiment were not significant. Also included in Table XIV is an indication of an increase in total yield of No. 1 fruit at the five per cent level resulting from the supplemental photoperiod. Here one may speculate that the increased light may have resulted in an increase in carbohydrate content which decreased the number of abnormally-shaped flowers as was reported by Howlett (23).

A 7.9% decrease in the number of days necessary to harvest fruit was obtained (data summarized in Table XV and Figure 8) with plants given the additional illumination from emergence to ground bed setting. This same treatment (Table XV) yielded fruit which contained significantly less "green pulp," a condition which is commercially desirable. Varietal differences were not significant.

TABLE XIV

YIELDS OF GREENHOUSE TOMATOES AS INFLUENCED BY DIFFERENTIAL LIGHT SUPPLEMENTS

Treatment Symbols	Total Yield of Fruit, Lbs. per Plant	Total Yield of No. 1 Fruit, Lbs. per Plant
A	10.6	7.0
B	11.2	8.0
C	11.5	8.2
Differences necessary for significance:		
5% level	1.2	1.1
1% level	1.8	1.5

TABLE XV

THE EFFECT OF PHOTOPERIOD ON THE QUALITY OF GREENHOUSE TOMATOES

Treatment Symbols	Days to First Harvest	Green Placental Tissue per Plant (%)
A	163.9	11.4
B	159.5	12.3
C	151.0	12.7
Differences necessary for significance:		
5% level	12.3	1.2
1% level	17.7	1.6

