THE COMBINED EFFECTS OF NITROGEN NUTRITION, TEMPERATURE AND DAYLENGTH ON GROWTH OF GREENHOUSE AZALEAS

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1958

APPROVED:

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Date thesis is presented May 13, 1958

Typed by Gladys Averette

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Dr. A. N. Roberts for assistance and guidance during the course of the investigations and to Dr. A. N. Roberts and Dr. L. T. Blaney for their constructive criticism of the manuscript.

Recognition is also given Dr. W. B. Bollen and Dr. K. C. Lu of the Department of Bacteriology for their helpful suggestions and guidance in making the nitrogen determinations in this study.

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INTRODUCTION

Applied plant scientists are becoming more aware of the need for studies which emphasize the interrelated effects of environmental factors, both soil and atmospheric, on plant growth and development.

Previous studies on the effects of temperature, daylength, and nitrogen nutrition on growth and flowering of the azalea have mostly considered these factors separately. Consequently it has been difficult to apply the findings from such single factor experiments to practical azalea culture since these three factors, among others, simultaneously act upon the plants. Until these three factors are studied simultaneously, it is difficult, if not impossible, to accurately determine the nitrogen requirements of the azalea under various temperature and daylength conditions.

With this objective in mind a study was undertaken to approach a solution of the problem of growing azaleas under greenhouse conditions by means of growth analysis. By this means the relationship of growth to climatic factors (light and temperature), to the effects of the major nutrient element (nitrogen) and to the differential response of this particular selection of azalea (Hexe var.) was measured.

In order to critically study the interactions between the factors controlling growth of the azalea, a series of studies was necessary. These involve controlled environmental conditions and nitrogen levels to study the effect of these factors on growth and development during each season of the year. Height and weight of the plant material produced was used as a measure of plant response in short term experiments with young vegetative plants, in which flowering response was not a factor. The results from such a series of studies would provide basic information on optimum temperature and daylength conditions for maximum growth and the nitrogen requirements of the plant during each season of the year. This basic information could then be used to define the optimal conditions of culture of the azalea which could be achieved in part through control of temperature, light and nitrogen level.

LITERATURE REVIEW

Soil requirements for azaleas and rhododendrons are well covered by Bowers (3, p. 136), who recommends peat moss at pH 4.5 - 6.0 as a growing medium. Monthly applications of sulfur are suggested to maintain the required acidity. Azalea soils should be moist, well aerated, spongy, and of a fibrous nature with good drainage qualities. The shallow fibrous root system of azaleas responds quite markedly to soils containing abundant moisture that are well aerated. He points out that sawdust may be used if sufficient nitrogen is added to offset any nitrogen depletion resulting from nitrate assimilation by the micro-organisms decomposing the sawdust.

Bosley (2, p. 33-35) believes tilth and porosity of the soil mixture to be more vital to the azalea than acidity, but subscribes to the well aerated conditions put forth by Bowers.

Nisen (12) theorizes that mineral deficiencies, especially iron, will cause chlorosis in the azalea if the pH of the growing medium is not low. He considers the optimum pH of the growing medium for azaleas to be between 4.0 and 6.0.

Shanks, Link and Preston (13, p. 441-445) found that the number of flowering stems as well as the number and size of flowers per plant in most azalea varieties tested increased with an increase in available nitrogen. Comparatively low levels of phosphorus and potassium were found to be sufficient for satisfactory flower production. Higher levels of these two elements resulted in fewer flowers per plant. A high potassium level resulted in smaller flowers.

Kiplinger and Brosser (9, p. 393-395) studied multiple flower bud production in the azalea. They maintained three levels of nitrate in an acid peat medium with ammonium sulfate at the rate of one ounce per two gallons of water. The three levels were 10-25 ppm nitrate (low), 25-50 ppm (medium) and above 50 ppm (high). They found increased numbers of flower buds and similarly numbers of multiple buds at successively higher nitrate levels. Later work of Kiplinger and Nelson (10, p. 16) confirmed these results. Furthermore, a low level of nitrogen (0-10 ppm) in an acid peat moss medium resulted in many blind shoots and few shoots with multiple buds. Plants grown at a high level of nitrogen (50-75 ppm), however, produced few blind shoots and many shoots with multiple buds.

A more recent study shows that the ammonium form of nitrogen is more quickly assimilated and used by the azalea than the nitrate form. Colgrove and Roberts (5, p. 522-536) found the ammonium form of nitrogen gave better plant growth with the Hexe variety of <u>Rhododendron</u>

obtusum than did the nitrate form. Smaller quantities of ammonium than nitrate nitrogen were required to produce satisfactory plant growth and foliage color. However, ammonium concentrations above 100 ppm decreased growth. Similarly, reducing the ammonium concentration and increasing the nitrate concentration decreased growth.

Earlier work by Cain (4, p. 161-166) with Highland blueberries indicated also the ammonium form of nitrogen to be superior to the nitrate form in the growth and development of this ericaceous plant. Cain believed ammonium might be essential for blueberry growth and nitrate nitrogen might be associated in some way with iron nutrition. In acid soils naturally favorable for the growth of blueberries, denitrifying bacteria predominate and rapidly convert nitrates into the ammonium form.

The amount of literature published on the forcing of azaleas attests to the economic importance of this florists' crop. From a review of recent literature, Nisen (12) concluded that the azalea was insensitive to photoperiod. He reports temperature to be the principal factor in flower bud initiation and that high temperatures (18° C minimum) are necessary for flower bud induction.

Skinner (14, p. 1007-1011) studied the factors influencing shoot growth and flower bud formation in young azalea plants. He found that shoot growth about doubled when the temperature was increased 25° F from a range of 50-55° F with a 13-hour day. However, shoot growth about doubled also when the period of illumination was increased from 13 hours to continuous illumination while the temperature was kept unchanged at 50-55° F. At temperatures of 75-80° F increases in daylength from 13 hours to continuous illumination had little effect on shoot production. With continuous illumination shoot growth was about the same at both high (75° F) and low (50° F) temperatures. The effect of temperature on shoot elongation was not pronounced in mature plants. Nisen (12) also had concluded that temperature seemed to be the limiting factor for vegetative growth in young cuttings and plants, whereas in mature plants the limiting factor was daylength.

The role of light intensity is mentioned briefly by Doorenbos (6, p. 141-146). He found rhododendrons and azaleas to be among those rare plants which remain healthy and vigorous in the low intensity light of winter.

METHODS AND MATERIALS

Basically the purpose of this study was to correlate seasonal variations in temperature and daylength with the nutritional requirements of azaleas. This objective was approached by means of several factorials conducted in each of four seasons. The 3x3x2 factorials consisted of three nitrogen levels, three temperature ranges and two daylengths, totaling 18 treatments for each season.

Rooted cuttings of Rhododendron obtusum, var. Hexe were used in all the experiments. The cuttings were taken from the parent plants two months prior to the date they were to be used to allow sufficient time for a good root system to develop before experimental treatment was started. At the beginning of each seasonal experiment uniform plants, 6.5 ± 1 centimeters long and weighing 2.5 ± 1.0 grams, were selected.

The seasonal effect of daylength and temperature on nitrogen requirements was studied by dividing the experiments into four arbitrary periods of 3-months each. These are referred to as "seasons" hereafter. The durations of the seasons were as follows: I - April 1, 1957 to June 30, 1957; II - July 1, 1957 to Sept. 30, 1957; III - Oct. 1, 1957 to Dec. 31, 1957; and IV - Jan. 1, 1958 to March 31, 1958.

Three sections in the greenhouses were maintained at night temperatures of 50, 60 and 70° F, respectively. An attempt was made to maintain day temperature within 10° F of the night temperature by means of evaporative coolers. In each section one-half of the plants every season were grown under the natural prevailing daylengths and the remaining half were grown under an 18-hour photoperiod. The 18-hour photoperiod was provided by extending the prevailing daylength with artificial illumination provided by incandescent lamps placed 30 inches above the plants and controlled by automatic timers. Light-tight black cloth curtains were drawn between the two benches at 5:00 p.m. daily to prevent light from the illuminated benches from influencing the plants under prevailing daylengths. During Season I, 200-watt lamps were used to provide the 18-hour photoperiod. However, under these lamps the temperature rose to 6-10° F above that on the unlighted benches. Therefore, warm-white flourescent lamps were used in the remaining seasons to avoid this heating. Light intensities ranged from 115 foot candles at the outer edge of the bench to 180 foot candles directly under the lamps.

Realizing the need for a standardized growing medium upon which to base the nitrogen studies, an exploratory experiment was conducted during the first three months of 1957. Douglas fir sawdust was used as a base for the standard mixture because of its low nutrient content and satisfactory aeration and drainage qualities. Sawdust, sawdust and peat moss, and sawdust and clay loam were compared in this preliminary experiment. Also, varying amounts of nitrogen, phosphorus, potassium and minor element mixtures were incorporated into the test mixtures to find the approximate needs of azaleas under these conditions. On the basis of the results obtained, unadulterated Douglas fir sawdust was selected as the growing medium in the several experiments. Only sawdust which had been aged for a year was used.

