STUDIES OF THE GROWTH OF *POA ANNUA* L. AS AFFECTED BY SOIL TEMPERATURE, AND OBSERVATIONS OF SOIL TEMPERATURE UNDER PUTTING GREEN TURF.

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University for the Degree of

Master of Science

by

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BIOGRAPHICAL SKETCH

Douglas Tilton Hawes was born in New Bedford, Massachusetts, on July 3, 1935. He received his secondary education at Dartmouth High School, Dartmouth, Massachusetts, graduating in June, 1953. He attended New Bedford Institute of Technology, New Bedford, Massachusetts, for the fall term of 1953. He then went into the service for two years and was discharged March, 1957.with the rank of specialist third-class. In June, 1959, he was awarded a diploma in Turf Management from the Stockbridge School of Agriculture, Amherst, Massachusetts. In April, 1961, he married the former Jane E. MacDonald of Taunton, Massachusetts. In June, 1962, he was awarded a Bachelor of Science Degree in Agronomy by the University of Massachusetts, Amherst, Massachusetts.

Since September, 1962, he has been enrolled in the Graduate School at Cornell University. During this period, he held a research assistantship in the Department of Agronomy until June, 1963; and a research assistantship in the Department of Floriculture and Ornamental Horticulture since June, 1963.

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INTRODUCTION

Poa annua L. is one of the principle weedy grasses common to fine turf, particularly golf course putting greens. A great deal of work has been done on developing chemical means for controlling this grass. A successful method of chemical control however has not yet been developed in over a half century of efforts. A little work has been done on developing cultural methods of control. But, what is needed before cultural methods can be developed is a better understanding of the effects of environment on this grass.

The fact that *Poa annua* behaves as a winter annual in the South and becomes an increasingly more permanent member of the turf as one goes north must be related to the effect of some factor of the environment. Factors that change as one goes north are light intensity, day length, and soil and air temperatures. It seemed that a study of the effects of soil temperature might provide the greatest amount of useful information on this grass.

The effects of soil temperature on *Poa pratensis*, a perennial species of the same genus, has been studied extensively. Several other fine turf grasses have been thus investigated, but there is very little information available on the effects of temperature on *Poa annua*.

Greenhouse studies on the effects of various soil temperatures, and a study of soil temperatures occurring naturally under putting green turf were undertaken.

LITERATURE REVIEW

Introduction.

The temperature of the soil affects plant growth directly through its influence on metabolism and indirectly through its influences on soil moisture, aeration, microbial activity, and the availability of plant nutrients. Kramer (1934) showed that the water supplying power of the soil increases with increasing temperatures. Aeration is aided by the expanding and shrinking of the soil air due to variations in soil temperature. Microorganisms are active within rather narrow temperature ranges. The availability of nutrients is affected by soil temperature in that higher temperatures increase to a small extent their solubility.

Soil temperature in any given location is determined by the interaction of environmental factors with the physical properties of the soil. Ultimately, all soil heat comes from two sources - radiation from the sun and conduction from the interior of the earth. The radiation from the sun is the principal source of heat. Heat from the interior of the earth is negligible.

The physical properties of the soil that influence the temperature are heat capacity and thermal conductivity. These properties are in turn influenced by the soil texture, soil density, percent organic matter, and the amount of water the soil contains.

Minimum, maximum and optimum temperatures.

Poa pratensis L. (Kentucky bluegrass). Sprague (1933) studied root growth on 5 year old Kentucky bluegrass sod cut at 7/8 inches.

He noted that the formation of new roots stopped by May 4th, when the mean soil temperature at the 2 inch depth was 55°F. Harrison (1934), growing Kentucky bluegrass in constant temperature chambers, showed that this bluegrass does not survive long at 100°F. and that it produces more tops and roots at 60°F. than at 80°F. Naylor (1939) found that Kentucky bluegrass produced more top and root growth at 59°F. than at 77°F. soil and air temperatures under various chemical treatments. Darrow (1939) found 59°F. to be the best soil temperature for growth of Kentucky bluegrass, even though he found approximately the same amount of root growth at 77°F. as at 59°F. He based his conclusion that 59°F. was the best of the temperatures on the fact that there was a decrease in leaf development from 59°F. to 95°F. soil temperature, and that there were larger, whiter, more succulent roots at the lower temperature. At 95°F. the root yield was half that at the lower temperatures. Brown (1939), growing plants in heated chambers, found that the optimum temperature for herbage production for Kentucky bluegrass was between 80°F. and 90°F. for 3 month old plants grown for 8 additional weeks. The optimum temperature for root and rhizome production was 60°F. Stuckey (1942) found that Kentucky bluegrass produced twice as much dry matter in roots and shoots with its roots in nutrient solution kept at 60°F. than at either 45°F. or 90°F. She also noted that the plants at 45°F. were a darker, healthier looking green and had thick white roots, while those at 90°F. had yellowish tops and thin dark brown roots. Hiesey (1953) grew 11 different strains of Kentucky bluegrass under the following temperature combinations. (D = day temperature, N = night temperature).

68°F.-D		73°F.-D				86°F.-D		
43°N	57°N	43°N	50°N	57°N	63°N	43°N	50°N	63°N

One of these 6 underlined temperature combinations was an optimum for at least 1 particular clone. These data indicate the great variability that is possible within 1 species.

Poa compressa (Canada bluegrass). Brown (1939) grew plants of Canada bluegrass in chambers kept at constant soil and air temperature. He found that, as with Kentucky bluegrass, the Canada bluegrass produced the most foliage between 80°F. and 90°F. Brown determined that the optimum temperature for root and rhizome production was 50°F. for Canada bluegrass as compared to 60°F. for Kentucky bluegrass. He grew Canada bluegrass plants at a soil temperature of 70°F. with air temperatures of 70°F., 85°F. and 100°F. in 1 experiment and in another experiment plants at both soil and air temperatures of 70°F., 85°F. and 100°F. By comparing yields of tops and roots from both experiments he showed that high air temperatures were not as harmful as high air and soil temperatures combined.

Lolium perenne L. (perennial ryegrass). Sullivan and Sprague (1949) grew perennial ryegrass at different day and night temperatures after a severe cutting back. They found the optimum temperature combination, based on yields of tops after 40 days, was 70°F. days and 60°F. nights. Days of 60°F. with 50°F. nights was second in yield, 80°F. days and 70°F. nights was third, and 90°F. days and 80°F. nights poorest. However, plants at 60°F. day and 50°F. night temperatures appeared more vigorous at the end of the experiment that those with the 70°F. day and 60°F. night treatment, even though the 70°-60° plants gave the greatest yield of tops. This lower range agrees with Mitchell's 1953 findings of optimum temperature for this grass.

Agrostis tenuis (Colonial bentgrass). Sprague (1933) studied root growth on 5 year old Colonial bentgrass sod cut at 7/8 inches. He noted that the bentgrass roots reached their peak of growth 15 to 30 days after those of Kentucky bluegrass. He observed that Colonial bentgrass formed no new roots after the 15th of June, when the mean soil temperature was 65°F. at the 2 inch depth. This was 1 month later and 10°F. higher than the time and temperature noted for Kentucky bluegrass the same year. Stuckey (1942) found that Colonial bentgrass produced twice as much root and top growth with its roots in nutrient solution at 60°F. as at 45°F. or 90°F. She also found that Colonial bentgrass grown in heated soil produced more dry matter at 60°F. than at 50°F. or 80°F. soil temperature.

Agrostis palustris (Creeping bentgrass). Beard (1959) found that 60°F. growth chamber temperature produced more total root growth of creeping bentgrass than 70°F., 80°F. or 90°F. He noted however, that the rate of growth of the individual roots was the same at all temperatures except 90°F. He thus concluded that although the growth rates were the same the reason for the smaller yields at higher temperatures was that higher temperatures increased the rate of maturation of the roots.