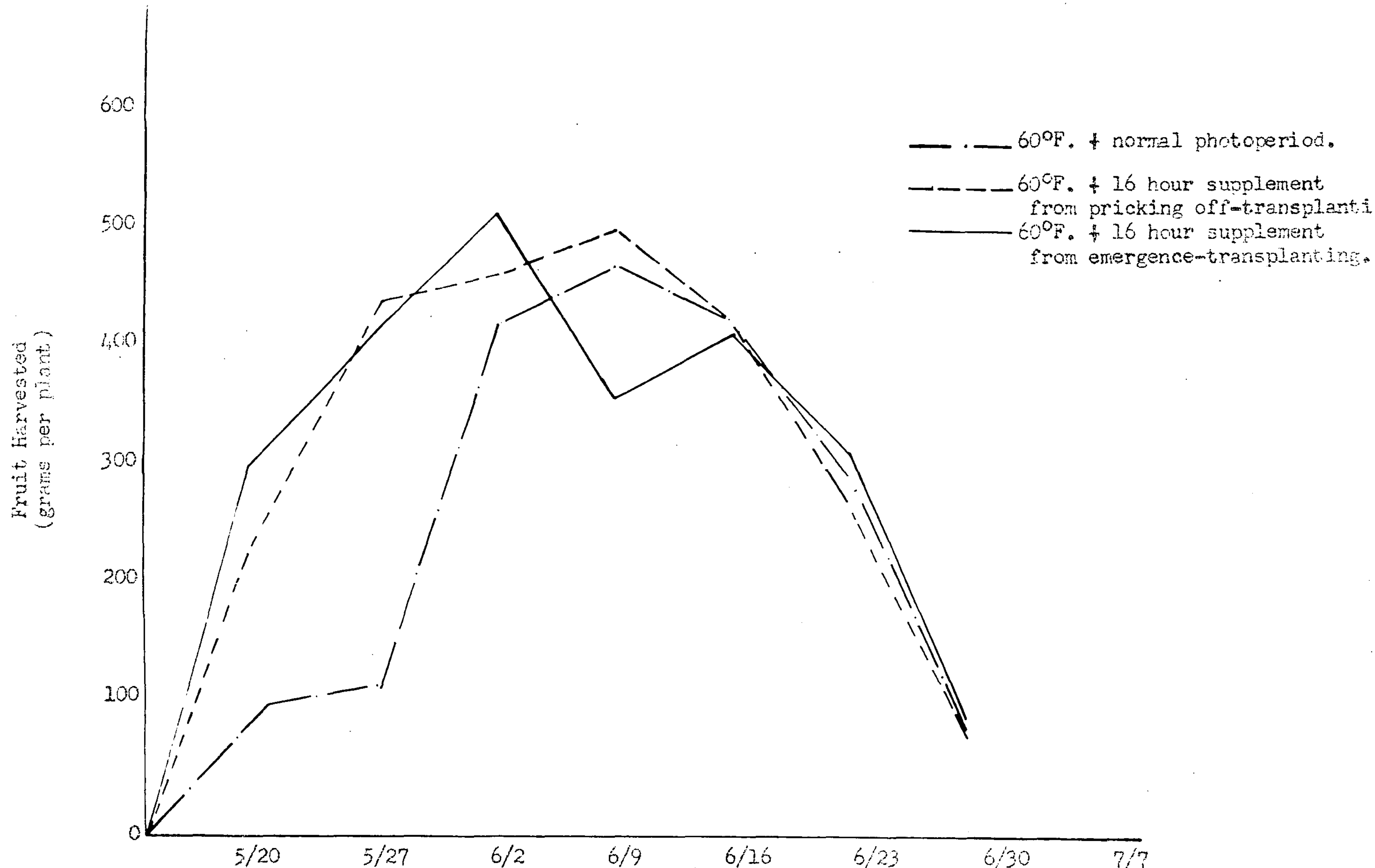

Figure 8
The Effect of Photoperiod on the Accumulative Yield of Early Fruit

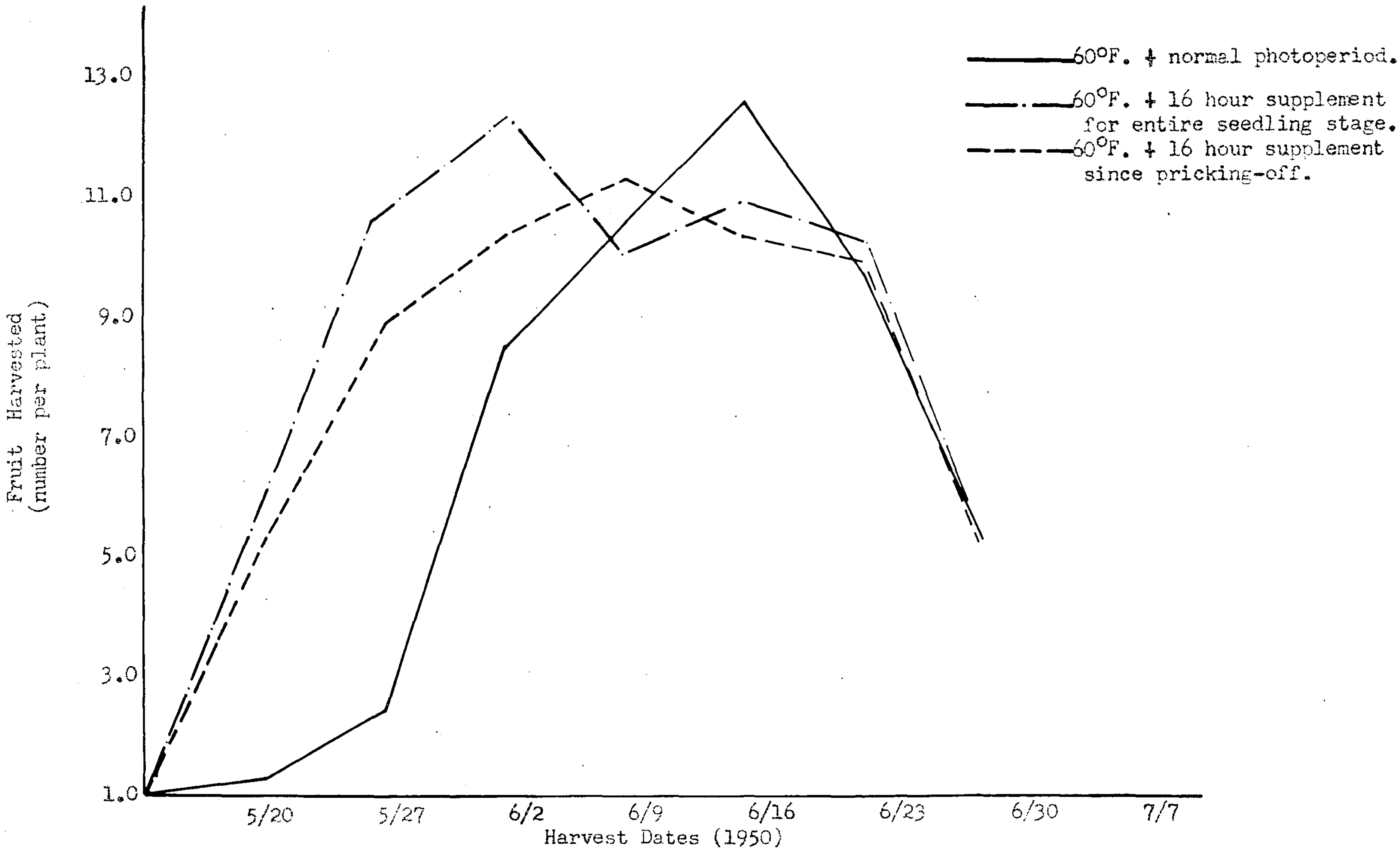

Figure 9
The Accumulative Number of Ripe Fruit Produced as Influenced by the Photoperiod

Experiment E

The Response of Greenhouse Tomatoes to the Interaction of Supplementary Photoperiod and Increased Temperatures

1. Objective. In Experiment B which was conducted with tomato plants exposed to differencial night temperatures the yield data indicate definite optimal night temperatures for the growth and subsequent development of different varieties of tomatoes. In addition, there is some evidence that optimal temperatures exist for specific phases within the developmental periods of any given tomato variety. Results obtained from these experiments corroborated Went's findings covering the thermoperiodic requirements of certain plants (51, 52). These optimum temperature requirements were found to vary not only with reference to a given physiological process or stage of development but also varied for these metabolic phenomena as they were influenced by variations in the environment. Thus it was maintained that the various optimum temperatures whether they be during the photoperiod or during the dark period, were highest during the seedling stage, gradually decreasing with approaching maturity.

It has furthermore been pointed out that this optimum is also influenced by the light intensity during the photoperiod, being lower for lower light intensities. With this information and the data presented by Withrow and Howlett (57, 23), it may be hopothecated that greenhouse-grown tomatoes exposed to supplemental photoperiods during light-deficient periods may respond with significant decreases in floral abnormalities and increase the per cent set, respectively. It was therefore suggested that increased temperatures and supplementary photoperiodic exposures be interacted under the prevailing Michigan environment.

2. Methods and materials. On January 5, 1950, seed of Michigan State Forcing variety of tomato from five different sources were planted in six separate flats of vermiculite. Two flats were then exposed to each of the following minimum night temperatures: 60° F., 70° F., and 80° F. One seeding at each temperature was then exposed to the natural daily photoperiod whereas the other was permitted the natural daily illumination plus artificial light of 300 foot-candles from a series of 40-watt white fluorescent bulbs to extend the normal day length to 16 hours.

These treatments were continued until the plants reached the "pricking-off" stage. . At that time those plants which were grown under each of the afore-mentioned treatments and had matured sufficiently to be "pricked off" were transplanted to standard four-inch clay pots.

In all treatments the originally-designated photoperiod was continued. However, those plants started at 80° F. where-upon reaching the "pricking-off" stage and transplanted were given a 10-degree temperature decrease as well as those started at 70° F. In other words, when the plants under a given treatment were transplanted to individual 4-inch clay pots each minimum night temperature was reduced 10° F., with the exception of the 60° F. treatment, which remained continually at 60° F. The six treatments are presented in tabular form in Table XVI. After transplanted to the ground bed all plants were grown at 60° F. minimum night temperature and with the normal daily photoperiods prevailing in Michigan during the late winter and spring months.

3. Results. The two higher germinating temperatures of 80° F. and 70° F. resulted in the seedlings reaching the "pricking-off" stage 14 days earlier than plants grown at 60° F.

Table XVII and Figure 12 indicate that the increased temperature was responsible for the very significant increase in stem elongation. This information again would corroborate Went's findings (51, 52). As indicated in Table XVIII and Figures 10 and 11, the interaction of the increased light and temperature treatment F did significantly increase the total weight and number of pounds of No. 1 fruit. These findings favorably agree with the data obtained in preliminary investigations apparently the supplementary photoperiod had a marked influence in reducing the number of days required of the fruit to reach maturity (data summarized in Table XIX and Figures 10 and 11). In the same table it will be noted that the per cent of green placental tissue was also individually influenced by both the additional illumination and increased temperature. In Figure 13 a fruit containing a relatively high proportion of green placental tissue is compared with a completely red pulped fruit.

Although five different selections of Michigan State Forcing variety were interacted with the six main treatments, the results obtained were of no apparent significance.

TABLE XVI

EXPLANATION OF TREATMENT SYMBOLS USED IN TABLES XVII, XVIII AND XIX

Treatment Symbol	Minimum Night Temperature	Duration of Minimum Night Temperature	Photoperiod and Light Intensity During Thermal Phase
A	60° F.	From emergence until transplanted to ground bed	Normal photoperiod
B	60°	From emergence until transplanted to ground bed	16 hours photoperiod, 300 f.c. supplement
C	70° F.	From emergence until "pricking off"	Normal photoperiod
	60° F.	From "pricking off" to ground bed	Normal photoperiod
D	70° F.	From emergence until "pricking off"	16 hours photoperiod, 300 f.c. supplement
	60° F.	From "pricking off" to ground bed	
E	80° F.	From emergence until "pricking off"	Normal photoperiod
	70° F.	From "pricking off" until transplanted to ground bed	Normal photoperiod

TABLE XVI (Continued)

Treatment Symbol	Minimum Night Temperature	Duration of Minimum Night Temperature	Photoperiod and Light Intensity During Thermal Phase
F	80° F.	From emergence until "pricking off"	16 hours photoperiod, 300 f.c. supplement
	70° F.	From "pricking off" until transplanted to ground bed	16-hour photoperiod

TABLE XVII

EFFECTS OF SUPPLEMENTARY PHOTOPERIOD AND THERMOPERIOD ON HEIGHTS OF TOMATO SEEDLINGS

Treatment Symbols	Average Heights[1] (cm./plant)
A	11.7
B	15.1
C	23.2
D	24.8
E	34.6
F	34.2
Differences necessary for significance:	
5% level	10.4
1% level	15.1

[1] Plant heights were determined immediately prior to transplanting to ground bed (plants were 10 weeks old).