Three arbitrary levels of nitrogen, expressed as percentage available nitrogen based on an average of 385 grams of sawdust per gallon can, were used in each seasonal experiment. The following amounts of urea-formaldehyde nitrogen fertilizer (38% N) were used to establish the three levels of total nitrogen: low- 9 grams per gallon can (0.88% available N); medium- 11 grams per can (1.08% N); and high- 13 grams (1.28% N).

To each can was added potassium (fritted), 5 grams, phosphorus (treble-superphosphate) 4 grams, and minor elements (Es-min-el[1], a combined form of minor elements) 0.84 grams. Calcium and magnesium were supplied in phosphate and Es-min-el, respectively.

[1] see Appendix

During Season IV a dilute nutrient solution was used in place of these solid fertilizers. Hoagland and Arnon's (8, p. 31) four-salt solution, containing ammonium sulfate as the source of nitrogen, was used at a concentration of 50 ppm total nitrogen. This solution was applied by the "slop culture" method at the rate of 150 ml. per can. The feeding schedule was as follows: every four days for the high level (40-60 ppm total nitrogen), every eight days for the medium level (25-40 ppm N), and every sixteen days for the low level (10-25 ppm N).

During each of the four growing seasons, Simplex soil tests were made every ten days to determine the level of NH_4-N and NO_3-N available at each nitrogen level. Five cans at each nitrogen level were placed on each bench for the purpose of furnishing sampling material for nitrogen determinations. These cans contained no plants but were watered and treated the same as the cans containing plants. The relative amounts of nitrogen being released by the urea-formaldehyde formulation were shown by these tests. In the second and following seasons the quick tests were supplemented at monthly intervals by more accurate laboratory analyses for ammonium and nitrate nitrogen. The laboratory soil testing procedure was essentially the same as that used by Bollen, (1, p. 1-3). Sawdust samples were taken from the cans and aliquots of each sample were weighed and dried for 24 hours at 90° F, and then reweighed to determine moisture content. Ammonium and nitrate determinations were based on dry weight of the samples.

At the beginning of each season, 180 plants were planted singly in the cans containing the sawdust in which the various fertilizer elements had been incorporated, or in the case of Season IV, were planted in sawdust containing no fertilizers. Sixty plants were used in each nitrogen series. Twenty plants at each nitrogen level were placed in each of the three greenhouse sections. Ten of those were maintained under the 18-hour photoperiod and ten under the prevailing daylength. This provided ten replications of each nitrogen level which were arranged in five randomized blocks on each bench. The plants were then grown under the several treatments for three months. During each three month period, pinches were made monthly as needed to control plant growth and shape. A pinch consisted of the removal of the growing tip of a vegetative shoot to stimulate branching and to prevent uneven growth. The dry weights of the shoots removed by pinching were added to that of the intact plant at the end of each season to determine the total dry matter produced.

At the end of each three month period the plants within a treatment were removed and growth measurements recorded. The tops were severed from the roots at the crown. Plant height from the crown, or soil line, was recorded in centimeters. The number of breaks and growing points were recorded for each plant. The term "breaks", as used here, refers to the number of times each main stem divided and produced two or more vegetative shoots. The term "growing points" refers to the number of terminal vegetative shoots.

Nitrogen deficiency symptoms were scored on an arbitrary scale as follows: 1- no deficiency, 2- less than half of the leaves showing nitrogen deficiency, and 3- half or more of the leaves showing nitrogen deficiency. Scorch, or foliage burning resulting from unbalanced nutrition, was recorded on the same arbitrary scale. Plant weight was recorded as total dry matter. The tops and roots were washed and then dried for 48 hours at 75° C before weighing.

The data obtained from these observations was subjected to analysis of variance for interpretation.

RESULTS OF SEASONAL EXPERIMENTS

In this study of the interaction of the major factors on growth of greenhouse azaleas, season is of importance only as it modifies temperature, light and nitrogen nutrition. In order to measure the relative influence of each of these factors on plant growth and development in a factorial study of this type, it is necessary to control within rather narrow limits the factors being considered. The extent to which these factors can be controlled and studied in various seasons depends upon the facilities available. To interpret the results of these several experiments and evaluate the relative influence of temperature, light and nitrogen nutrition on plant growth, we must consider first the degree of control achieved and the influence of season on each of the several factors studied.

Night temperatures were maintained within the desired 50±4°, 60±4° and 70±4° F ranges during each of the four seasons. However, control of day temperatures presented a problem during certain seasons because of the limitations of the cooling equipment. During Seasons I, III and IV, day temperatures ranged between 50-65, 60-75, and 70-84° F in the 50, 60 and 70° F houses respectively. During Season II, the respective temperature ranges were 50-75, 60-88, and 70-100° F. The daily mean temperatures for the four seasons were 60° F in the 50° F night temperature treatment, 71° F in the 60° F night treatment, and 81° F in the 70° F night temperature treatment. During Seasons I, III and IV the mean daytime temperatures were 57° F, 67° F and 77° F for the respective night temperature treatments. In Season II the respective mean temperatures were 62° F, 74° F and 85° F.

Prevailing daylengths of course varied with season, ranging from 8.8 to 12.7 hours during Season I, 12.7 to 15.6 hours during Season II, 15.6 to 11.8 during Season III, and 11.8 to 8.8 hours during Season IV. Mean prevailing daylengths during each season are shown in Table I. Light intensity varied from day to day and from season to season.

Table 1. Mean prevailing daylength during each season.

Season	Hours
I	14.2
II	13.7
III	11.0
IV	10.8

The level of available nitrogen in each nitrogen series was influenced indirectly by seasonal changes in temperature and light intensity. At the higher temperatures the release of nitrogen from the urea-formaldehyde source was accelerated, while at lower temperatures (50° F night temperature) this release was retarded. The average level of available nitrogen in each season is given in Table 2.

It must be kept in mind that the same amounts of fertilizers were used in each of the first three seasons. The observed differences in available nitrogen between seasons are considered to result from differences in temperature, and possibly light intensity (plant utilization) during Season III. In Season IV a lower level of available nitrogen was maintained by using the dilute nutrient solution feeding method.

Table 2. Average level of available nitrogen as affected by season and nitrogen supply, (in parts per million).

Season	Low	Medium	High
I	59	79	107
II	66	100	108
III	99	199	195
IV	17	31	50

Because the growth responses recorded for each season, total dry weights, plant heights, numbers of breaks and growing points, and symptoms of nitrogen deficiency, must be considered as resulting from separate experiments of an overall study, the results for each season are considered separately.

Season I.

Decomposition of the urea-formaldehyde fertilizer increased with higher night temperatures. The average total available nitrogen at 50° F night temperature was 52, 74, and 97 ppm respectively, in the low, medium and high nitrogen series. At 60° F the respective available nitrogen totals were 60, 80, and 106 ppm; while at 70° F they were 66, 85, and 119 ppm. These relationships are presented graphically in Figure 2.

On the basis of the several growth measurements the medium nitrogen level (averaging 80 ppm nitrogen) was the most favorable, (Table 3a). The plants grown at this level of nitrogen produced approximately five times more total dry weight than those at the low level (averaging 59 ppm N), and two and one-half times more than those at the high nitrogen levels (averaging 107 ppm N).

In Figures 1a and 1b are shown the combined effects of nitrogen and temperature on plant growth, expressed as plant height and total dry weight. These data indicate that maximum growth both in height and weight was obtained somewhere near the high level (97 ppm) of nitrogen when night temperatures were maintained at 50° F. As temperature was increased from 50° to 70° F, significant increases in growth were obtained with each 10° increase in temperature with the medium nitrogen level (80 ppm). The low and high nitrogen series gave varied responses to the 60 and 70° F temperatures, possibly because nitrogen was out of balance in these two nitrogen series.

Data presented in Table 3b indicate plant height increased as temperature was increased from 50 to 70° F. These growth responses find further expression in the nitrogen deficiency symptoms observed in these plants. As temperature increased to 70° F, the nitrogen deficiency index increased accordingly.

Extending the daylength during Season I did not significantly increase total dry weight nor plant height (Table 3c).

Table 3. Effects of nitrogen level, night temperature and daylength on certain growth responses of the azalea, Season I.

a. Nitrogen level:*

Treatment	Dry Weight**	Growing Points	Nitrogen Deficiency	Breaks	Height**
Low	3.13	5.16	1.71	0.93	8.31
Medium	16.23	8.23	1.60	1.78	11.13
High	6.37	6.16	1.90	1.15	8.31
L.S.D. 5%	3.14	1.20	0.25	0.27	0.99

b. Night temperature:*

Treatment	Dry Weight	Growing Points	Nitrogen Deficiency	Breaks	Height
50 degrees	7.79	6.50	1.60	1.11	8.71
60 degrees	8.04	6.33	1.60	1.31	8.68
70 degrees	9.91	6.73	2.01	1.43	10.36
L.S.D. 5%	3.14	1.20	0.25	0.27	0.99

c. Daylength:***

Treatment	Dry Weight	Growing Points	Nitrogen Deficiency	Breaks	Height
18 hours	8.87	6.44	1.75	1.30	9.37
Prevailing	8.29	6.60	1.72	1.27	9.13
L.S.D. 5%	2.56	0.98	0.21	0.22	0.81

*figures denote averages of 60 plants
**weight is expressed in grams, height in centimeters
***figures denote averages of 90 plants

Figure 1a. Effect of temperature and nitrogen on plant height, average of 20 plants, (composite of 2 daylength treatments), Season I.