Poa annua L. (annual bluegrass). Juhren (1957) found that optimum conditions for Poa annua, measured by total dry weight of roots and tops combined, was at greenhouse temperatures of 79°F. days with 63°F. nights and with a 16 hour photoperiod and a high light intensity. He also found that plants growing at high temperatures made better growth at high light intensities than at low light intensities, while those at low temperatures made better growth at low light intensities than at high light intensities. No explanation of this phenomenon was given. Early and Cartter (1945) showed with soybeans that as the root temperatures were increased, greater illumination was necessary to maintain a similar top to root ratio.

In summary, temperate zone turf grasses reviewed here are reported to grow best at soil temperatures between 50°F. and 70°F. In a few cases a grass species would grow best at day temperatures above this range if the night temperatures were in this range or below it. In some cases other factors were found to affect the optimum temperature for growth. Those investigators who have reported on the subject note that the optimum temperature for root growth is usually found to be lower than that for top growth.

Went (1953), reviewing his own and other works on the problem of why higher light intensities are needed to maintain an adequate root system at high temperatures, concluded that the translocation rate of the products of photosynthesis decreases with rising temperatures. This decrease, combined with an increase in respiration with rising temperatures, is responsible for the low accumulation of carbohydrates in roots at high temperatures. Higher light intensity offsets the effects of high temperature to some extent by increasing the products of photosynthesis.

Sullivan and Sprague (1949) correlated temperature with the amount of sugars present in the various tissues of perennial ryegrass and found, as would be expected, that there was a decrease in sugars with an increase in temperatures from 50°F. to 90°F. At a temperature lower than the optimum for growth, synthesized carbohydrates were stored. At temperatures higher than the optimum, carbohydrates were rapidly respired without having served as reserves in the sense that they contributed to the formation of new tissue. Darrow (1939) reached a similar conclusion working with Kentucky bluegrass.

Effects of temperature on roots versus tops.

Brenchley (1922), growing peas in a greenhouse, noted that when the nutrient solution was kept cool the yields of tops were one and one-half times as great as those from plants not having their roots in cooled nutrient solution. Carroll (1943) noted that *Poa annua* withstood an air temperature of 122°F. much better than a soil temperature of 122°F. His experiments showed that a 6 hour exposure at 122°F. air temperature was needed to give the same degree of injury as was inflicted in four hours of 122°F. soil temperature. He also found that the plants that received the greater amount of nitrogen were the most severely damaged.

Jacques and Edmond (1952) showed that the maximum root growth of *Lolium perenne* and *Dactvlis glomerata* occurred when shoot growth was slow, and that growth and initiation of roots was slow during periods of maximum shoot growth. Harrison (1934) noted that Kentucky bluegrass grown at 60°F. air and soil temperature without supplemental nitrogen continued to produce new roots while plants with additional nitrogen did not, thus indicating that nutrient supply differences will result in differences in root growth for plants at the same temperature.

Root growth in the fall is usually first an extension of pre-existing roots followed by initiation of new roots. It is often noted that growth in the fall as measured by total root weight is much less than that in the spring even though soil temperature is similar at both times of the year. The fact that fall growth is less than spring growth was shown by Brown (1943). Beard (1959) noted initiation of new roots of creeping bentgrass in late spring only after periods of lower than normal soil surface temperatures. Rice (1961) noted that Poa annua root growth increased during one period in midsummer and thought that this might have been due to a previous period of low temperature which had occurred. These observations point to the possibility of a need for a conditioning at lower temperatures before new roots are initiated in some grasses.

GREENHOUSE EXPERIMENTS

Experiment I.

Purpose. The purpose of the first experiment was to determine the optimum soil temperature for both top and root growth of *Poa annua* when the plants are allowed to grow uncut and to study the effects of soil temperature on *Poa annua*.

Location. The experiment was set up in a 50°F. night and 60°F. day greenhouse, Ithaca, New York, 1962.

Procedure. Four-inch pots containing a soil-peat mixture were seeded with *Poa annua* and the plants were grown for $3\frac{1}{2}$ months. Then the pots were placed at 5 different soil temperatures. Twelve pots were placed at each soil temperature, and 3 pots per temperature treatment were harvested every 2 weeks to determine the effects of temperature on root and top growth.

The soil mixture consisted of 4 bushels of soil and 2 bushels of peat with 2 ounces of 20 percent superphosphate, 2 ounces of 10-10-10 fertilizer and 2 ounces of lime per bushel. This mixture was steam sterilized on August 23rd.

Seeding was done August 24th in four-inch clay pots filled to one-eight inch of the top. Twenty-five seeds, more or less, were sprinkled on the surface and then lightly covered with screened soil-peat mixture. All pots were thinned by September 20th to leave 12 *Poa annua* plants per pot.

The pots in the 95°F., 85°F. and 75°F. sections were watered every 4 or 5 days while those at 65°F. and 55°F. were watered weekly. The irrigation water was adjusted to the same temperature as the soil of the section.

The soil was heated with plastic heating cables controlled by General Electric Thermostat controls, HSC-3. The greenhouse bench was divided into 5 sections, each section with a seperate thermostat and cable. The cables were wound through the sand in which the pots set, about halfway up on the pots. The pots were buried so that no more than $\frac{1}{4}$ inch of the pot stuck out of the sand. There was $1\frac{1}{2}$ inches of sand and gravel under the pots.

This method of heating the soil was satisfactory for the sections held at 55°F. and 65°F. However, this method was not completely satisfactory at 75°F. and even less so at the 85°F. and 95°F. sections for several reasons. First, the surface temperature usually dropped 5 to 10 degrees at night, with the 95°F. section showing the greater drop. Two weeks growth was enough to insulate the soil surface so that it was not greatly influenced by the low night temperatures of the greenhouse. Thus, for the first 2 weeks the surface temperature was 95°F. during the days and 85°F. at night rather than a constant 95°F.

The grass was cut a $\frac{1}{4}$ inch every third day for 3 months. Then it was allowed to grow uncut for the 3 weeks prior to the start of the experiment. The grass was cut down to $\frac{1}{4}$ inch at the start of the temperature treatments, and then allowed to go unclipped until harvested.

Plants were first harvested 2 weeks after the beginning of treatments. In harvesting, the tops were held in one hand while the roots were gently washed free of soil in a bucket of water. Then the roots were cut off and washed more thoroughly. Both the tops and roots were then dried for 48 hours at 70°C. and weighed.

There were still small pieces of peat clinging to the roots when they were weighed but it was thought the amount of peat was proportional to the amount of roots and thus would allow a good comparison of root weights.

Results and Discussion. A count of infloresences on 3 pots from each section was made on January 4th, (Table 1). Pots at 65°F. and above had comparable numbers of infloresences; only at 55°F. was there a significant difference.

Table 1. Numbers of infloresences per pot counted after 4 weeks of growth in Experiment I.

Temperature	55°F.	65°F.	75°F.	85°F.	95°F.
	20	53	62	53	56
	15	47	55	48	55
	14	47	51	30	48
Average	16	49	56	44	53

In spite of similar numbers of infloresences the plants had the appearance of increasing numbers of infloresences with increasing temperatures. This was due to a decreasing amount of foliage with increasing temperature, as shown in Table 3, 4th week. The shorter foliage at the higher temperatures made the infloresences more visible and thus appear more numerous.

The differences in length of roots at the different temperatures were not significant except for a sharp difference between those at 75°F. and below compared with those above 75°F. (Table 2). The height of tops showed a sharp decrease at temperatures above 75°F.

Measurements of the length of roots and height of tops indicated that for both roots and tops the optimum soil temperature was between 55°F. and 75°F. (Table 2).

Table 2. Mean growth of Poa annua for three pots at each temperature in Experiment I.

Roots	55°F.	65°F.	75°F.	85°F.	95°F.
4th wk.	$7\frac{1}{2}$ in.	8 in.	$5\frac{1}{4}$ in.	$5\frac{1}{4}$ in.	$3\frac{1}{4}$ in.
6th wk.	7 in.	8 in.	8 in.	4 in.	$3\frac{1}{2}$ in.
8th wk.	$7\frac{1}{2}$ in.	8 in.	$7\frac{1}{2}$ in.	$3\frac{1}{2}$ in.	3 in.
Tops					
4th wk.	4 in.	4 in.	4 in.	$3\frac{1}{2}$ in.	3 in.
6th wk.	6 in.	6 in.	6 in.	$4\frac{1}{2}$ in.	$3\frac{1}{2}$ in.
8th wk.	7 in.	6 in.	6 in.	5 in.	$4\frac{1}{2}$ in.