TABLE XVIII

YIELDS OF GREENHOUSE TOMATOES AS AFFECTED BY THE INTERACTION OF PHOTOPERIOD AND THERMOPERIOD

Treatment Symbols	Total Yields, Lbs. of Fruit per Plant	Total Yields, Lbs. of No. 1 Fruit per Plant
A	5.4	3.5
B	5.9	4.2
C	5.3	3.4
D	5.9	4.4
E	4.0	3.1
F	6.6	5.0
Differences necessary for significance:		
5% level	1.2	0.9
1% level	1.8	1.4

TABLE XIX

QUALITY OF GREENHOUSE TOMATOES AS AFFECTED BY THE INTERACTION OF PHOTOPERIOD AND THERMOPERIOD

Treatment Symbols	Number of Days From Emergence to First Harvest	Green Placental Tissue (%)
A	167.3	24.8
B	164.1	26.1
C	165.8	23.7
D	157.1	28.1
E	168.0	21.3
F	154.2	34.5
Differences necessary for significance:		
5% level	7.5	2.3
1% level	10.6	3.0

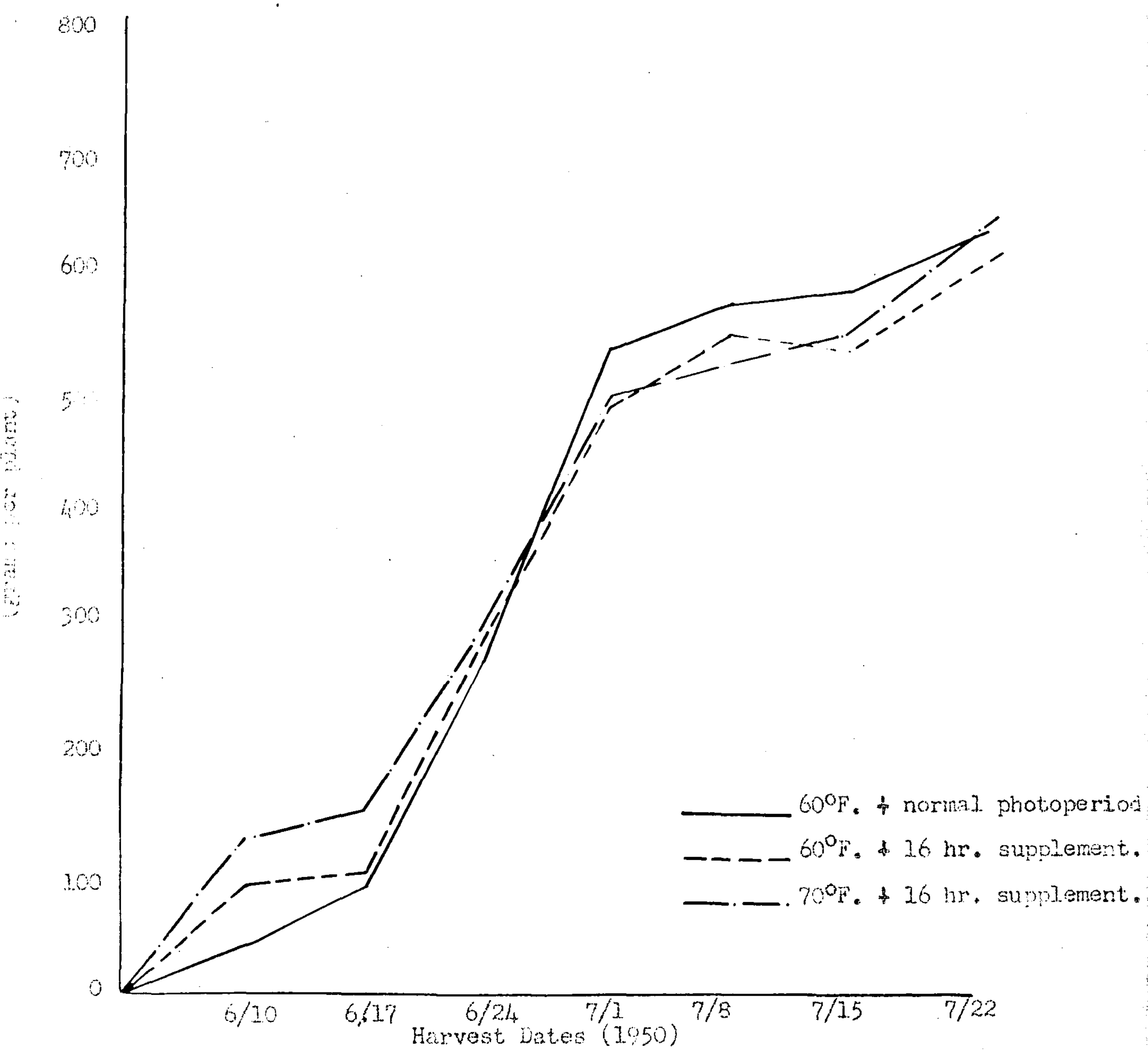

Figure 10
Accumulative Total Yield of Fruit as Influenced by the Interaction of Photoperiod and Temperature