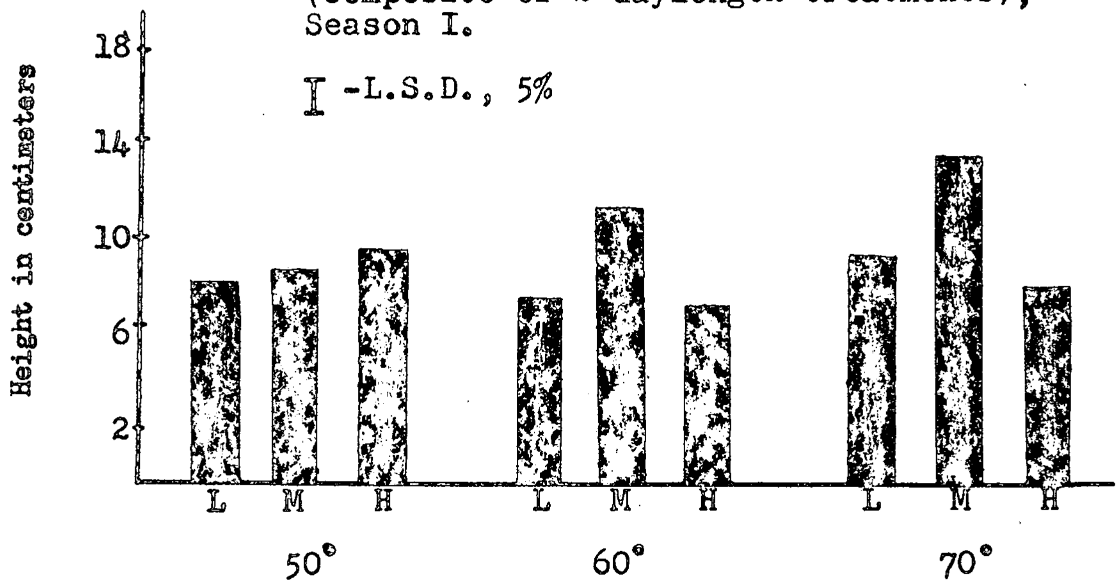


Figure 1b. Effect of temperature and nitrogen on total dry weight, average of 20 plants, (composite of 2 daylength treatments), Season I.

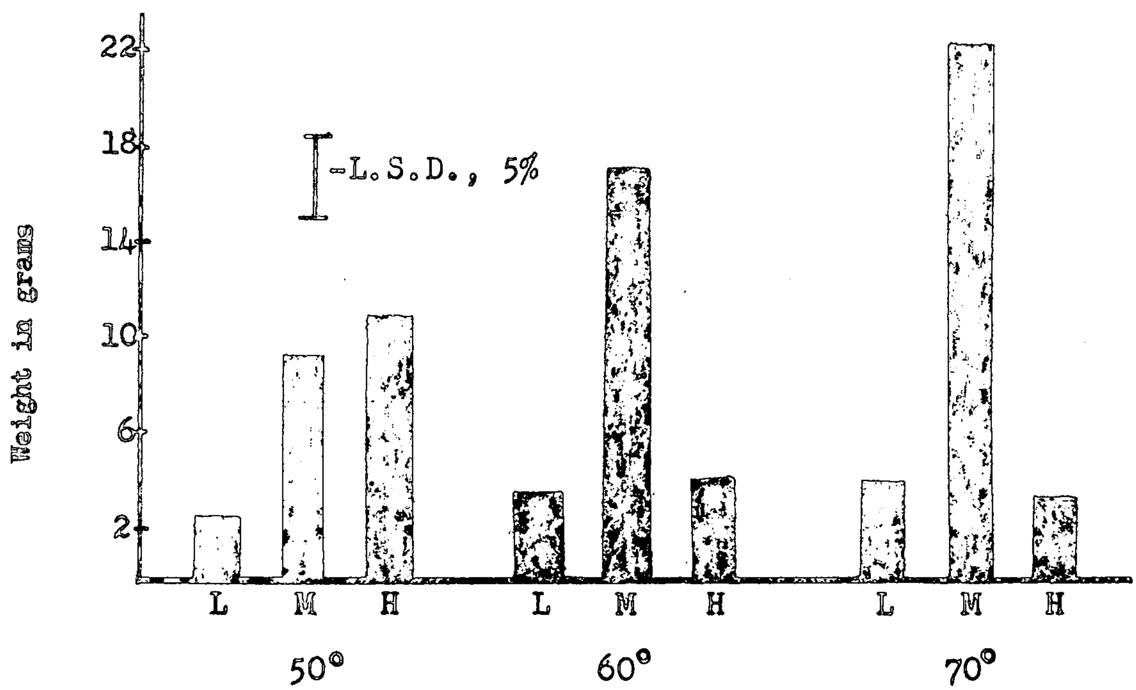
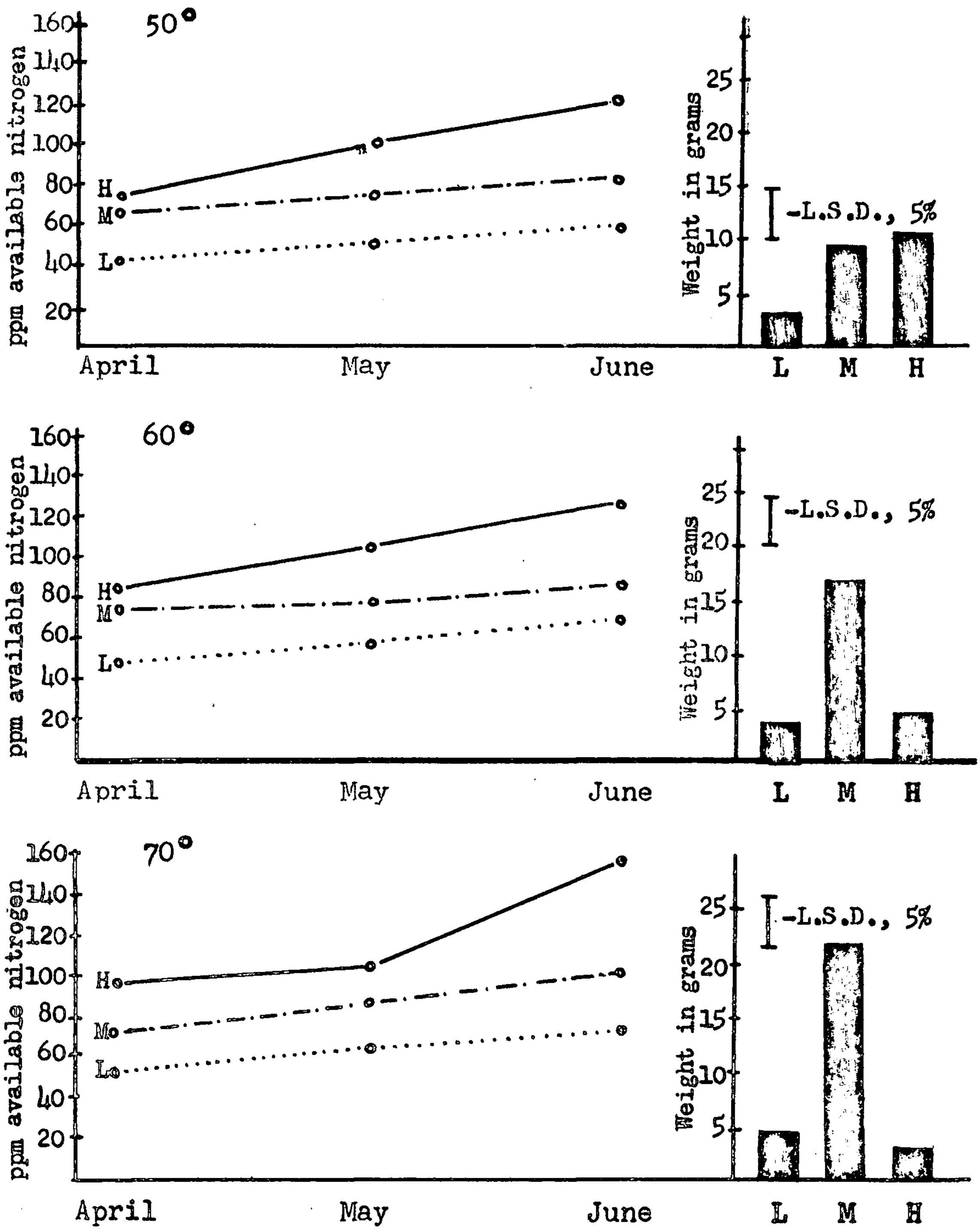


Figure 2. Monthly fluctuations in level of available nitrogen at the three night temperatures with corresponding average dry weight of plants, Season I. *



*H, M, and L, denote the high, medium, and low nitrogen series respectively.