The dry weights of the tops were statistically analyzed using Duncan's test on means (Steel & Torrie, section 7.5). This analysis showed that there was no difference in the dry weight of tops at the time of the first harvest, (Table 3).

The analysis of the harvest at 4 weeks showed only that the tops at 95°F. were significantly less than those at lower temperatures. The statistical analysis of the harvest at 8 weeks shows that the means of top growth at 55°F., 65°F. and 75°F. are each different from one another with yields decreasing as the temperature increases.

The statistical analysis of the roots was made by the Duncan's

Table 3. Dry weights of *Poa annua* tops harvested at 2 week intervals in Experiment I.

Temperature		2 Wk.	4 Wk.	6 Wk.	8 Wk.
55°F.		1.38	3.82	4.29	7.40
		1.08	2.85	4.60	6.79
		1.16	3.19	4.55	7.80
	mean -	1.21a	3.28a	4.48a	7.33a
65°F.		1.22	4.34	2.98	5.71
		1.45	3.13	4.75	5.41
		.66	2.29	3.43	6.70
	mean -	1.11a	3.25a	3.72a	5.94b
75°F.		1.38	2.73	4.00	4.45
		1.05	3.97	4.09	4.49
		1.27	2.70	4.63	lost
	mean -	1.23a	3.13a	4.24a	4.47c
85°F.		1.05	2.37	2.42	
		.82	2.03	3.02	
		.89	2.03	2.58	
		.92a	2.14a,b	2.67b	
95°F.		1.40	1.77	1.75	
		1.20	1.54	2.15	
		1.48	1.81	1.71	
		1.36a	1.71b	1.87b	

a,b,c - Means in any one column having the same small letter are not significantly different at the five percent level.

test on means. The analysis of the harvest at 4 weeks shows that the weight of roots is significantly less at 95°F. than at 75°F. or lower. The mean at 85°F. is significantly less than that of 55°F.

The analysis of the harvest at 6 weeks shows the yield of roots at 95°F. to be significantly less than any other treatment. The mean at 85°F. is significantly less than the mean at 65°F. or at 55°F. The mean at 75°F. is less than the mean at 55°F. The data indicate that the optimum soil temperature for root growth is 55°F. or 65°F.

The data presented in Table 4, Figure 1 show that there is a constant decrease in yields of roots with an increase in temperature from 55°F. to 95°F.

At the time of the second harvest there was an increasing amount of dead leaves on the plants with increasing temperatures. By the time of the third harvest there was a clear division, with those plants at 85°F. and 95°F. having many dead and yellowish leaves and plants at 75°F. and below having few dead leaves.

When the plants and soil were taken out of the pots at the second harvest the plants at 65°F. and 55°F. had many roots going down the sides and on the bottom of the soil mass while those at 75°F. had noticeable less. At 85°F. and 95°F. the roots were concentrated in the top 1 inch.

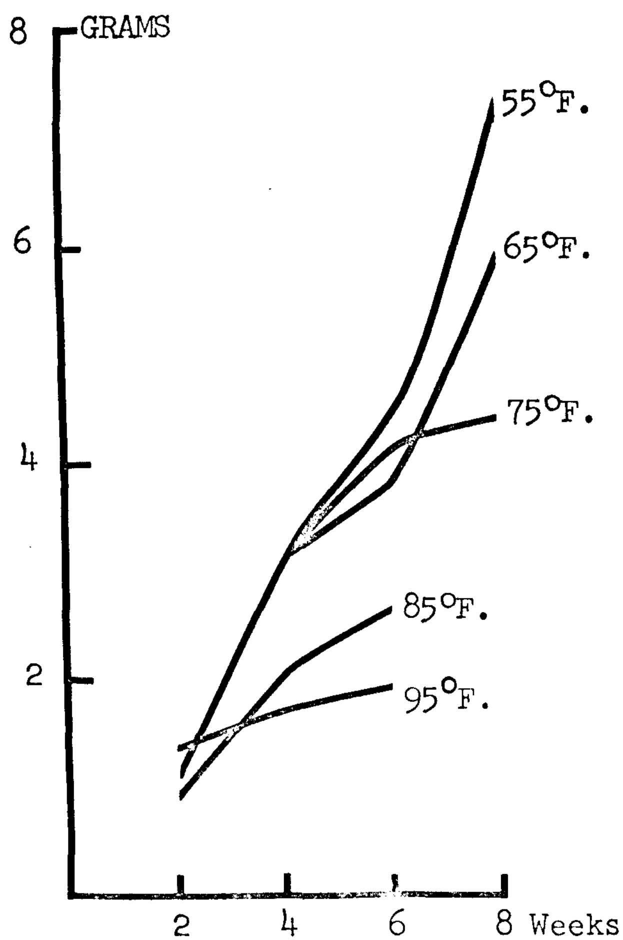
At the time of the second harvest the roots at 65°F. and 55°F. appeared whiter and thicker than those at 75°F. and those at 95°F. were thin and brownish. Beard (1959) and Stuckey (1942), working with other grasses, both noted a similar change in root appearance from thick white roots to thin brownish ones with increasing temperature.

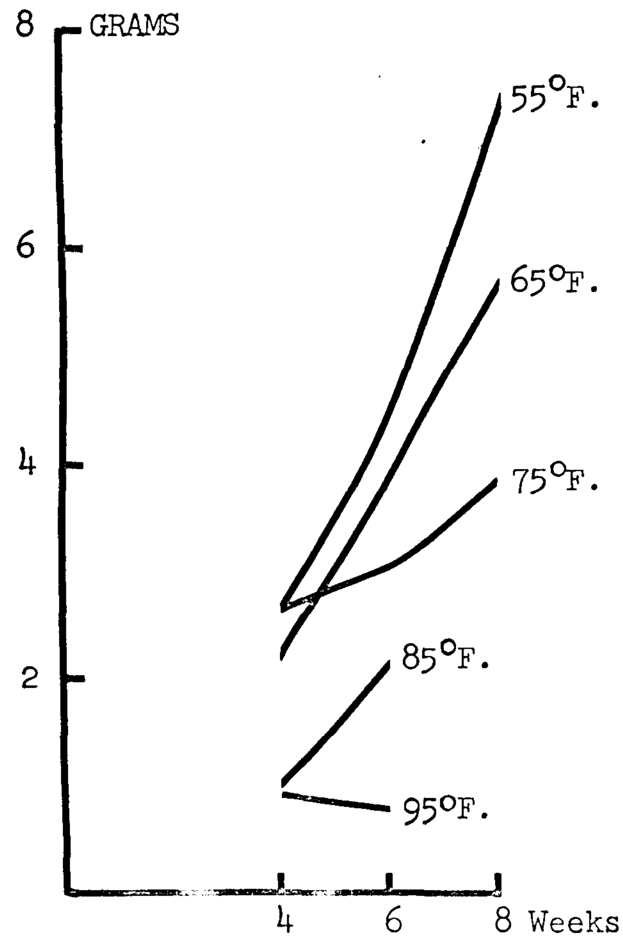
Table 4. Dry weights of *Poa annua* roots harvested at 2 week intervals in Experiment I.

Temperature		4 Wk.	6 Wk.	8 Wk.
55°F.		3.69	3.41	8.19
		1.44	4.52	6.84
		2.63	5.25	6.94
	mean -	2.57a	4.39a	7.32a
65°F.		2.34	3.91	5.07
		2.29	4.12	5.00
		1.86	3.62	6.93
	mean -	2.19a,b	3.88a,b	5.67a,b
75°F.		2.49	3.27	3.84
		1.22	3.06	4.80
		2.50	2.88	2.39
	mean -	2.07a,b	3.07b,c	3.68b
85°F.		.93	1.50	
		1.13	2.52	
		1.06	2.37	
	mean -	1.04b,c	2.13c	
95°F.		.90	.52	
		.85	1.18	
		.89	.59	
	mean -	.88c	.76	

a,b,c - Means in any one column having the same small letter are not significantly different at the five percent level.