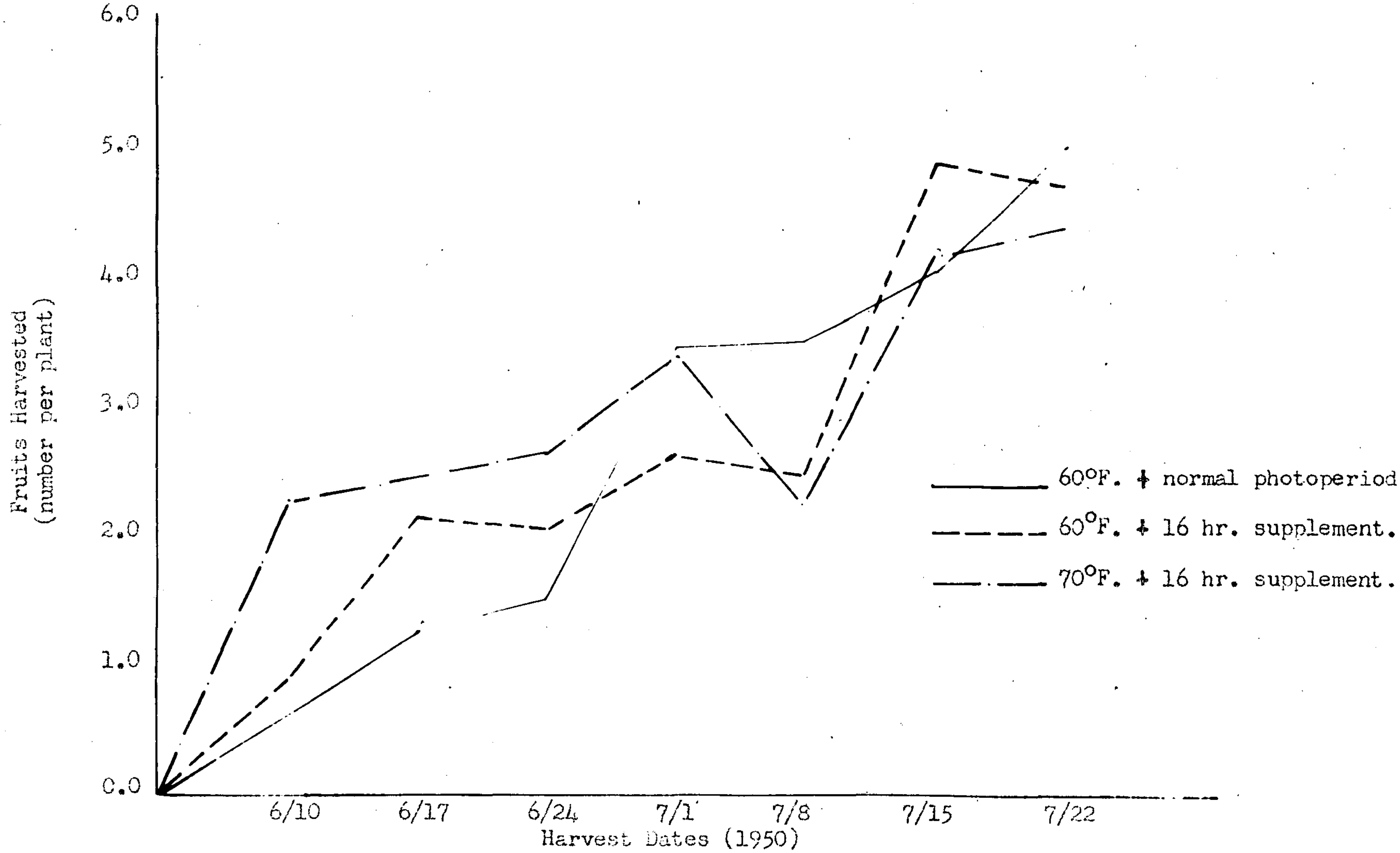

Figure 11
The Interaction of Supplementary Photoperiod and Temperature on Accumulative Number of Fruits

Figure 12. The growth response of tomato seedlings as influenced by the interaction of photoperiod and temperature.
Left to Right:
60°F. night temperature; normal daily photoperiod.
60°F. night temperature; 16 hour supplement.
70°F. night temperature; normal daily photoperiod.
70°F. night temperature; 16 hour supplement.

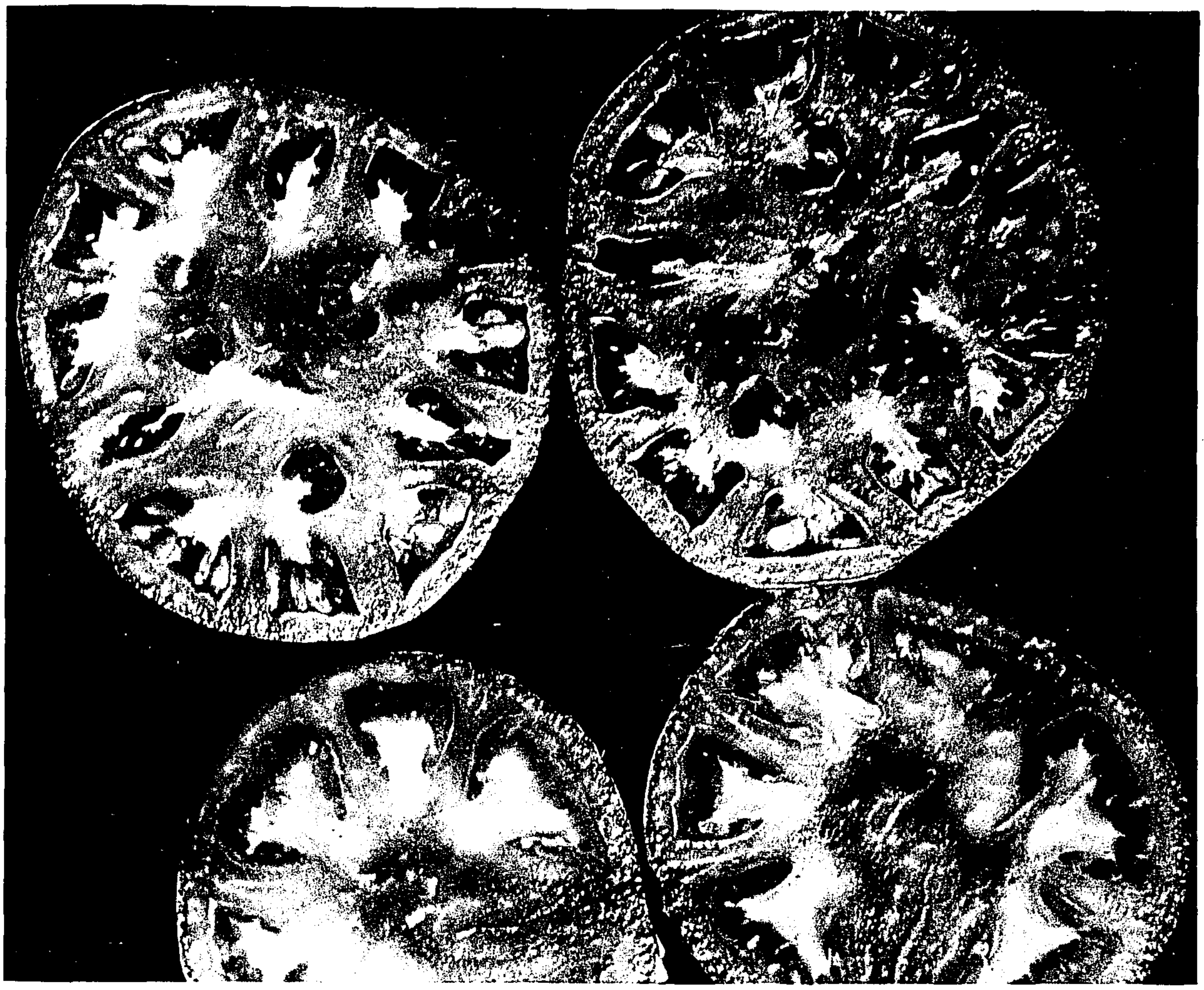

Figure 13. The effect of the interaction of light and temperature on the placental tissue in the tomato fruit.

Top to Bottom:

60°F. night temperature; normal daily photoperiod.

60°F. night temperature; normal daily photoperiod plus 16 hours of 300 f.c. daily supplement.

Experiment F

The Effect of Certain Growth-regulating Chemicals on the Carbohydrate Content of Tomato Plants With Special Reference to Their Subsequent Yield

1. Objective. The classical investigations of Kraus and Kraybill (26), and those of Howlett (22, 23), and Withrow and Withrow (58) have indicated that the low carbohydrate plus a high nitrogen content resulting during the winter and early spring months is responsible for the low percentage of fruit set on greenhouse-grown tomatoes. The environmental factors of temperature and moisture, when limited to a certain degree are considered to reduce the plant's rate of respiration. This in turn theoretically causes an accumulation of carbohydrates.

It was thereby suggested that accumulation of carbohydrates might be accomplished by the use of organic chemicals since recent results indicate that certain growth-regulating compounds have been found to alter the mineral composition (7); amino-acid (15); vitamin C (29) and carbohydrate content of plants (16, 66).