Season II

During Season II the average total available nitrogen at 50° F night temperature was 59, 82, and 101 ppm, respectively, in the low, medium and high nitrogen series. At 60° F the respective amounts of available nitrogen were 66, 104 and 118 ppm; while at 70° F the amounts were 74, 115 and 106 ppm respectively. As seen in Figure 4, the plants had more total available nitrogen during the first two months at the successively higher night temperatures. However, excessive decomposition of the urea-formaldehyde and excessive leaching from heavy watering during the warmer temperatures that prevailed in Season II resulted in less available nitrogen in the 60 and 70° F houses during the latter part of the season. In the 70° F house, daytime temperatures were as high as 100° F during some of the warmer days. These excessive temperatures complicated the available nitrogen levels. For example, the medium nitrogen series had 115 ppm available nitrogen while the high nitrogen series had but 106 ppm at the higher night temperature treatments.

Maximum growth was obtained at the medium (100 ppm average) nitrogen level (Table 4a). Slightly less growth was made at the high (108 ppm average) nitrogen level.

The combined effects of nitrogen and temperature on plant height and dry weight are shown in Figures 3a and 3b.

These data indicate that maximum growth, both in height and dry weight, was made at the medium (82 ppm) level of nitrogen in the 50° F treatment. No significant variations in growth were obtained at the higher night temperatures.

Plant height tended to decrease with increasingly higher night temperatures (Table 4b). Other growth measurements did not vary significantly under the three night temperature treatments.

Plant height increased significantly during this season under extended photoperiod (Table 4c); on the other hand, total dry weight decreased significantly when the photoperiod was extended to 18 hours.

Table 4. Effects of nitrogen level, night temperature and daylength on certain growth responses of the azalea, Season II.

a. Nitrogen level:*

Treatment	Dry Weight**	Growing Points	Nitrogen Deficiency	Breaks	Height**
Low	14.0	5.10	1.33	1.15	9.70
Medium	18.0	6.20	1.18	1.33	10.73
High	15.2	5.88	1.31	1.25	10.23
L.S.D. 5%	2.7	0.97	0.19	0.17	0.75

b. Night temperature:*

Treatment	Dry Weight	Growing Points	Nitrogen Deficiency	Breaks	Height
50 degrees	16.2	5.65	1.25	1.26	10.51
60 degrees	16.3	5.90	1.23	1.23	10.20
70 degrees	14.6	5.63	1.35	1.25	9.95
L.S.D. 5%	2.7	0.97	0.19	0.17	0.75

c. Daylength:***

Treatment	Dry Weight	Growing Points	Nitrogen Deficiency	Breaks	Height
18 hours	14.6	5.76	1.32	1.26	10.64
Prevailing	16.9	5.68	1.23	1.23	9.80
L.S.D. 5%	2.2	0.79	0.15	0.13	0.61

*figures denote averages of 60 plants
**weight is expressed in grams, height in centimeters
***figures denote averages of 90 plants

Figure 3a. Effect of temperature and nitrogen on plant height, average of 20 plants, (composite of 2 daylength treatments), Season II.

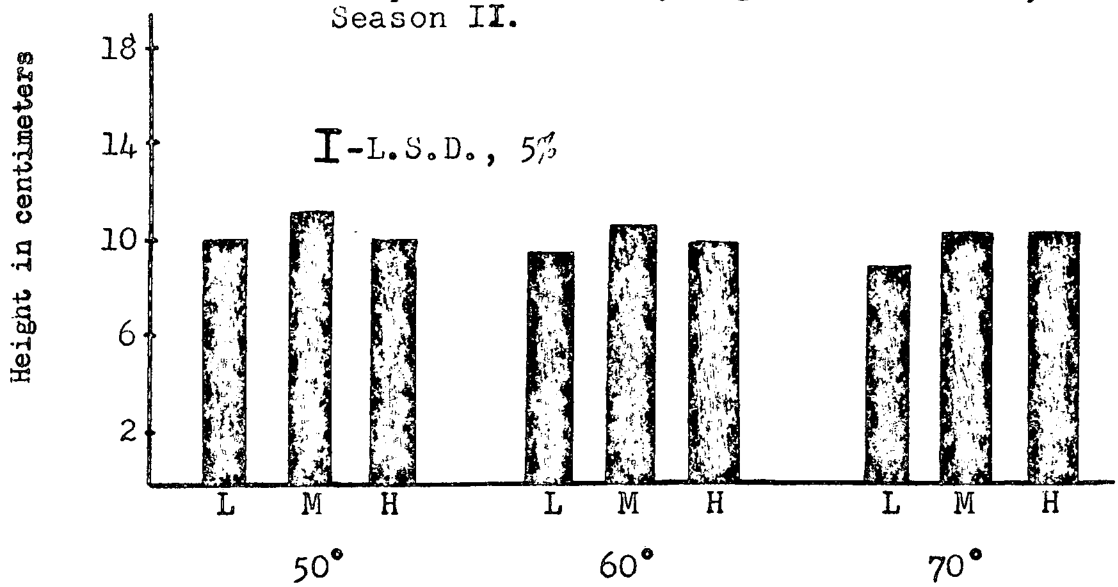


Figure 3b. Effect of temperature and nitrogen on total dry weight, average of 20 plants, (composite of 2 daylength treatments), Season II.

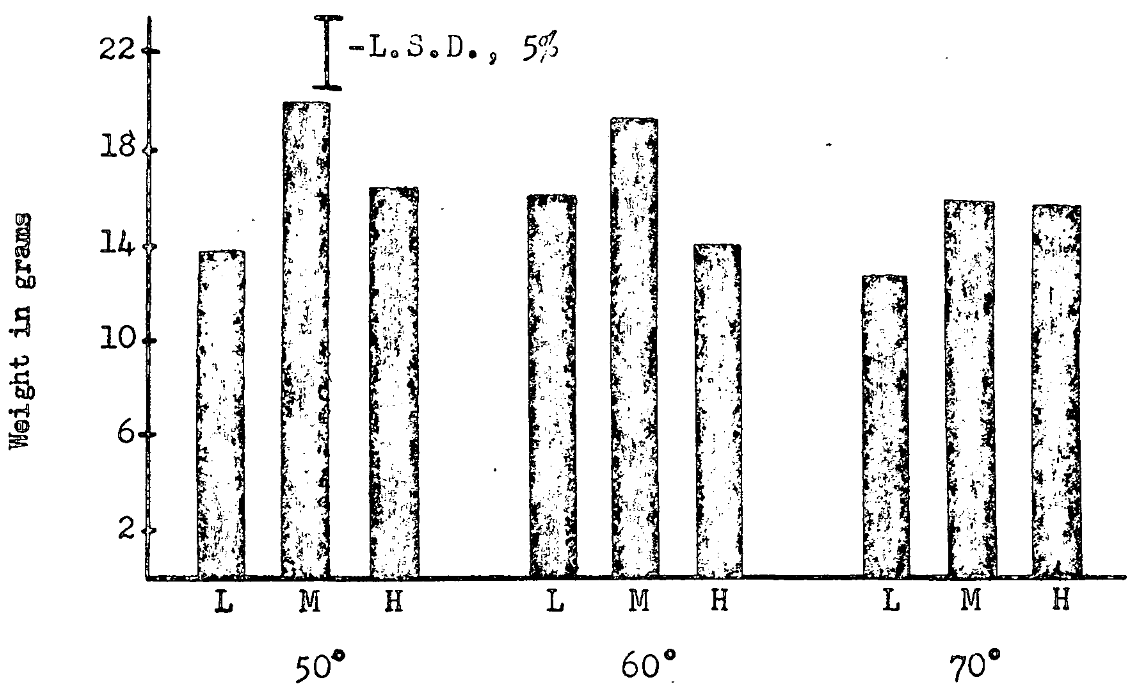
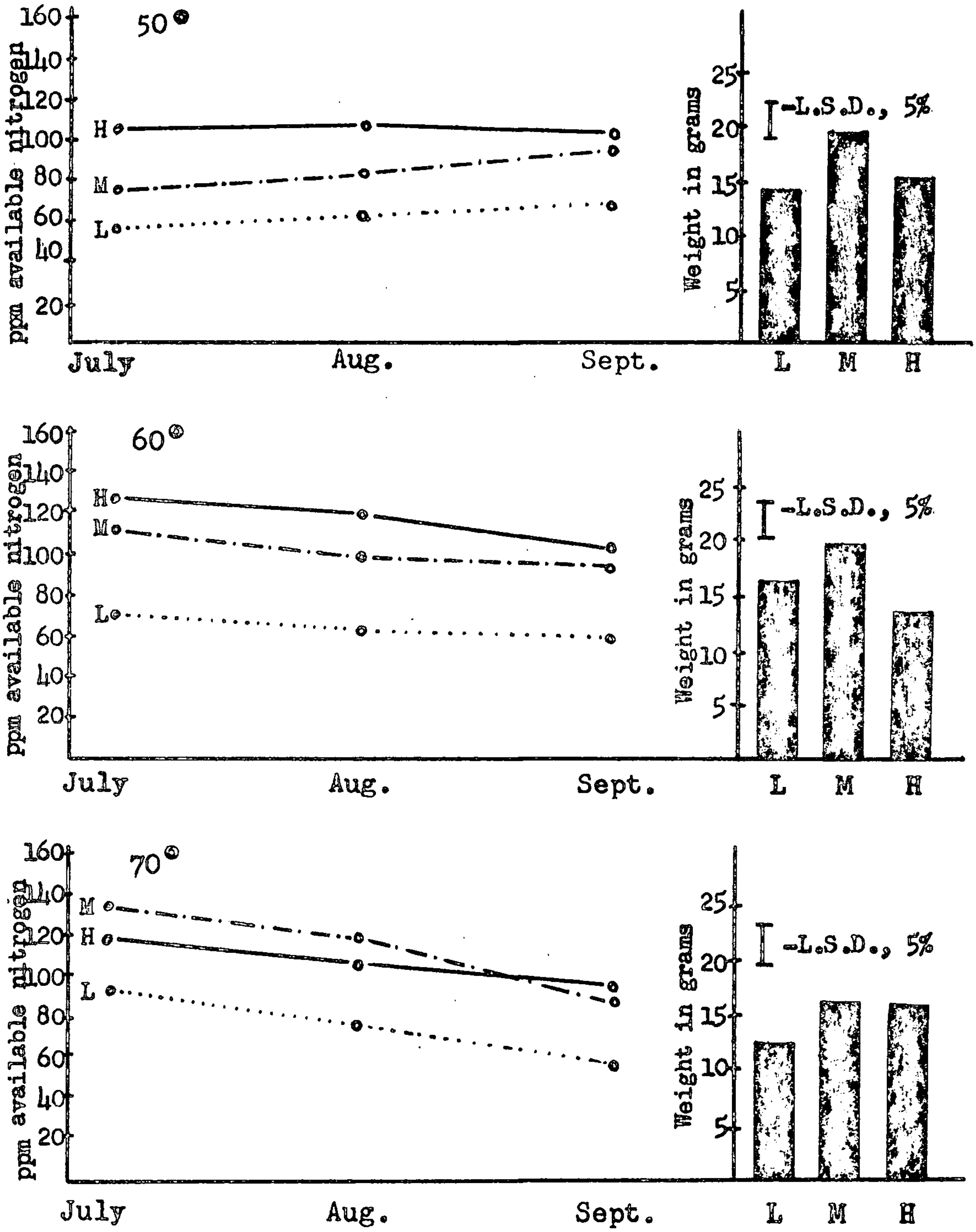