Figure 1. Means of the dry weight of roots and tops of Poa annua plotted at two week intervals for the different temperature treatments in Experiment I.


GRAMS
8
6
4
2
55°F.
65°F.
75°F.
85°F.
95°F.
2
4
6
8 Weeks
Tops


GRAMS
8
6
4
2
55°F.
65°F.
75°F.
85°F.
95°F.
4
6
8 Weeks
Roots

Experiment II.

Purpose. Experiment II was designed to determine the optimum soil temperature for both top and root growth of Poa annua plants kept clipped at $\frac{1}{4}$ inch; and to study the effects of soil temperature on Poa annua.

Procedure. The procedure in this experiment was like that of Experiment I except for the manner of clipping and harvesting. Six pots were placed at the same 5 temperatures used in Experiment I and started on December 10th at the same time as Experiment I.

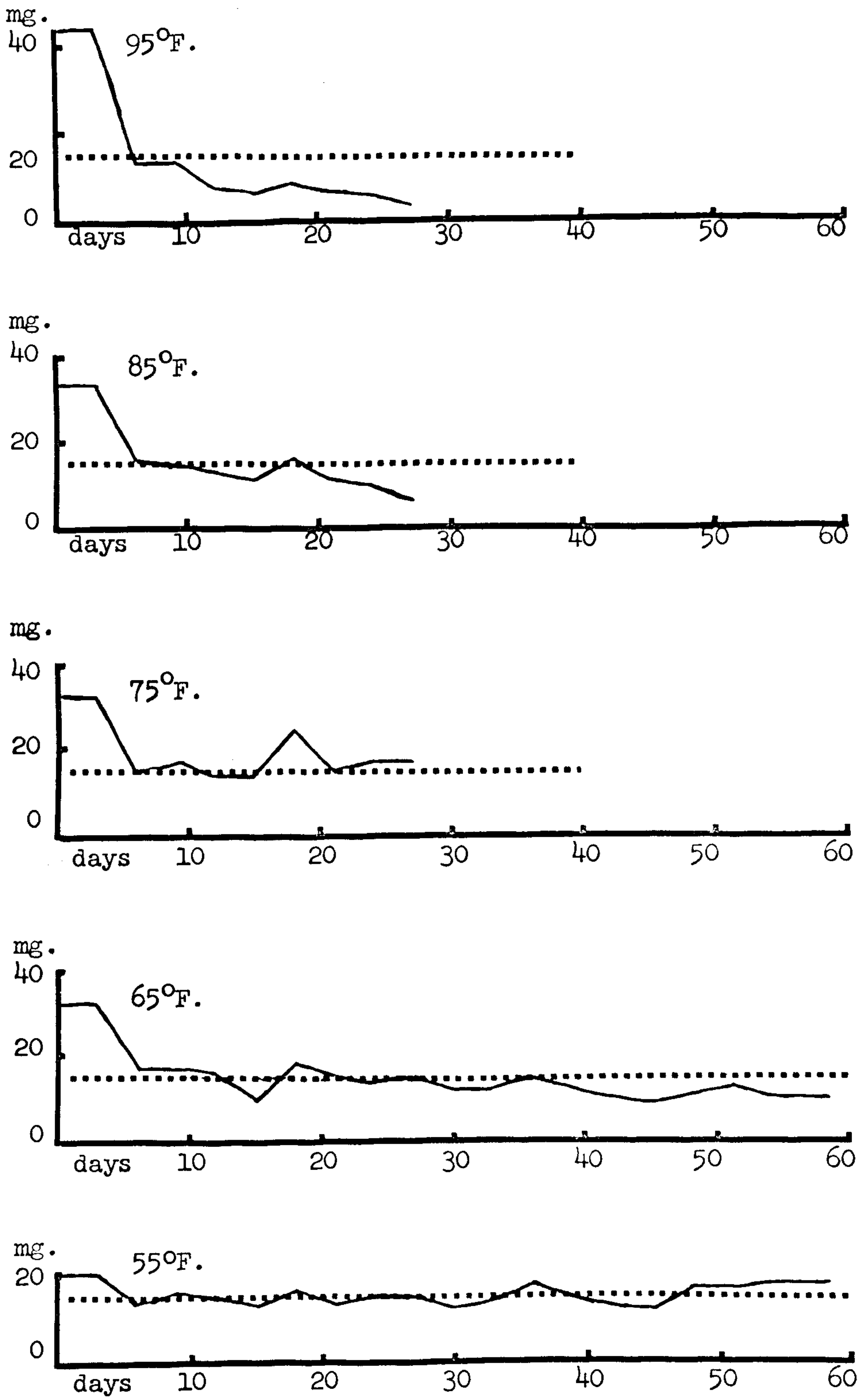
The plants were clipped every third day both before and after the start of the temperature treatments. (Exceptions were the first harvest, which was for a 2 day period and the 15 and 19 harvests, which were for 4 day periods.)

At the higher temperatures, Poa annua had very upright growth with only a few tillers per plant while at the lower temperatures, particularly 55°F. and 45°F., the plants had a horizontal growth habit and many tillers. The plants at 55°F. often covered a 2 inch diameter area while those at 95°F. covered a half inch or less when the clipping stopped.

After the 19 harvest of clippings the entire plants were harvested, weighed, and tillers counted. Weights and counts were only made on plants at 45°F., 55°F. and 65°F. since the plants grown at higher temperatures were dead.

Results and Discussion. Yields of clippings are shown by graphs in Figure 2, and are also presented in Tables 5 and 6. The harvesting of the treatments at 75°F., 85°F. and 95°F. was terminated after the ninth harvest due to the fact that the plants in treatments of 85°F. and 95°F. were dying and an electrical malfunction in the 75°F.

Figure 2. Means of clippings in milligrams plotted at 3 day intervals as harvested from Poa annua plants grown at different temperatures in Experiment II.



Dotted line across graphs at 15 mg. is for comparisons.

Table 5. Yields of clippings in milligrams per day from the pots in Experiment II.

Harvest - Temp.	Pot No.	1	2	3	4	5	6	7	8	9	Totals
	20	22	18	18	14	19	20	17	20	19	167
	64	22	14	16	19	11	18	11	17	15	143
55°F.	63	20	13	15	15	10	12	11	14	11	121
	1	14	10	8	13	8	12	9	7	14	95
	132	24	13	16	15	17	19	15	18	18	155
	46	17	10	20	14	14	17	16	15	14	137
	Totals -	119	78	93	90	79	98	79	91	91	818
	32	24	18	12	18	9	18	13	13	15	140
	144	27	14	19	15	11	17	16	14	12	145
65°F.	147	43	18	18	15	10	23	14	12	13	166
	99	31	14	14	14	8	14	13	11	15	134
	10	41	17	19	16	9	18	17	13	14	164
	51	29	19	23	19	13	21	18	21	18	181
	Totals-	195	100	105	97	60	111	91	84	87	930
	95	32	16	16	12	14	16	14	22	22	164
	69	18	13	11	11	12	20	12	10	15	122
75°F.	121	28	9	15	13	15	18	15	17	14	144
	80	36	20	22	15	12	21	17	18	17	178
	33	34	19	17	15	15	27	16	18	17	178
	143	42	13	19	15	17	41	18	19	20	204
	Totals -	190	90	100	81	85	143	92	104	105	990
	68	21	12	17	10	11	13	10	9	6	109
	8	36	14	15	13	12	20	12	9	12	143
85°F.	16	40	16	16	10	12	14	8	7	2	125
	118	32	15	16	16	9	15	6	11	5	125
	89	31	18	11	18	11	14	15	11	6	135
	6	38	20	16	13	12	19	12	16	11	157
	Totals -	198	95	91	80	67	95	63	63	42	794
	17	48	12	14	8	5	6	5	4	3	105
	35	45	15	13	6	5	5	3	2	1	95
95°F.	108	36	18	12	5	9	17	8	9	5	119
	40	53	12	18	9	9	5	7	5	5	123
	126	47	16	15	11	10	13	10	7	5	134
	2	35	9	11	9	6	6	6	8	3	93
	Totals -	264	82	83	48	44	52	39	35	22	669

Table 6. Yields of clippings in milligrams per day from the pots in Experiment II.