2. Methods and materials. Seed of Michigan State Forcing variety of tomato were sown on January 2, 1950, and grown according to accepted commercial procedures. February 25, ten days prior to transplanting to the ground bed, the tomato seedlings (five replications of five plants per replication) were subjected to one of eight different treatments. The treatments were of two general classes: the first four being the interaction of reduced temperature and moisture levels while the remaining four were of aqueous soil additions of several growth-regulating chemicals having selective inhibitory properties. Maleic hydrazide was found by Schoene and Hoffman (43) to be a unique growth regulant. Hamner (14) observed that roots of kidney bean plants did not grow into or through soil to which beta-methyl Umbelliferone had been added. The root-inducing activity of phenoxy acids was determined by Zimmerman and Hitchcock (66). The heretofore unknown compound, 4-phthalimido-2,6-dimethyl pyrimidine[6] was also used. (Treatments and their abbreviated symbols are listed in Table XX.)

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[6] Supplied through the courtesy of Dr. L. D. Goodhue of The Phillips Petroleum Company.

Eight days following treatment the water loss from each plant was determined six consecutive times at eight-hour intervals (8:00 a.m., 4:00 p.m., and 12:00 midnight). Each pot was enclosed in a pliofilm bag (Figure 14) fastened at the base of the stem, thus exposing only the foliage to cause a weight difference which would result in water lost.

Treatment III was considered as the control for the experiment. Treatments V, VI, VII and VIII were all at 60° F. minimum night temperature. All other temperatures of the experiment were minimum night temperatures. Plants of all treatments were then transplanted to the ground bed and grown according to standard greenhouse procedures.

3. Results. Maleic Hydrazide was the only treatment which did not significantly reduce weight of water loss as determined by comparing weight differences at end of the eight day period following exposure to treatments. The heights of the treated seedlings were apparently decreased only by the influence of the 40° temperature (data summarized in Table XXI). The fresh and dry weights of the roots were decreased by the Maleic hydrazide application (Table XXII). The beta-methyl umbelliferone treatment was only effective in reducing the

Figure 14. Method used to prevent water loss from areas other than the foliage.

fresh weight of roots. Cool temperature and/or low moisture interaction resulted in definite reductions in all indexes of fresh and dry weights of the foliage as well as of the roots. The remaining growth regulators, alpha-ortho-chlorophenoxy propionic acid and 4-phthalimido-2,6-dimethyl pyrimidine, had no apparent effect on the fresh and dry weights of foliage or roots (data summarized in Table XXII and Figure 15). Although there is an interesting comparison of stem growth response as illustrated in Figure 16.

The data in Table XXIII gives evidence to the previous assumption that, if a plant's respiratory processes are reduced, an accumulation of carbohydrates will result; thus we see that limited water supply at both temperatures, 40^{o} F. and 60^{o} F., respectively, caused an approximate 25 to 30 per cent of total sugars[7] in the tops of plants so exposed. The roots, however, had their constituent sugars increased only by the reduced moisture level when grown at the 40^{o} F. level.

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[7] Quantitative analysis of per cent total sugars according to Scott Methods and standard A. O. A. C. procedures on a dry-weight basis.

The organic-chemical treatment of alpha-ortho-chloro-phenoxy propionic acid increased the percentage of sugars in the tops while decreasing them in the roots. Maleic hydrazide on the other hand did not significantly alter the photosynthetic products in the tops, but did cause an accumulation of sugars 45 per cent greater than that of the control plants (Treatment III). These obvious alterations in the ratio of the per cent of total sugar in the foliage and roots can be seen by comparing ratios enumerated in Table XXIII.

The total yields (Table XXIV) of fruit were increased by treatments IV and VIII, but not significantly. The yields of plants treated with Maleic hydrazide were drastically reduced, indicating that the concentration employed in this investigation was obviously toxic. The afore-mentioned data concerning Maleic hydrazide would warrant further investigation with special emphasis on its ability to induce carbohydrate accumulation in the roots perhaps at less toxic concentrations.

TABLE XX

EXPLANATION OF TREATMENT SYMBOLS USED IN TABLES XXI, XXII, XXIII AND XXIV

Treatment Symbols	Treatments
I	40° F. + high moisture level (200 ml./3 days)
II	40° F. + low moisture level (50 ml./3 days)
III	60° F. + high moisture level (200 ml./3 days)
IV	60° F. + low moisture level (50 ml./3 days)
V	Maleic Hydrazide at 0.25 mg./plant
VI	beta-Methyl Umbelliferone (lightly dusted on inside wall of pot as it is not water soluble
VII	alpha-ortho-chlorophenoxy propionic acid at 0.25 mg./plant
VIII	4-phthalimido-2,6-dimethyl pyrimidine at 0.25 mg./plant

Treatment III was used as control

TABLE XXI

WATER LOSS AND HEIGHTS OF TOMATO SEEDLINGS AS AFFECTED BY MOISTURE AND TEMPERATURE LEVELS AND GROWTH-REGULATING CHEMICALS

Treatment Symbols	Treatment Averages	
	Water Loss (gms./plant)	Heights (cms./plant)
I	14.9	17.5
II	6.4	15.0
III	65.6	25.2
IV	23.5	20.2
V	55.1	26.1
VI	34.8	20.6
VII	37.7	23.6
VIII	47.4	21.7
Differences necessary for significance:		
5% level	9.9	6.2
1% level	13.9	8.7

TABLE XXII

FRESH AND DRY WEIGHTS OF TOMATO SEEDLINGS AS INFLUENCED BY ORGANIC CHEMICALS AND LIMITED MOISTURE AND TEMPERATURE

Treatment Symbols	Treatment Averages			
	Foliage Weights (gms./plant)		Root Weights (gms./plant)	
	Fresh	Dry	Fresh	Dry
I	68.7	17.3	39.7	8.7
II	51.0	15.5	34.2	8.5
III	91.7	20.2	70.6	12.0
IV	75.0	18.4	51.0	13.5
V	113.7	23.9	36.3	8.0
VI	81.3	19.4	52.3	10.8
VII	86.7	19.8	59.6	11.8
VIII	72.7	18.2	67.6	11.5
Differences necessary for significance:				
5% level	21.3	3.0	12.9	3.4
1% level	29.7	4.3	17.9	4.6

TABLE XXIII

THE EFFECT OF ORGANIC CHEMICALS AND LIMITED TEMPERATURE AND MOISTURE ON TOTAL SUGAR CONTENT OF TOMATO SEEDLINGS

Treatment Symbols	Total Per Cent Sugar		Ratio-Per Cent Sugar
	Foliage	Roots	Foliage/Root
I	8.9	3.6	2.5:1
II	12.1	5.7	2.1:1
III	9.7	4.0	2.4:1
IV	11.3	3.9	2.8:1
V	8.2	7.3	1.1:1
VI	9.0	3.0	3.0:1
VII	10.5	1.3	8.1:1
VIII	8.2	3.2	2.5:1
Differences necessary for significance:			
5% level	0.9	0.4	
1% level	1.4	0.6	

TABLE XXIV

YIELDS OF GREENHOUSE TOMATOES SUBJECTED TO MOISTURE AND TEMPERATURE REDUCTIONS AND GROWTH REGULATORS

Treatment Symbols	Total Yields, Lbs. of Fruit per Plant	Total Yields, (No. per Plant)
I	4.5	19.0
II	3.4	17.0
III	4.4	23.5
IV	5.5	24.6
V	0.9	3.5
VI	4.3	21.8
VII	4.2	20.6
VIII	5.0	26.9
Differences necessary for significance:		
5% level	1.3	1.9
1% level	1.8	2.6

Figure 15. Growth responses of seedlings as influenced by soil applications of 4-phthalimido-2,6-dimethyl pyrimidine. Left to right, control (non-treated), and 25 parts per million of 4-phthalimido-2,6-dimethyl pyrimidine.