Figure 4. Monthly fluctuations in level of available nitrogen at the three night temperatures with corresponding average dry weight of plants, Season II.*



* H, M, and L, denote the high, medium, and low nitrogen series respectively.

Season III.

Decomposition of the urea-formaldehyde was quite rapid during this season. Also, there was less leaching of nitrogen because of the decreased need for water under the cooler daytime temperatures of this season. Consequently, the range of total nitrogen in the 50° F house was 70-186, 115-347, and 100-400 ppm, respectively, in the low, medium and high nitrogen series. At 60° F night temperature, the respective ranges in nitrogen levels were 75-215, 100-367, and 95-340 ppm; and 50-100, 80-450, and 85-395 ppm in the 70° F night temperature treatment. Data presented in Figure 6 shows that during the last month of this season the available nitrogen level increased greatly in all treatments.

Neither total dry weights nor plant heights increased significantly with higher nitrogen levels (Table 5a). Evidently the lowest nitrogen level was above the minimum requirement for maximum growth.

The combined effects of nitrogen and temperature on plant height and total dry weight are shown in Figures 5a and 5b. Maximum height was obtained at the high (100-400 ppm) nitrogen range at 50° F night temperature. Average total dry weight, however, was greatest at the medium (115-347 ppm) nitrogen range. Plants became the tallest and produced the greatest total dry weight in the 60 and

70° F houses at the low nitrogen levels, which in these respective night temperature treatments were 75-215 ppm and 50-100 ppm, respectively. Both plant height and total dry weight were significantly less at all nitrogen levels in the 70° F night temperature treatment than in the 60° F night temperature treatment.

The night temperature of 60° F was the most favorable for shoot elongation and production of dry matter at all nitrogen levels (Table 5b). Night temperatures 10° above or below 60° F resulted in significant decreases in plant height, total dry weight, number of breaks and growing points. Further expression of the response to temperature is found in the scorch symptoms observed in these plants. The scorch index became increasingly greater at successively higher night temperatures, but was significantly greater only in the 70° F house.

Table 5c shows that extending the daylength to 18 hours significantly increased plant height, but did not increase total dry weight to a significant degree.

Table 5. Effects of nitrogen level, night temperature and daylength on certain growth responses of the azalea, Season III.

a. Nitrogen level:*

Treatment	Dry Weight**	Growing Points	Scorch Index	Breaks	Height**
Low	12.15	5.68	1.31	1.25	9.19
Medium	12.86	6.02	1.19	1.11	9.00
High	12.05	5.90	1.32	1.12	8.36
L.S.D. 5%	2.06	0.87	0.26	0.18	0.31

b. Night temperature:*

Treatment	Dry Weight	Growing Points	Scorch Index	Breaks	Height
50 degrees	10.57	5.55	1.16	1.05	8.13
60 degrees	15.30	7.08	1.19	1.36	10.80
70 degrees	10.59	4.80	1.50	1.06	7.61
L.S.D. 5%	2.06	0.87	0.26	0.18	0.31

c. Daylength:***

Treatment	Dry Weight	Growing Points	Scorch Index	Breaks	Height
18 hours	12.82	5.96	1.45	1.19	9.46
Prevailing	11.68	5.78	1.09	1.13	8.24
L.S.D. 5%	1.70	0.79	0.21	0.15	0.25

*figures denote averages of 60 plants
**weight is expressed in grams, height in centimeters
***figures denote averages of 90 plants

Figure 5a. Effect of temperature and nitrogen on plant height, average of 20 plants, (composite of 2 daylength treatments), Season III.

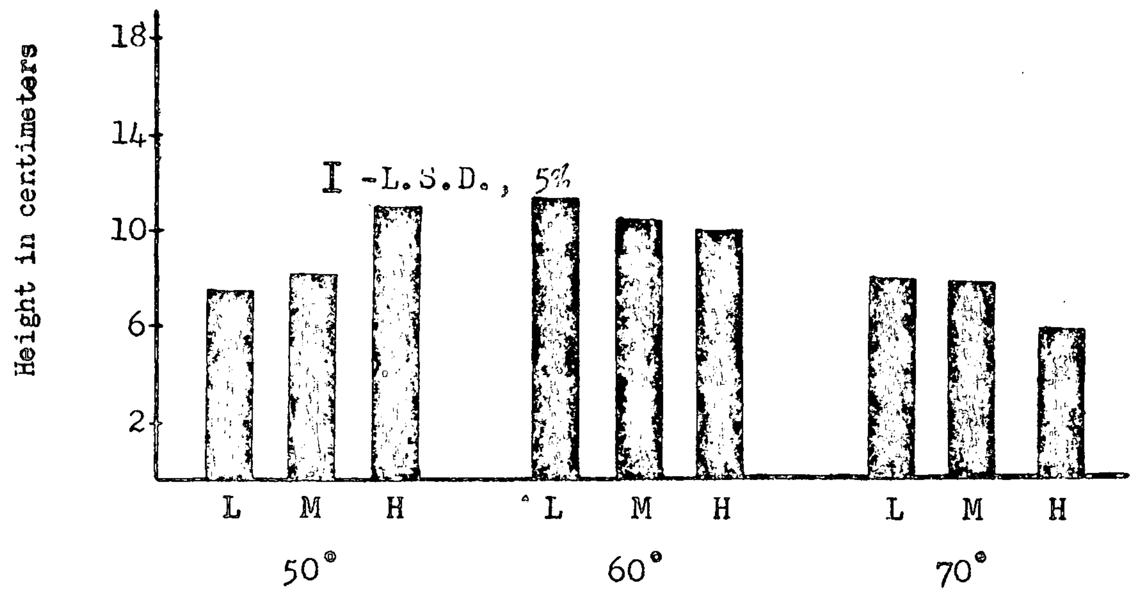


Figure 5b. Effect of temperature and nitrogen on total dry weight, average of 20 plants, (composite of 2 daylength treatments), Season III.