Harvests

Trt.	Pot	10	11	12	13	14	15	16	17	18	19	Total
	20	13	20	17	18	19	16	20	20	26	18	197
	64	11	17	17	14	14	11	20	16	15	16	151
55°	63	10	6	20	12	10	13	14	18	18	23	144
	1	7	11	11	14	9	9	14	14	14	16	119
	132	13	16	19	16	13	12	18	19	19	20	165
	46	15	13	16	14	15	10	15	16	16	13	143
	Totals -	69	83	110	88	80	71	101	103	108	106	919
	32	12	11	14	13	13	10	13	13	12	11	122
	144	12	12	11	14	8	6	10	8	7	5	93
65°	147	11	13	15	10	10	8	10	10	7	10	104
	99	11	10	17	13	9	8	10	15	9	13	115
	10	14	8	14	8	8	7	8	12	9	10	98
	51	10	16	16	15	14	12	14	20	16	13	146
	Totals -	70	70	87	73	62	51	65	78	60	62	678

Trt.	Pot	1	2	3	4	5	6	7	8	9
	24	14	8	7	9	13	11	10	16	12
	104	9	8	6	9	9	8	7	10	9
45°	106	11	10	8	11	12	10	8	15	20
	23	7	5	4	9	10	6	4	7	10
	92	7	7	7	6	10	8	13	11	14
	111	8	9	6	7	11	7	7	9	16
	Totals -	54	47	38	51	65	50	49	68	81

section caused a lack of temperature control.

The analysis of variance (Table 7) indicates a difference between treatments at the one percent level. The treatments were therefore further analysed by orthogonal comparisons, (Table 8). A comparison of the 3 lower temperatures (55, 65 & 75°F.) with the 2 higher temperatures (85°F. and 95°F.) showed a significant difference at the one percent level. As in Experiment I, yields at the 2 higher temperatures were significantly less than those at the three lower temperatures, indicating more optimum conditions for growth at temperatures below 85°F.

Table 7. Values of F from analysis of variance for the first 9 cuttings of Experiment II.

Source of variation	df	SS	MS	F
Treatments (T)	4	1,157	289.3	5.52**
Error (a)	25	1,311	52.4	
Cuttings (C)	8	10,204	1,275.5	119.20**
C x T	32	3,471	108.5	10.10**
Error (b)	(200-1)*	2,120	10.7	
Total	269	18,263		

*Loss of one degree of freedom due to estimated missing value.
**Significant at the one percent level.

Table 8. Orthogonal comparisons of treatments in Experiment II.

Comparison	df	MS	F
1-3 Vs 4,5	1	729.4	13.9**
1,3 Vs 2	1	8.3	0.1
1 Vs 3	1	273.9	5.2*
4 Vs 5	1	144.7	2.8

*Significant at the one percent level.
**Significant at the five percent level.

A significant difference was found between treatments one (55°F.) and three (75°F.) at the 5% level indicating that the yields at 75°F. were greater than those at 55°F. It seemed possible that the significant statistical difference between treatments of 75°F. and 55°F., and the lack of significant difference between treatments at 85°F. and 95°F. were mainly due to the large yields of the first harvest. To explore this possibility a second statistical analysis was made on the second through ninth harvests. The absence of the abnormally high first harvest in the second statistical analysis increased the differences between treatments, and decreased differences between cuttings and cuttings times treatments (Table 9). Table 10 gives the orthogonal comparisons of the treatments in this experiment.

Table 9. Values of F from analysis of variance for the second through the ninth cuttings of Experiment II.

Source of variation	df	SS	MS	F
Treatments (T)	4	1,979	495	12.4**
Error (a)	25	1,003	40	
Cuttings (C)	7	858	123	17.6**
C x T	28	907	32	4.6**
Error (b)	(175-1)[c]	1,227	7	
Total	269	5,974		

[c]Loss of one degree of freedom due to estimated missing value.
**Significant at the one percent level.

Table 10. Orthogonal comparisons of treatments in Experiment II using only the second through the ninth cuttings.

Comparison	df	MS	F
1-3 vs 4,5	1	1,660	42**
1,3 vs 2	1	2.9	0.07
1 vs 3	1	106	2.7
4 vs 5	1	380	9.5**

** Significant at the one percent level.

The yields for the pots at 55°F. and 65°F. which were clipped 19 times are shown in Table 8. An F test revealed that the yields at 55°F. were greater than those at 65°F. (Table 11). The data indicate that over a 2 month period *Poa annua* produced clippings at a continuous and reasonably steady rate when held at a soil temperature of 55°F., while the yields of *Poa annua* grown at higher temperatures decline at rates which are greater, the higher the temperature is above 55°F.

Table 11. Values of F from analysis fo variance for the tenth through the nineteenth cuttings at 55°F. and 65°F. in Experiment II.

Source of variation	df	SS	MS	F
Treatments (T)	1	729	729.00	14.92**
Error (a)	10	531	53.10	
Cuttings (C)	9	353	39.22	19.90**
C x T	9	167	18.56	9.42**
Error (b)	90	177	1.97	
Total	119	2020		

** Significant at the one percent level.

The weights of tops at 55°F. was significantly greater than those at 65°F. The harvest of whole plants at 45°F., 55°F. and 65°F. did not show significant differences in numbers of tillers per plant or in the dry weight of roots. Data is presented in Table 12.

Table 12. Numbers of tillers and yields of tops and roots of the plants in Experiment II.

Treatment	Pot No.	Tiller/pot	Plants/pot	Tillers/plant	Dry wt. of roots	Dry wt. of tops
45°F.	24	358	11	32.5	2.80	1.57
	104	325	12	27.1	2.64	1.20
	106	379	12	31.6	1.77	1.96
	23	170	10	17.0	1.62	0.69
	92	353	23	15.3	2.50	1.29
	111	335	12	27.9	2.11	1.63
	Averages	320	13.3	25.2	2.24	1.39
55°F.	20	392	12	32.7	2.86	1.40
	64	264	12	22.0	2.11	1.02
	63	318	13	24.5	1.96	1.41
	132	425	11	38.6	2.53	1.54
	46	407	11	37.0	2.63	1.75
	Averages	361	11.4	31.0	2.42	1.43
65°F.	32	389	14	27.8	1.63	0.99
	147	176	6	29.3	1.43	0.42
	99	290	11	26.4	2.03	0.92
	10	146	9	16.2	1.28	0.60
	51	314	11	28.5	3.01	1.13
	Averages	263	10.1	25.6	1.87	0.81

Experiment III.

Purpose. Experiment III was designed to determine what the effect of a 10°F. lower night than day temperature would be on *Poa annua* cut every 3 days at $\frac{1}{4}$ inch.

Procedure. The procedure for this experiment was the same as that used in Experiment II, except pots were moved every night to a 10°F. lower temperature. The plants were not thinned to 12 per pot as was done in Experiment II. The experiment was started on the morning of January 6, 1964, when 3 pots were placed in each of the sections at temperatures of 95°F., 85°F., 75°F. and 65°F. Three pots were placed in the 55°F. section on the morning of January 12th when it was found that a 45°F. night temperature could be obtained by placing pots on the greenhouse floor at night. Pots were moved at 8:30 A.M. and 4:30 P.M. each day.

Results and Discussion. The means of the yields of clippings for this experiment are shown in Figure 3. Clipping was stopped on treatments 1 and 2 (95°F.-85°F. and 85°F.-75°F.) after 11 harvests. At this time it had become obvious that these 2 treatments were killing the plants, see Figure 3 for graphs of yields.