Figure 16. The effect of growth regulating chemicals on the heights of tomato seedlings.

Left to Right:

25 parts per million of 4-phthalimido-2,6-dimethyl pyrimidine.
beta-methyl Umbelliferone dusted on inside of pot.
25 parts per million of alpha-ortho-chlorophenoxy propionic acid.

Figure 17. The comparative heights of seedlings as affected by "hardening" treatments.
Left to Right:
60°F. night temperature; high moisture level.
60°F. night temperature; low moisture level.
60°F. night temperature; 25 parts per million Maleic hydrazide

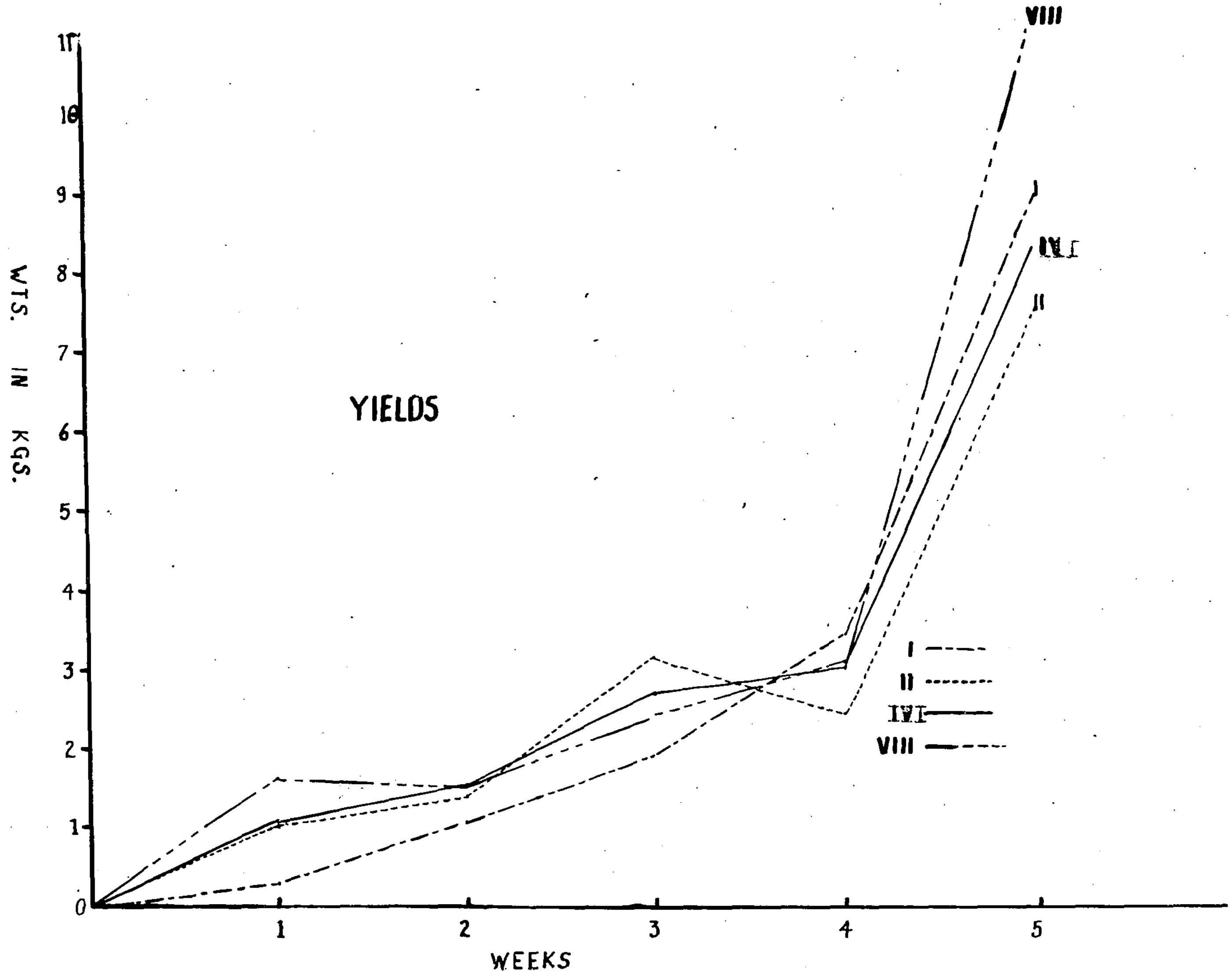

Figure 18
The Effect of "Hardening" Treatments on the Early Yield of Fruit

IV. DISCUSSION

A. Thermoperiod

The optimum environmental conditions have been determined for many plant species either by agrarian practitioners or by carefully-controlled investigations. It is significant to note that many of the different developmental processes in plants are not necessarily correlated with each other. Similarly, it has been aptly demonstrated that conditions essential for the expression or attainment of one phase of development must be fulfilled before a succeeding process can be brought about; essentially exemplifying Lysenko's (28) concepts of phasic development.

F. W. Went (51, 52, 53), who has determined many of the optimum environmental conditions necessary for the development of the tomato plant, has demonstrated that many of this plant's physiological manifestations are due primarily to a phenomenon termed Thermoperiodicity. Just as Hartsema, Luyten, and Blaauw (18) have shown that sliding temperature optimums involving seasonal variations are necessary to complete the life cycle of tulips, so Went has asserted that certain plant responses whether they be growth, flowering, or fruiting, are due to temperature differentials during the light and dark periods (51). Stem elongation as determined by plant heights was found to be significantly altered when grown at various night temperatures.

Figure 2 and Tables V, VI, and VII of the results of Experiment B herein illustrate the marked influence that night temperatures had on the varieties studied, apparently being between 55° F. and 65° F. for both John Baer and Rutgers whereas Early Chatham tomato seedlings attained greater elongation at a point 10 degrees lower. Seedlings of Michigan State Forcing however attained their greatest height at a night temperature of approximately 75° F. Thus, these findings are in part substantiated by Went's observations, although specific comparisons to the thermoperiodic investigations cannot be made due of course to the dissimilarity of the variables employed such as diurnal temperature, varieties, photoperiods, and light intensity. Our data however concur with those of Went's (51, 52) in that plants grown with lower night than day temperatures attain more significant height increases.

Tomato plants of all varieties grown out of doors during the day and at a 60° F. minimum night temperature during May and June of 1949 had an increased dry weight over plants grown at any of the other minimum night temperatures, 40° F., 50° F., and 70° F., respectively (Figure 3, Experiment B). The plants grown at night temperatures lower than 60° F. developed varying degrees of nutritional deficiency symptoms despite soil tests which revealed an ample supply. The conglomerate necrotic and chlorotic lesions made specific elemental deficiency diagnosis almost impossible, however, the spectacular blue-purple coloration resulting from phosphorus deficiencies was discernible.

The dry weights of the seedlings, which may speculatively be considered an index of accumulation of the products of photosynthesis, were significantly higher when the plants were grown at a 60° F. night temperature, whereas those grown at 40° and 50° F. nocturnal minimum yielded obviously less dry weight (Figures 3 and 4). This would suggest opposition to the theoretical concept of a carbohydrate accumulation which may result if the plants' respiration is reduced. The data in Table XXIII will in part substantiate per cent of total sugar accumulation caused by reduced moisture levels, but there is some disagreement when temperature is considered. If one can consider water loss or transpiration, which was markedly influenced by temperature, as an indication of a decrease in the respiratory rates of a plant, then these data herein contained can again be corroborated (Table XXI).