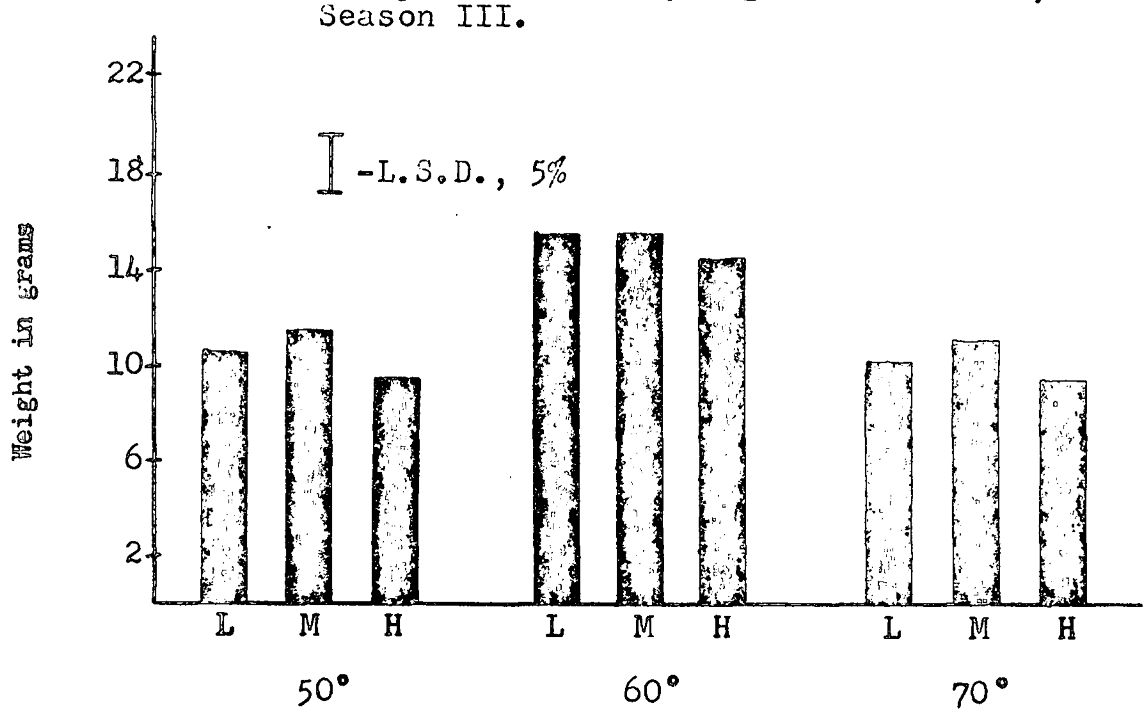
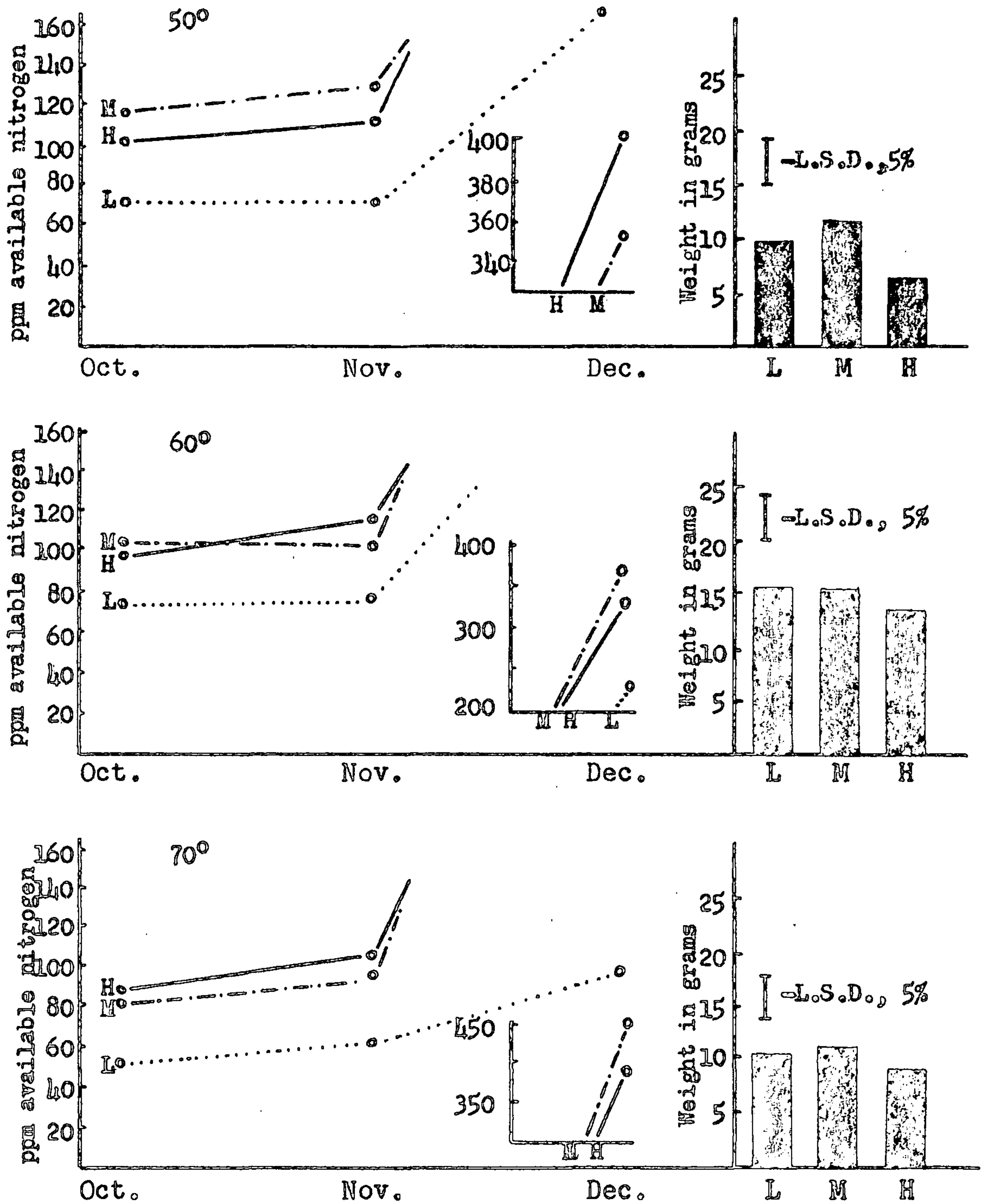


Figure 6. Monthly fluctuations in level of available nitrogen at the three night temperatures with corresponding average dry weight of plants, Season III.*



* H, M, and L, denote the high, medium, and low nitrogen series respectively.

Season IV.

As pointed out earlier, a dilute Hoagland's nutrient solution was used during this season in place of the urea-formaldehyde fertilizer. It was possible by this means to maintain a more uniform level of nitrogen in the growing medium. This had not been possible with the urea-formaldehyde approach, which was subject to constant fluctuation. In this experiment the low, medium, and high levels of total available nitrogen were maintained at 10-25, 25-40, and 40-60 ppm, respectively.

The greatest dry weight was obtained at the high (40-60 ppm) level of nitrogen, but was not significantly greater than at the medium (25-40 ppm) level (Table 6a). When the growth responses at the high nitrogen level are compared with those at the low level, it will be seen that those at the former were significantly greater. On the other hand, differences between the low and medium levels were not significant, with the exception of total dry matter produced. Nor were the growth measurements obtained at the medium and high levels significantly different.

The combined effects of temperature and nitrogen on height and total dry weight are shown in Figures 7a and 7b. The data again indicates that plant height and total dry weight were greatest at the medium level of nitrogen, although at the 50 and 70° F night temperature treatments the only significant differences were between the high and the low nitrogen levels.

Average plant height increased significantly at the successively higher night temperatures (Table 6b). Total dry weight of the plants was significantly greater at 60° F night temperature than at either 50° F or 70° F.

The responses to supplemental illumination are shown in Table 6c. Both total dry weight and height were greater with the 18-hour photoperiod, but the differences were significant only in the case of plant height. More growing points and breaks were produced under the prevailing daylengths, however, the differences were not significant.

Table 6. Effects of nitrogen level, night temperature and daylength on certain growth responses of the azalea, Season IV.

a. Nitrogen level:*

Treatment	Dry Weight**	Growing Points	Nitrogen Deficiency	Breaks	Height**
Low	9.7	5.78	1.1	1.48	8.6
Medium	11.5	6.95	1.0	1.65	9.4
High	11.9	8.04	1.0	1.75	9.9
L.S.D. 5%	1.30	1.61	0.1	0.22	1.02

b. Night temperature:*

Treatment	Dry Weight	Growing Points	Nitrogen Deficiency	Breaks	Height
50 degrees	8.6	7.11	1.0	1.36	7.6
60 degrees	13.0	7.14	1.0	1.65	9.6
70 degrees	11.5	6.51	1.0	1.87	10.8
L.S.D. 5%	1.30	1.61	0.1	0.22	1.02

c. Daylength:***

Treatment	Dry Weight	Growing Points	Nitrogen Deficiency	Breaks	Height
18 hours	11.4	6.85	1.1	1.59	10.4
Prevailing	10.8	6.99	1.0	1.72	8.2
L.S.D. 5%	1.06	1.32	0.01	0.18	0.83

*figures denote averages of 60 plants
**weight is expressed in grams, height in centimeters
***figures denote averages of 90 plants

Figure 7a. Effect of temperature and nitrogen on plant height, average of 20 plants, (composite of 2 daylength treatments), Season IV.