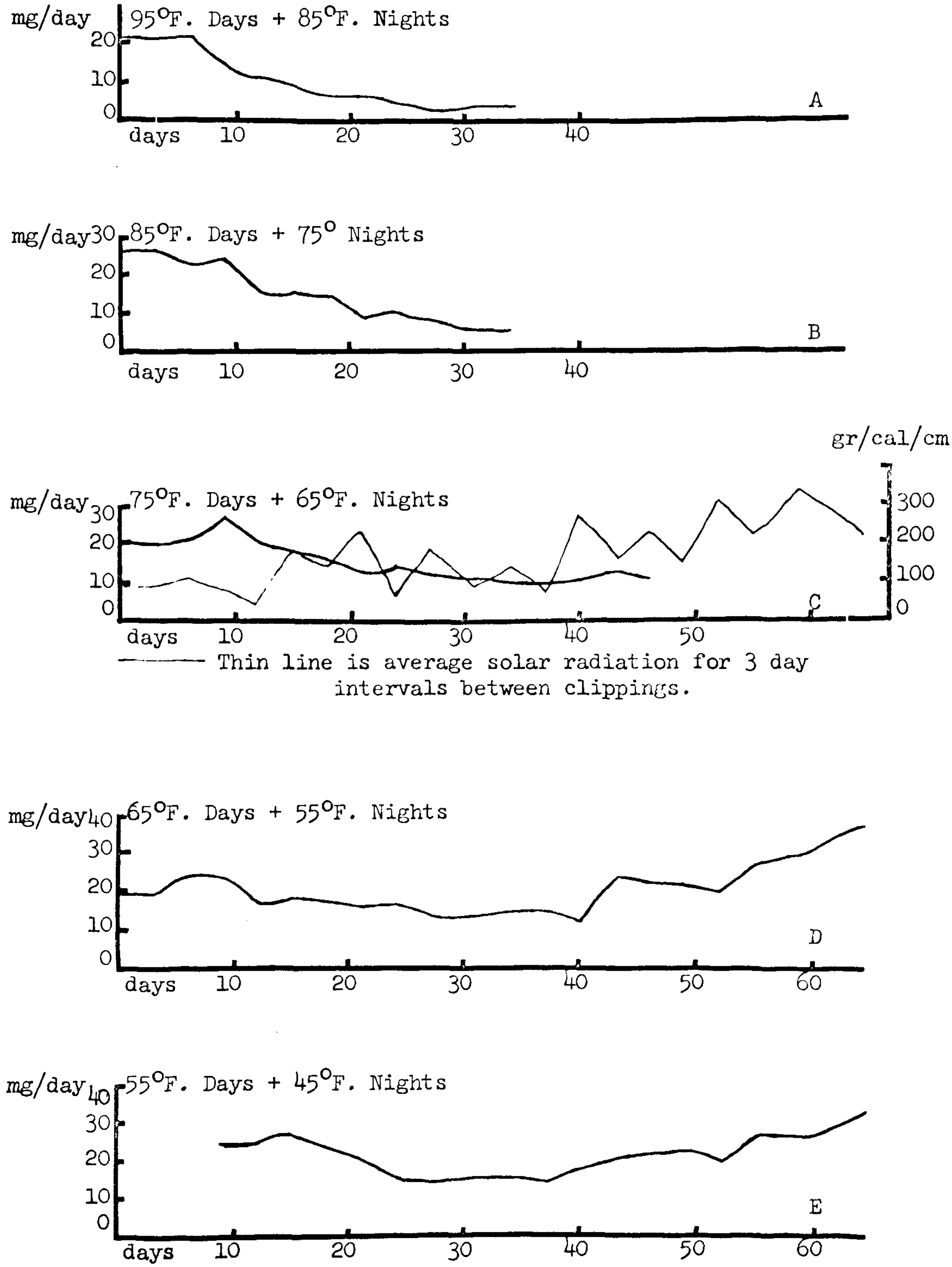
A Duncan's test on means was applied to the yields at this time for treatments 1 through 4. The analysis, (Table 13), shows that the 2 low temperature treatments produced significantly more clippings than the 2 high temperature treatments.

Table 13. Analysis of clippings taken from treatments 1 through 4, harvest 2 through 11 of Experiment III.

Treatments -	(1) 95°-85°F.	(2) 85°-75°F.	(3) 75°-65°F.	(4) 65°-55°F.
Means* -	0.97	1.28	<u>1.61</u>	<u>1.69</u>

*Any 2 means underscored by the same line are not significantly different at the five percent level.

Figure 3. Means of clippings in milligrams plotted at 3 day intervals as harvested from *Poa annua* plants grown at different temperature treatments in Experiment III.


mg/day
95°F. Days + 85°F. Nights
20
10
0
days 10 20 30 40
A
mg/day
85°F. Days + 75° Nights
30
20
10
0
days 10 20 30 40
B
gr/cal/cm
mg/day
75°F. Days + 65°F. Nights
30
20
10
0
300
200
100
0
days 10 20 30 40 50
C
Thin line is average solar radiation for 3 day intervals between clippings.
mg/day
65°F. Days + 55°F. Nights
40
30
20
10
0
days 10 20 30 40 50 60
D
mg/day
55°F. Days + 45°F. Nights
40
30
20
10
0
days 10 20 30 40 50 60
E

Included in graph C of Figure 3 is a plot of the solar radiation in grams per calorie per centimeter. This information is plotted as the average of the days preceeding the date of harvest. The solar radiation measurements are those taken from the Caldwell Field Monthly Meteorological Summaries for the period of the experiment.

After 15 harvests clipping was stopped on the plants in treatment 3 (75°F.-65°F.) because the plants were beginning to die and were not responding to the increase in light intensity which was then taking place as shown in Figure 2. There was no significant difference between clipping yields of the 75°F.-65°F. treatment and the 65°F.-55°F. treatment as shown in Table 14.

Table 14. Values of F from analysis of variance for the second through the fifteenth cuttings of treatments 3 and 4 of Experiment III.

Source of variation	df	SS	MS	F
Treatments (T)	1	110	110.0	2.04
Error (a)	4	216	54.0	
Cuttings (C)	13	1,400	107.7	18.57**
C x T	13	319	24.5	5.95**
Error (b)	52	300		
Total	83	2,345		

** Significant at the one percent level.

The 65°F.-55°F. and 55°F.-45°F. treatments were continued on for 5 more harvests. They were halted because it was no longer always possible to obtain 45°F. at night for treatment 5. Because the total yields of the last 13 harvests differed by only one milligram, no statistical analysis was made.

Experiment IV.

Purpose. Experiment IV was devised to compare Penncross bentgrass with *Poa annua* at different soil temperatues and to check some of the results of Experiment I with more mature turf.

Procedure. *Poa annua* and Penncross bentgrass (*Agrostis palustris*) sod used for this experiment was 10 months and 8 months old respectively.

Both sods were cut into 2 inch squares 3 inches in depth on February 4, 1964. The squares were put into 4 inch pots and the remaining volume of the pot was filled with a coarse quartz sand. The sand was used to make the harvests of roots more accurate.

This experiment included 4 differenct sets of pots. The first 3 sets were made up of bentgrass and the last of *Poa annua*. Each set was started at a different time and run for a different length of time. The different lengths of time before harvests permitted a better estimation of optimum temperatures.

The experimental area and method of heating the soil was the same as used in Experiment I. In this experiment pots going to temperatures higher than 75°F. were placed at 75°F. for 3 days and then moved up to their proper temperature.

Three pots of *Poa annua* and 3 pots of bentgrass were harvested on February 20th. These pots shall be referred to as the reference plants in the following discussion. The roots of the reference plants were dried but not ashed. The ash weights of roots for the reference plants were estimated by assuming that there would be the same percentage loses from the dry weights of these roots as was lost from the dry weights of the roots of sets 2 and 3.

Set 1. The first set of pots containing bentgrass was started on February 4, 1964. Three pots were placed at each of the following soil temperatures, 45°F., 55°F., 65°F., 75°F., 85°F., and 95°F. This set of pots was harvested March 17th, after 6 weeks at different soil temperatures.

Results. The yields of tops and roots from the first set of pots containing bentgrass were analyzed by Duncan's test on means,(Table 15). Tops at 95°F. were significantly less than those grown at a soil temperature of 75°F.