Flowering has been a subject of much concern in recent years. Thompson (46) found that an exposure for as short a period as two days at 40° to 50° F. caused floral inception in celery. This was true whether the low temperature treatment was given during the dark or light phase of the 24-hour cycle. The development of the tulip is controlled by variations in temperature and cessation of its development could be accomplished by temperature either above or below the optimum (18). Premature seeding of lettuce, according to Thompson and Knott (48) is primarily due to relatively high temperatures. There is, however, very little data available at present with respect to temperature effects on flowering in the tomato.

The data herein indicate that there is some relation between temperature and flowering in the tomato. Table VII and Figure 6 illustrate the number of fruits harvested with respect to the minimum night temperature; this may indicate that at the higher temperature of 70° F. more flowers are developed. Although the exact number of flowers initiated on the individual clusters when plants were subjected to various night temperatures is not included, the subsequent fruit count may be used as such an index (Figures 6 and 7). This may be defended on the basis that the developing seedlings were inspected daily and any flowers visibly open were sprayed with 30 parts per million of para-chlorophenoxy acetic acid to insure fruit set, thus giving indirect evidence of the flowers which had developed. The data representing the first three harvests are of special interest in that these fruits developed from the first and second flower clusters. The later-developing clusters are of less significance in this respect since as the season progressed natural temperature and photoperiod increased, thereby making minimum environmental conditions within the greenhouse impossible. Thus as indicated by the data presented, there were more fruits produced at the relatively higher minimum nycturnal temperatures of 60° to 70° F. This was also true for fruit development expressed in weight of fruit which was significantly greater from those seedlings which were given the higher minimum night temperatures during the first nine to ten weeks of their life cycle.

B. Photoperiod

Evidence has been presented by previous investigations with many plant species of the importance of a given photoperiodic exposure before certain developmental phases can be attained; the induction of flowering being of cardinal interest. The investigations herein are concerned only with the tomato, which is generally considered to be day-neutral. However, it has been found that when supplemental lighting is given tomato plants grown in the greenhouse during the fall, winter and early spring months the supplement may exert a definite influence on the plants' growth and development. Of this, however, a carbohydrate relationship has been suspected. Kraus and Kraybill (26) indicated the vegetative and reproductive response of the tomato to be primarily a function of the relative carbohydrate-nitrogen content of the plants; that drastic ratios of one constituent to the other will appreciably alter the normal course of development.

According to Burk (8) a daily photoperiod of eight hours caused an increase in the pistil length whereas plants given a sixteen-hour photoperiod exhibited no abnormal pistil elongation. Microspore degeneration with its resulting pollen sterility and modification in the relative lengths of the pistils and stamens of Lycopersicum esculentum were attributed by Howlett (22, 23) to deficiencies of the products of photosynthesis resulting from short photoperiods of low light intensity. Withrow (57) logically assumes that the carbohydrate content of the plant could be materially increased by the daily use of high irradiances from artificial sources. Certain obvious difficulties associated with greenhouse experiments involving mature productive tomato plants grown under artificial illumination, made it necessary to study the residual effects of the supplemental photoperiod and intensity on mature plants which were exposed to differential illuminations during their seedling stage, which obviously would, if proven satisfactory, be of more economic feasibility for possible commercial adaptation.

When viewing the data presented one quickly can see agreement with the afore-mentioned investigators. Plants produced under the additional light were stockier, darker green, and of superior growth as shown by the greater dry weight and decreasing number of days required for the first anthesis (Tables XV and XVII, and Figure 12). These results favorably agree with previously-published information by Withrow (57). The ratio of the number of normal to abnormally-formed flowers was significantly and favorably altered; thereby increasing the number of more marketably-acceptable fruit which would subsequently develop from them. It was also found that the yields of early harvested fruit, presumably those developing from the first two or three formed flower clusters, were significantly increased by the supplemental photoperiod. This would in part answer the question often asked by commercial greenhouse growers, "How can we force some of those first flower buds to open during the dark winter and early spring days?"

Figures 8 and 9 illustrate that the critically concerned period during which the additional illumination is most efficient appears to extend from the "pricking-off" stage until transplanting to the ground bed. Therefore, it may be suggested that the light is of minor importance to the cotyledons, but is efficiently utilized by the true leaves. This is further substantiated when one considers that the "pricking-off" stage is designated as that phase of growth when the first pair of true leaves are discernible. Another commercially-important phase of the influence apparently exerted by the supplementary light is in the placental coloration. The percentage of "green-pulp" was in part reduced within those earlier maturing fruits by the light supplement (Table XV and Figure 13). The fruits formed on the subsequent clusters were induced and initiated later in the season when the naturally-occurring daily photo-periods had advanced beyond control.

C. Interaction of Thermoperiod and Photoperiod

In the discussion of photoperiod, reference was not made to the possible interactions of increased night temperatures and the supplemental photoperiod. In this respect the results of these investigations proved enlightening.

Seedlings which were grown under the high minimum night temperature of 70° F. plus the 16 hours of 300 foot-candles daily light supplement had their growth and development favorably altered. The most significant advantages were found in the increased number and weight of fruit harvested from the first flower clusters (Figures 10 and 11). In normal greenhouse culture this would be advantageous in the early spring, at a time when the market demand is high for the greenhouse-grown fruit. Correspondingly, the indications of the data obtained from these seedlings which were grown at nights of 70° F. at normal photoperiod (Table XVII) are such that their light allotment was insufficient to supply the plants' increased respiratory needs resulting from the higher temperatures. Those plants which were grown at the 60° F. night temperatures in addition to the daily supplementary illumination gave strong indications of their potentiality, but were not expressed significantly until grown at a ten degree higher minimum night temperature.

D. Foliar Nutrient Sprays

Unfortunately, due to the relative newness of this field of endeavor, few investigations have been reported as to the effect of foliar-applied nutrient sprays to plants. The meager experiment herein reported sufficed only to stimulate interest in further investigations along this line, but time and facilities did not permit. There appeared no apparent significance in the results other than that they demonstrated that certain of the employed treatments were apparently of too toxic a concentration for the existing variables (Tables XI and XIII).

E. Chemical Hardening[8]

This investigation was conducted primarily in an attempt to determine what effect certain growth-regulating chemicals, known to have selective inhibitory properties, have upon the metabolic processes associated with hardening of tomato plants.

In general the most striking information was obtained with the 0.25 mg. per plant soil amendment of 4-phthalimido-2,6-dimethyl pyrimidine. It resulted in an increase in early yield of tomato fruit as well as increasing the total number of fruit harvested (Figure 18 and Table XXIV). In all of the remaining indexes of comparison it did not differ from the non-treated control plants.

Maleic hydrazide, however, yielded striking results in all treatment indexes involved in this investigation. Although causing accumulation in the roots of 45 per cent more total

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[8] A term applied to any treatment that results in a firming or hardening of the tissue of the plant, thus enabling it to better withstand unfavorable environmental conditions.

sugars than the nontreated samples, it had no effect on increasing the yield of fruit. Maleic hydrazide was the only treatment which did not drastically reduce amount of water loss; suggesting perhaps that all treatments other than Maleic hydrazide exerted a definite inhibitory effect on certain of the plants metabolic processes, especially those associated with transpiration. This observation was substantiated by the significantly greater fresh and dry weights of the foliage of plants treated with Maleic hydrazide (Table XXII). An interesting comparison of growth response to Maleic hydrazide can be seen in Figure 17.