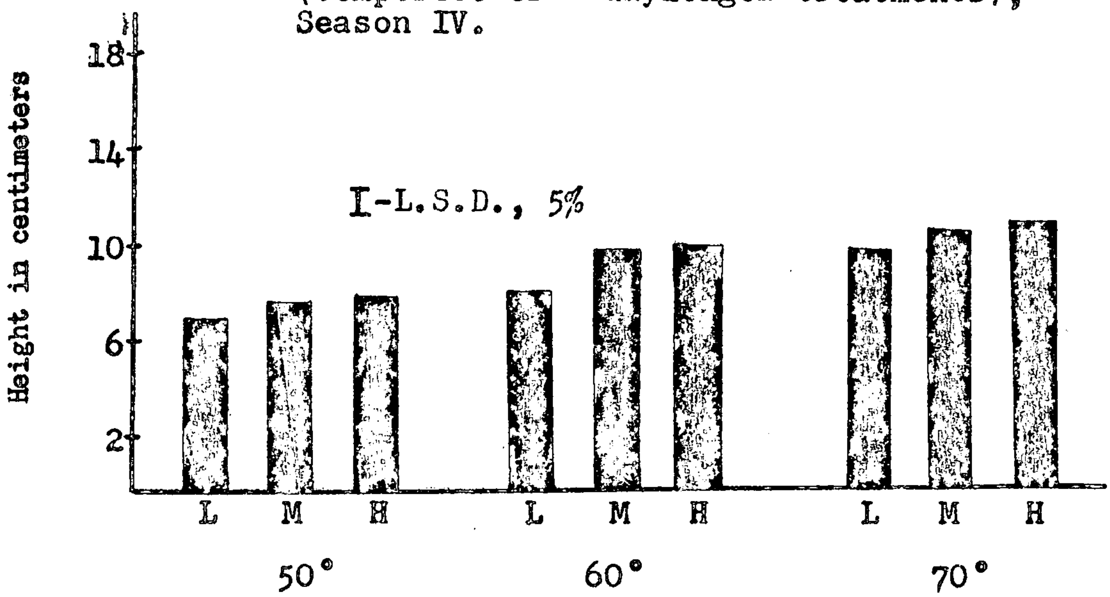
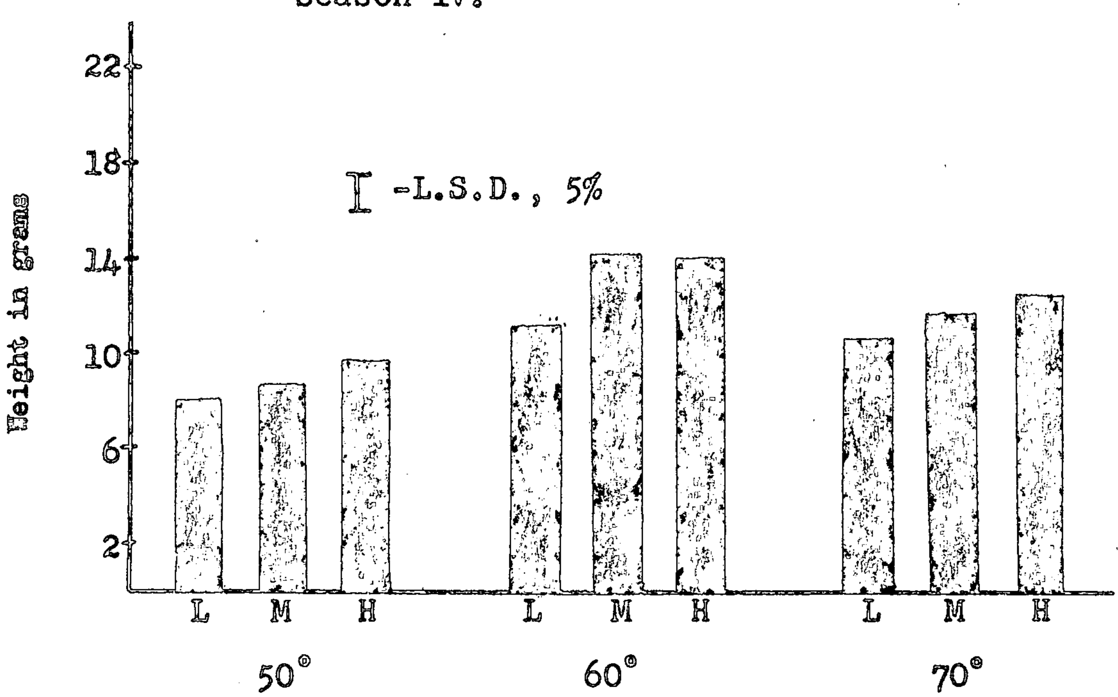


Figure 7b. Effect of temperature and nitrogen on total dry weight, average of 20 plants, (composite of 2 daylength treatments), Season IV.



DISCUSSION

In interpreting the results obtained from the four seasonal experiments, comparisons can be made only between those factors which were similarly controlled in each three month period. However, since this study was designed to observe the effects of interactions between temperature, daylength, and nitrogen level in each season on growth of the azalea, an attempt will be made to compare the influences of those factors which were controlled and the influences of those factors which were not controlled within sufficiently narrow limits will be discussed separately, since comparisons would not be valid.

Desired night temperatures were successfully maintained each season, but daily mean temperatures fluctuated so much that only those growth responses between Seasons I, III and IV can be compared. The temperature fluctuation was so great in Season II that actual daily mean temperatures of 60, 70 and 80° F were maintained in the three houses instead of the desired 50, 60 and 70° F series.

Differences in growth response obtained with the 18-hour photoperiod must be considered as being due to changes in light intensities each season, because this photoperiod was maintained over half of the plants at each of the three temperatures in each of the four seasons. However, differences in growth obtained under prevailing daylengths were apparently due to the seasonal changes in daylength and light intensity. For this reason comparisons can be made between the two daylength treatments in a given season on the assumption that light intensity was equal for both during the daytime, and that the only difference between the two light treatments was the period of low intensity light which extended the prevailing daylength to an 18-hour photoperiod. Growth comparisons made between light treatments for each season, however, must be based on differences in daylength and light intensity with the changing seasons.

Nitrogen availability also varied between seasons. However, a definite range in available nitrogen was maintained in each nitrogen series during Seasons I, II and IV and until the last month of Season III. Growth comparisons then can be made on the response to available nitrogen. Growth responses to nitrogen were closely related to temperature and light and as such must be discussed by season.

Temperature

The facilities available for temperature control were such that constant day and night temperature could not be maintained in the three houses. Night temperatures were controlled within ±4° F of the desired temperature, but daytime temperatures ranged as much as 28° above the night temperatures. This resulted in little difference in growth between temperature treatments during Season II.

As seen in Tables 7a and 7b, maximum height and dry weight was obtained during Season I at a night temperature of 70° F and daily mean temperature of 77° F. Plant growth during Season II was greatest in the 50° house where daytime temperatures ranged up to 75° F, thus giving a mean temperature of 62° F. Plant growth, both height and dry

Table 7a. Effect of night temperature and season on total dry weight.*

Season	night temperatures 50°	60°	70°
I	7.76	7.98	9.85
II	16.20	16.30	14.56
III	10.55	15.26	10.36
IV	8.65	13.05	11.55

*figures denote average dry weight in grams

Table 7b. Effect of night temperature and season on plant height.*

Season	night temperatures 50°	60°	70°
I	8.71	8.68	10.36
II	10.51	10.20	9.95
III	8.10	10.76	7.60
IV	7.53	9.58	10.76

*figures denote average plant height in centimeters weight, during Season III was greatest in the 60° F house, where daily temperatures averaged 67° F with a maximum during the day of 75° F. Total dry weight during Season IV was also highest under a mean temperature of 67° F. Plant height, however, during this period was greatest under a 77° F mean temperature.

In general it was found that during the winter and spring months, Seasons I and IV, a higher temperature (77° F) was desirable for obtaining maximum growth of young azalea plants. During the summer, Season II, a lower mean temperature (62° F) was more favorable for growth than the 77° mean temperature which was optimum during the winter and spring months. Hence, mean temperatures ranging from 62° to 77° F may be put forth as optimum for growth of young greenhouse azaleas, with the lower mean being optimum during the summer and the upper during the winter and spring months.

Daylength

In considering the importance of daylength and/or light intensity on azalea growth, as obtained in these experiments, it is necessary to consider first the changes that occurred in these two factors during the course of the four seasons. Furthermore, it must be remembered that growth measurements between seasons are not comparable since, as pointed out previously, it cannot be assumed that all factors were controlled equally in all seasons. However, such general comparisons as can be made may lead to a partial explanation of the seasonal differences in growth obtained in a 3-month period.

The average prevailing daylength for this area, and the mean light intensity in gram calories per square centimeter (as measured by a pyroheliometer at the Lewis-Brown Horticultural Farm) recorded during each of the four seasons, are given in Table 8. It is realized of course, that the figures for intensity of light would not apply to the conditions in the greenhouse, but the same relative values for the season would prevail.

Table 8. Average prevailing daylength and light intensity as related to season. 1957-1958, Corvallis, Oregon.

Season	Light intensity*	Daylength (hours)
I	540	14.2
II	542	13.7
III	148	11.0
IV	98	10.8

*light intensity is expressed in gram calories per square centimeter.

In those treatments where daylength was extended to 18-hours, the duration of exposure to light was the same regardless of season. However, light intensity differed considerably in the four seasons. Although, while approximately the same in Seasons I and II, intensity was much lower in Season III and still lower in Season IV.

On the basis of plant height and total dry weight (Tables 9a and 9b), growth apparently increased as a result of extending the daylength to 18-hours in Seasons III and IV. During these seasons the prevailing daylength was

Table 9a. Effect of daylength and season on total dry weight.*

	Daylength	
Season	18-hours	Prevailing
I	8.8	8.2
II	14.5	16.8
III	12.5	11.6
IV	11.4	10.7

*figures denote average dry weight in grams

little more than half the 18-hour photoperiod (Table 8). There was no significant difference in growth that could be attributed to light in Season I and it appeared in Season II that extended daylength actually decreased plant weight. However, this decrease cannot be attributed to light, since daylengths and light intensities were practically the same in Seasons II and I, where plant weight was not adversely affected.