The yields of roots reached a maximum at 75°F. and again there was a more rapid drop in yields at higher temperatures than at lower temperatures. The yield of roots at 95°F. soil temperature was significantly less than those at 75°F., at 55°F. and at 85°F., but not 65°F. due to a missing sample at this temperature. Roots at both 45°F. and 95°F. were significantly less than those of the reference plants indicating a loss in roots at these temperatures.

Set 2. The second set of pots containing bentgrass was put in the heated sand on February 8th. Three pots were put at each temperature. This second set of pots was harvested after 7 weeks at different soil temperatures. The roots in this set were ashed after the dry weights were taken and the loss in weight resulting from ashing, to be henceforth called ash weight, was used as a measure of root weights.

Results. The yield of the second set of bentgrass tops was analyzed by Duncan's Test on means,(Table 16). This analysis showed the highest yields at 75°F., 85°F. and 65°F. to be significantly greater than those at 95°F. and 45°F. Yields at 85°F. and 75°F. were

Table 15. Dry weights of tops and roots in grams for Penncross bentgrass in the first set of pots grown in Experiment IV.

Treatment	Tops	Mean	Roots	Mean
45°F.	0.96 1.53 1.28	1.26c	1.25 1.03 0.77	1.02b
55°F.	3.28 3.11 3.76	3.38a,b	2.46 4.64 4.25	3.78a
65°F.	3.87 3.81 3.63	3.77a,b	4.11 3.72 lost	3.92a,b
75°F.	3.51 4.38 4.00	3.96a	6.52 4.50 3.33	4.78a
85°F.	3.99 2.38 3.99	3.45a,b	3.26 3.26 3.91	3.48a
95°F.	3.01 3.34 2.36	2.90b	1.59 1.82 2.02	1.81b
Reference plants	1.14 1.07 0.90	1.04c	2.86 3.15 5.16	3.72a

a,b,c,d - Means having the same small letter are not significantly different at the five percent level.

Table 16. Dry weights of tops and ashed weights or roots in grams for Penncross bentgrass in the second set of pots grown in Experiment IV.

Treatment	Tops	Mean	Roots	Mean
45°F.	1.48 1.37 1.07	1.31d	1.26 1.53 1.81	1.53b
55°F.	5.29 5.96 5.47	5.57b	2.31 2.56 3.18	2.68a
65°F.	7.02 6.59 7.00	6.87a,b	2.60 3.86 2.75	3.07a
75°F.	7.93 6.70 7.89	7.51a	2.53 2.69 2.51	2.58a
85°F.	8.53 5.42 7.36	7.10a	2.67 2.08 2.54	2.43a
95°F.	3.11 3.70 5.43	4.08c	1.56 0.95 1.50	1.34b,c
Reference plants	1.14 1.07 0.90	1.04d	0.63 0.69 1.14	0.82c

a,b,c,d - Means having the same small letter are not significantly different at the five percent level.

statistically greater than those at 55°F. Yields were highest at the 75°F. soil temperature.

There was a significant difference between the weights of the roots grown at soil temperatures of 55°F., 65°F., 75°F. and 85°F. as compared to the lower weights of those roots grown at 95°F., 45°F. and those of the reference plants. Roots made little growth at 95°F. and 45°F. The greatest yield of roots was at a soil temperature of 65°F. as compared to 75°F. for the first set.

Set 3. On March 4th the third set of pots containing bentgrass was placed in the heated sand. Temperatures used were those at 10 degree intervals between 55°F. and 95°F. All pots in this set were harvested after 4 weeks at the different soil temperatures.

Results. The weights of the tops as analyzed by Duncan's test on means, (Table 17), were significantly greater at 85°F., 75°F., and 65°F. than at 55°F. and 95°F. The weights of the tops at 55°F. and 95°F. were significantly greater than the tops of the reference plants.

The analysis of the roots of this third set showed no difference in the weights of roots at 55°F., 65°F., and 75°F. The weights of roots however, were greater at 55°F. than at 85°F. and 95°F. The weights of roots at 65°F. and 75°F. were greater than those at 95°F.

Set 4. Sixteen pots of *Poa annua* were used in this set, 4 pots each at 45°F., 55°F., 65°F., and 75°F. Soil temperatures of 85°F. and 95°F. were omitted because Experiments I and II had clearly shown the severe detrimental effect of these temperatures on *Poa annua*. The plants were put at the different soil temperatures on February 20th and harvested after 5 weeks.

Table 17. Dry weights of tops and ashed weights of roots in grams for Penncross bentgrass in the third set of pots grown in Experiment IV.

Treatment	Tops	Mean	Roots	Mean
55°F.	4.22 3.82 4.32	4.12b	3.33 2.32 3.23	2.96a
65°F.	5.01 6.10 7.01	6.04a	1.51 2.64 1.82	1.99b
75°F.	6.46 5.87 5.69	6.01a	3.35 1.86 2.09	2.43a,b
85°F.	6.21 4.90 5.46	5.52a	1.60 1.77 1.55	1.64b,c
95°F.	3.83 4.24 4.32	4.13b	1.47 0.63 0.94	1.01b,c
Reference plants	1.14 1.07 0.90	1.04c	0.63 0.69 1.14	0.82c

a,b,c,d - Means having the same small letter are not significantly different at the five percent level.

Results. This set of Poa annua plants gave results similar to those found in Experiment I. See Table 18 for statistical analysis.

Discussion. Figures 4 and 5 allow a comparison of all 3 sets of bentgrass with each other and with Poa annua. Figure 4, which gives graphs of the dry weights of tops, shows the almost complete lack of top growth for bentgrass when grown at 45°F. The optimum temperature for bentgrass as expressed by yields of tops is shown to be 75°F. with yields at 65°F. and 85°F. quite close to those at 75°F.

Only in set 2, where the Penncross bentgrass was allowed to grow for 7 weeks uncut, was there a sharp drop in yields going from 85°F. to 95°F. With Poa annua a sharp drop in yields at high temperatures was experience after 4 weeks in Experiment I and this drop was between 75°F. and 85°F. rather than between 85°F. and 95°F. as experienced here with Penncross bentgrass. The occurrence of this drop in yields only after 7 weeks of growth indicates that bentgrass is much more tolerant of high soil temperatures than is Poa annua.

Figure 5, which gives the weights of the roots, shows a difference in curves between sets 1 and 2 as compared to the curve of set 3. In set 3 the high yields found at 55°F. and the lower yields found at 65°F. give a dip in the curve which is not normally found in growth-temperature curves. Therefore, this curve will not be considered in the discussion.