When one compares the per cent of total sugars (Table XXIII) it is readily seen that the lower moisture level rather than temperature caused the greatest carbohydrate accumulation. Even more interesting than the comparison of per cent of total sugar of the foliage and roots is a comparison of their ratios to one another. Here it is seen that the mean ratios of most of the treatments is approximately 2.5 to 1 whereas Maleic hydrazide and alpha-ortho-chlorophenoxy propionic acid yield ratios of 1.1 to 1 and 8.1 to 1, respectively (Table XXIII); indicating that Maleic hydrazide caused sugars to accumulate in the roots while alpha-ortho-chlorophenoxy propionic acid induced the accumulation in the foliage. The accumulation of carbohydrates can also be seen by comparing the stem sizes of the plants in Figure 16. The plants receiving these chemical treatments resulted in lower yields.

An interesting question is brought to mind--does a correlation or relationship exist between the total sugar content of the plants' storage organs and its final yield of fruit? These data indicate that there is some relationship at least between the ratio of per cent of total sugars in foliage and roots to yields, and that any deviation above or below the mean ratio results in depressions of yield. Here one may perhaps visualize a similarity to Kraus and Kraybill (26) and Howlett (22) theories of carbohydrate-nitrogen relations to vegetative and fruiting responses of the tomato.

A practical application of these chemical soil treatments may be suggested. If these treatments, by further investigation, are found to be suitable, what objections would there be in using them as possible hardening agents. Reduction of early fruit production has been the main opposition to the use of hardening practices (6). However, the 0.25 mg. concentration of 4-phthalimido-2,6-dimethyl pyrimidine increased the early yields when compared with the treatments which are generally accepted methods of hardening. With labor cost high the need for extra handling and special water and temperature houses may be eliminated; the chemical can be added in the routine watering process. Figures 1 and 16 offer another possible field application concerning increased stem thickness resulting from soil application of 20 to 25 parts per million of a-o-clpp. This increased stem growth of field transplants may be able to withstand windwhipping more advantageously.

V. SUMMARY

Tomato seedlings grown in an environment in which the normal photoperiodic exposure was extended to 16 hours by using 300 foot-candles of white fluorescent light had significantly greater heights and dry weights of foliage and roots. The number of days required for the plants receiving the additional illumination to attain their first anthesis was on the average 3.2 days less than was necessary for those grown under the normal daily photoperiod and intensity.

The minimum night temperature of 60° F. caused significant increase in stem elongation and dry weights, whereas minimum night temperatures of 70° F. resulted in the most significant increase in the yield of immature fruit.

Weekly foliar spray applications of mineral nutrients consisting of 0.3 per cent potassium chloride, 0.3 per cent ortho phosphoric acid, or 0.75 per cent urea and 10.0 per cent sucrose to ten varieties of greenhouse-grown tomatoes during the winter of 1949 and 1950 at 60° F. night temperature yielded little in the manner of an economic advantage. The weekly foliar application of 0.3 per cent ortho phosphoric acid significantly reduced the per cent of green placental tissue of the fruit subsequently produced, but failed to increase yields.

Seedlings of five selections of Michigan State Forcing tomato which were germinated and grown under night temperatures of 70° F. plus an additional light supplement of 16 hours of 300 foot-candles of white fluorescent light yielded 18 per cent greater total weight of fruit and 30 per cent increase in total weight of No. 1 fruit. Correspondingly, these same plants produced fruits for harvest 13.1 days earlier and fruit which contained 29 per cent less green placental tissue.

The investigations concerning the affects of growth-regulating chemicals as hardening agents were as follows: Total weight of the first two weeks of harvest of mature fruit from plants hardened with 25 parts per million of 4-phthalimido-2,6-dimethyl pyrimidine was increased by 12 per cent or 250 grams. A soil application of 25 parts per million of Maleic Hydrazide induced a 45 per cent greater accumulation of total sugars in the roots and a drastic reduction of the fruit yield of the recipient tomato plants. Alpha-ortho-chlorophenoxy propionic acid at 25 parts per million, when applied to the soil, resulted in a 67 per cent decrease in per cent of total sugar in the roots and a subsequent 12 per cent reduction in total number of ripe fruit harvested.

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GROWTH AND DEVELOPMENT OF <u>LYCOPERSICUM</u> <u>ESCULENTUM</u> AS AFFECTED BY THERMOPERIOD, PHOTOPERIOD, CHEMICAL GROWTH REGULATORS AND NUTRITIONAL SPRAYS

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AN ABSTRACT OF THESIS

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The objectives of these studies were to develop economically feasible methods of improving or increasing the number of normal flowers, per cent set, and subsequent fruit quality of the first three clusters developing on tomato plants grown in Michigan greenhouses during the light deficient winter and early spring months. Adjustments of the photoperiods, thermoperiods, light intensities and the application of certain nutrient element sprays and growth regulating chemicals were utilized.

Seven week old seedlings of Early Chatham, John Baer and Rutgers varieties which were grown outdoors during the day were exposed to minimum night temperatures of 40°F., 50°F., 60°F., or 70°F. for five weeks. Significant increases in stem elongation and dry weights resulted from night temperature exposures of 60°F. whereas the most significant yield of immature fruit resulted at the 70°F. exposure.

Seven commercial selections of greenhouse forcing tomato varieties were subjected to minimum night temperatures of 60°F., 70°F., or 80°F. until "pricking-off"; 60°F. or 70° F. night exposures were employed until transplanting to the ground bed, and 60°F. for the remaining developmental periods. A daily light supplement of 16 hours of white fluorescent light of 300 f.c. intensity superimposed upon the normal light intensity and day-length was interacted at all minimum night temperatures prior to ground bed planting. Night temperature exposures of 70°F.

plus the 16 hour light supplement resulted in an 18 per cent greater total weight of fruit, 30 per cent increase in total weight of No. 1 fruit, a 13.1 day earlier harvest, and 29 per cent less green placental tissue in fruit harvested.

Weekly foliar spray applications of aqueous solutions of 0.3 per cent of H_3PO_4; 0.3 per cent KCl; 0.75 per cent urea and 10 per cent sucrose were applied to twelve week old greenhouse grown tomato plants of ten different forcing varieties. No economic advantage resulted from successive applications of these nutrients to the leaves of the tomato plants.

Nine week old tomato plants were subjected to one of the following treatments: 40^{o} F. or 60^{o} F. minimum night temperatures and/or high or low moisure levels; soil applications of 0.25 mg. per plant of Maleic hydrazide, alpha-ortho-chlorophenoxy propionic acid, or 4-phthalimido-2,6-dimethyl pyrimidine; or interior of pot lightly dusted with beta-methyl Umbelliferone.

The Maleic hydrazide treatment resulted in a 45 per cent greater accumulation of total sugars in the plant roots, while alpha-ortho-chlorophenoxy propionic acid resulted in 67 per cent decrease of total sugar in the roots. Both treatments reduced the number of fruit harvested.

Total weights of fruit of the first two weeks of harvest were increased 12 per cent by 4-phthalimido-2,6-dimethyl pyrimidine.

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