Table 9b. Effect of daylength and season on plant height.*

Season	Daylength 18-hours	Daylength Prevailing
I	9.3	9.1
II	10.6	9.8
III	9.4	8.2
IV	10.3	8.2

*figures denote average plant height in centimeters

In all seasons, the 18-hour photoperiod increased plant height to a certain extent, but plant dry matter increased with additional hours of light only if the prevailing daylength was less than 11 hours, and then only slightly. It appears that photoperiod is not a critical factor in the growth of young azalea plants making vegetative extension within the range of temperatures used in these studies. This agrees closely with Skinner (14, p. 1007-1011) and Nison (12) who both concluded that temperature, rather than photoperiod, seemed to be the limiting factor for vegetative growth in young azalea plants.

It is apparent that light intensity, as such, cannot be considered as limiting growth in this experiment, since the season producing the greatest (Season II) and the season producing the least (Season I) amount of dry matter during a 3-month period had essentially the same light intensity in gram-calories per square centimeter.

Nitrogen

The level of available nitrogen in the growing medium appeared in great measure to be a function of temperature. Nitrogen application, night temperatures, and seasonal fluctuations in day temperature were associated with changes in available nitrogen. These changes appeared not only as differences in total nitrogen, but also in the proportion of NH_4-N to NO_3-N. Utilization of this available nitrogen by the plants was no doubt in turn affected in great measure by both daylength and light intensity. Nitrogen released from the urea-formaldehyde fertilizer in the first three seasons, but not used by the plant under a given set of environmental conditions, was no doubt leached out of the media by repeated watering. This leaching was relatively high in the porous medium used because of its low base exchange capacity. This probably accounts for the difficulty experienced in maintaining constant nitrogen levels during a growing season.

A concentration of 74-122 ppm total nitrogen resulted in maximum growth irrespective of season. This level of nitrogen was maintained in the medium nitrogen series in Seasons I and II, most of Season III, and was approached in the high nitrogen series in Season IV. In the latter season the urea-formaldehyde fertilizer was replaced by repeated dilute applications of Hoagland's ammonium nutrient solution (8, p. 31) in which the three levels of nitrogen were maintained by varying the interval between nitrogen applications. The high series in this case supplied 40-60 ppm total nitrogen and produced growth equivalent to that obtained at higher (74-122 ppm) nitrogen levels made available with urea-formaldehyde. The efficiency of regular nutrient applications of low concentration to that of irregular applications of rather high concentration is well known. These studies indicate that the problem of maintaining a satisfactory nitrogen level over extended periods of time with urea-formaldehyde alone would be rather difficult, especially under conditions of varying temperature and moisture. Lunt and Sciaroni (11, p. 11) using this form of nitrogen in incubated beds (76° F) found the rate of decomposition of urea-formaldehyde reached a peak during the third to fifth week after application, dropping to low values three to four months after application. Changes in plant demands for nitrogen with growth rate would further complicate this problem of management.

In general, these studies suggest that the azalea will grow rather well over a relatively wide range of available nitrogen. This could vary from 50 to 125 ppm total nitrogen depending upon the method and frequency of nitrogen application. These findings are in agreement with those of Kiplinger and Bresser (9, p. 393-395) and of Kiplinger and Nelson (10. p. 16) who found a definite increase in multiple flower production and growth at concentrations above 50 ppm nitrogen. It would appear that frequent applications of a nutrient solution to maintain this concentration in the low range (40-60 ppm) would be preferred to infrequent applications of a material like urea-formaldehyde at two or three month intervals. With the latter method the nitrogen level would fluctuate considerably, depending upon environmental conditions, and at times would reach 125 ppm, a rather high concentration. However, with experience, under controlled greenhouse conditions, it is conceivable that urea-formaldehyde might be used to advantage as a supplement.

Some interactions of temperature, daylength and nitrogen

In all seasons, with the exception of Season IV, where a dilute nutrient solution was applied at regular intervals, the influence of temperature on release of nitrogen from the urea-formaldehyde proved to be an important factor in the amount of growth obtained. As discussed previously, a mean daily temperature of 62° to 77° F was optimum for vegetative growth of young plants during each of the four seasons. This range in temperature appeared to be optimum for both release of nitrogen and its utilization by the plant.

At a daily mean temperature of 57° F, release of nitrogen as NH_4 from the urea-formaldehyde and conversion of NH_4 to NO_3 was slower than at higher daily means of 67° F and 77° F. Thus, a smaller supply of nitrogen was provided to the plants at this lower mean temperature. This combined with the lower temperature itself, resulted in less total plant growth in all seasons except Season II. At a 77° F daily mean, the release of nitrogen was at times apparently in excess of amount used, and consequently considerable nitrogen leached away. This was indicated by the fact that nitrogen deficiency symptoms were greater in the high night temperature (70° F) treatments during all seasons when urea-formaldehyde was used as the source of nitrogen. In Season III the excessive release of nitrogen to the medium resulted in leaf scorching. Also, the results for Season II in the 70° F house, where daytime temperatures occasionally reached 100° F, show that the influence of temperature on the decomposition and subsequent leaching of nitrogen was quite erratic. In this instance, the level of available nitrogen averaged 115 ppm in the medium nitrogen series and this was higher than in the high nitrogen series where the level averaged 106 ppm nitrogen. The increased growth at 50° F night temperature during Season II was probably due to a more uniform release and utilization of nitrogen under temperature conditions prevailing during that season.

In general, the effect of temperature on growth and its secondary influence on nitrogen availability seems to be a case of too slow release of nitrogen at a 57° F daily mean temperature; a balance between release, utilization and leaching at a 67° F mean temperature; and an excessive supply, at times even toxic, with leaching at a 77° F mean temperature.

Nitrogen toxicity became a problem during Season III in the 70° F house. As shown in Figure 6, the nitrogen level during the latter part of this season increased considerably in all series. Temperatures were favorable for a rapid decomposition of the urea-formaldehyde during this season, yet excessive watering, which would have leached the nitrogen out of the cans, was not done because of decreased water needs with the lower light intensities and the absence of excessive temperatures. Consequently, the available nitrogen built up to toxic levels in many instances.

Burning of the foliage was significantly greater under the 18-hour photoperiod than under the prevailing daylengths, which during Season III averaged 11.6 hours. Two mechanisms might account for the scorching of the leaves. Perhaps permeability in the plant was increased by the high mean temperature (77° F) at which this symptom was observed. Increased salt or nutrient uptake might have resulted from the increased permeability. Also, possibly, carbohydrate synthesis in the plant decreased as a consequence of the low light intensities prevailing during this period. Such an unbalanced condition would result in a plant with a low carbohydrate reserve but with a high salt content, thus leading to phytotoxicity. However, such mechanisms can only be theorized as no proof was obtained by which positive assertions can be made.

The fact that foliage burning was significantly higher in plants maintained at an 18-hour photoperiod than in those under prevailing daylengths agrees with results reported by Hibbard (7, p. 24-27). He found that short days reduced the total salt absorption by the roots of certain varieties of peas.

SUMMARY

This investigation was conducted in an attempt to define the optimal conditions for culture of the azalea which can be achieved in part through control of temperature, daylength and nitrogen level. The influence of season in relation to these three environmental factors was studied by dividing the investigation into four seasons, each three months in length.

Rooted cuttings of Hexe azaleas were grown in a sawdust medium at three levels of nitrogen and subjected to night temperatures of 50, 60 and 70° F, under natural and supplemental daylengths. At the end of each season, the plants were removed from the containers and growth responses in the form of plant height, total dry weight, number of growing points, number of breaks, and nitrogen deficiency symptoms were recorded for each treatment. Analysis of variance was used to interpret the results.

On the basis of this study, a temperature range of 62-77° F is suggested as optimum for growth of young azalea plants when urea-formaldehyde was used as a source of nitrogen. This temperature range appeared optimum for nitrogen release from this nitrogen source, and its utilization in growth by the plant.

On the basis of plant height and total dry matter produced, the 18-hour photoperiod did not increase growth unless the prevailing daylength was less than 11 hours.

Young azalea plants, making extension growth, were found to grow well on a wide range of available nitrogen. In general, maximum growth occurred at a nitrogen concentration of 74-122 ppm, when urea-formaldehyde was used as the nitrogen source. A dilute nutrient solution applied at frequent intervals, however, was found to be more efficient and growth comparable to that in the above concentration was obtained at 40-60 ppm total nitrogen.

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APPENDIX

ANALYSIS OF ES-MIN-EL

"Es-min-el" is manufactured by the Tennessee Corporation, East Point, Georgia. The analysis of this fertilizer supplement is:

Manganese	9.87%
Copper	3.81%
Zinc	3.50%
Iron	3.00%
Magnesium	2.42%
Calcium	0.95%
Boron	0.16%
Chlorine	trace

The ingredients of this supplement are derived from copper sulphate, manganese sulphate, zinc sulphate, ferric sulphate, magnesium sulphate and borax.