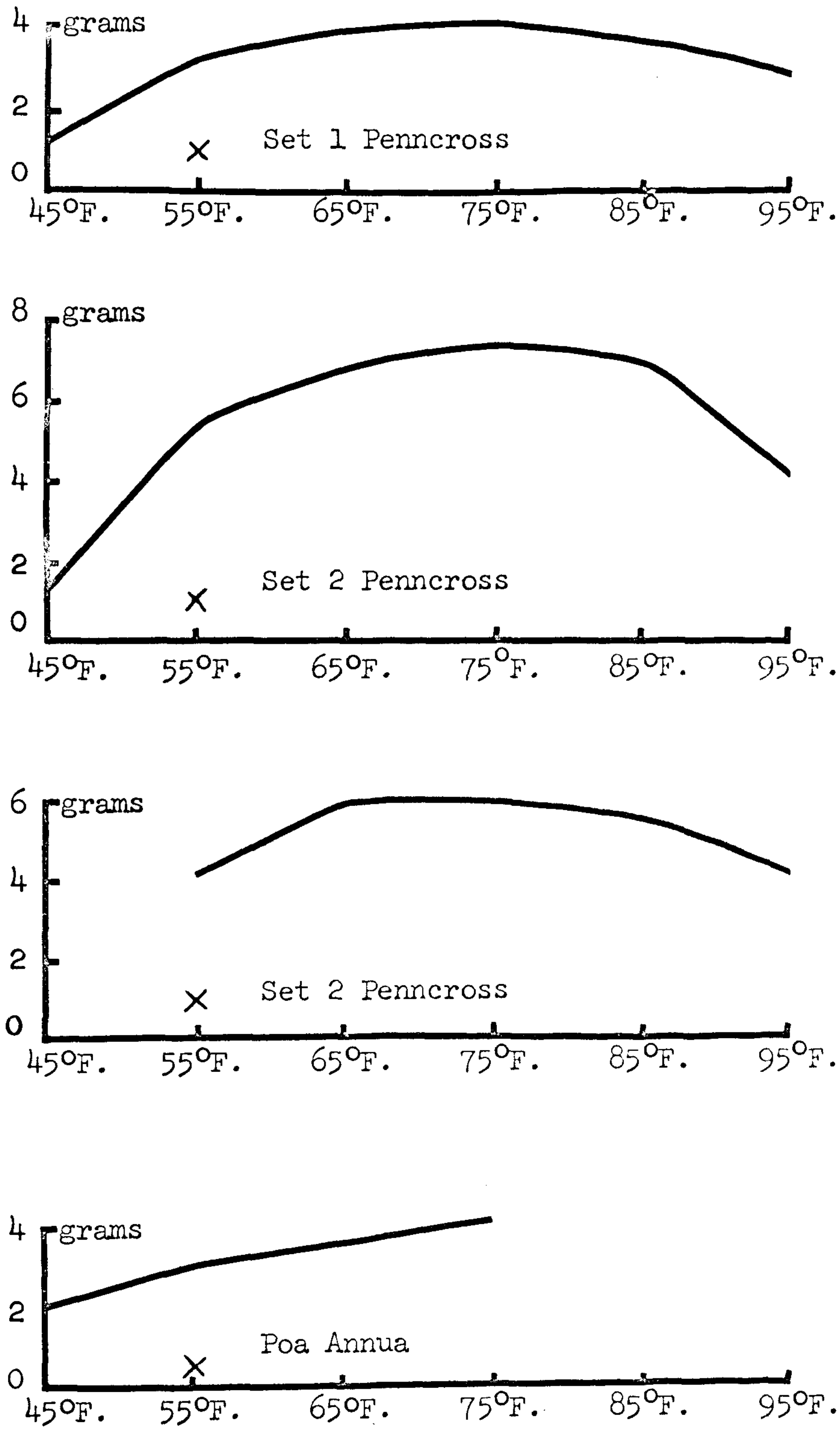
The yields of bentgrass roots are not as adversely affected by 45°F. soil temperatures as the tops were. The fact that the curve of the second set peaks at 65°F. rather than at 75°F. for set 1, indicates that 65°F. is probably the more optimum temperature for root growth when bentgrass is grown for long periods of time.

Table 18. Dry weights of tops and ashed weights of roots in grams of *Poa annua* grown in Experiment IV.

Treatment	Tops	Mean	Roots	Mean
45°F.	1.58 1.95 1.88 2.43	1.96c	0.85 0.79 1.31 0.96	0.98b
55°F.	2.87 3.47 2.90 3.20	3.11b	1.41 1.38 1.23 2.01	1.51a
65°F.	3.13 3.16 3.72 4.65	3.67a,b	1.00 1.48 1.51 1.49	1.37a
75°F.	4.20 4.39 3.68 4.31	4.15a	1.53 1.36 1.40 1.42	1.43a
Reference plants	0.70 0.53 0.46	0.56d	0.37 0.24 0.12	0.24c

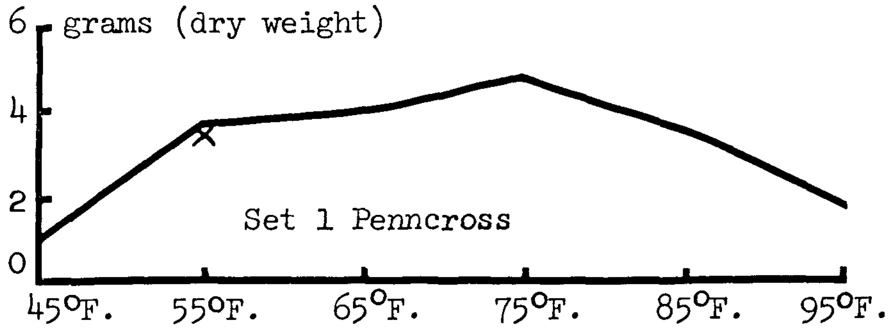
a,b,c,d - Means having the same small letter are not significantly different at the five percent level.

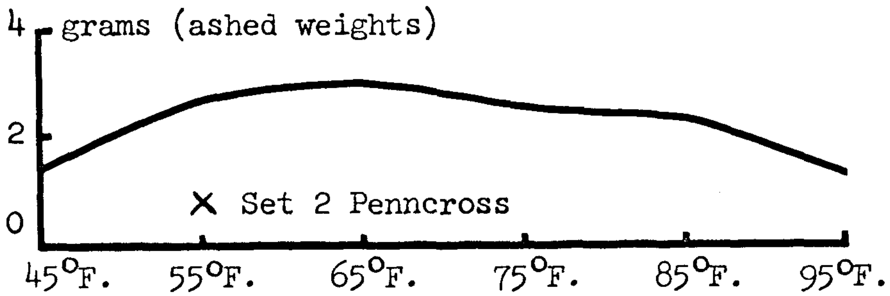
Figure 4. Means for the dry weights of Poa annua tops plotted at their respective temperatures as harvested for different sets of pots in Experiment IV.

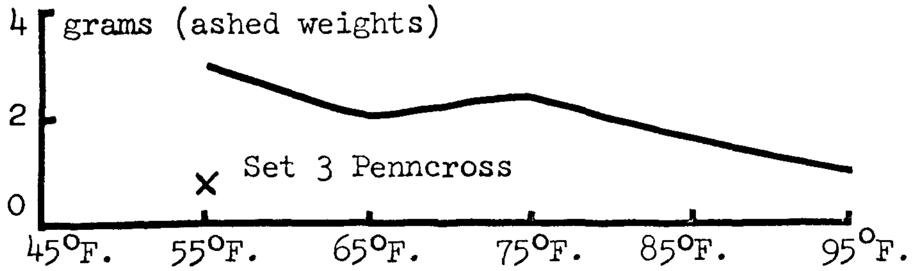


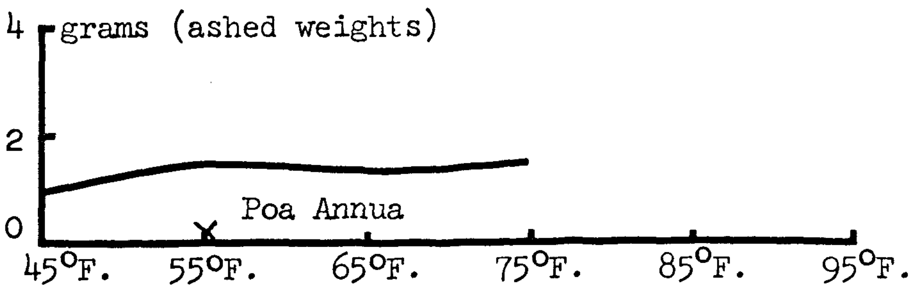
X=Reference Plants

Figure 5. Mean weights of *Poa annua* roots plotted at their respective temperatures as harvested for different sets of pots in Experiment IV.


6
4
2
0
grams (dry weight)
Set 1 Penncross
45°F.
55°F.
65°F.
75°F.
85°F.
95°F.


4
2
0
grams (ashed weights)
Set 2 Penncross
45°F.
55°F.
65°F.
75°F.
85°F.
95°F.


4
2
0
grams (ashed weights)
Set 3 Penncross
45°F.
55°F.
65°F.
75°F.
85°F.
95°F.


4
2
0
grams (ashed weights)
Poa Annua
45°F.
55°F.
65°F.
75°F.
85°F.
95°F.

Experiment V.

Purpose. Results of preliminary trails suggested that *Poa annua* could survive high day temperatures if it were given cool nights. Experiment V was designed to find the frequency of cool nights necessary to maintain a quality turf at approximately $\frac{1}{4}$ inch height of cut under summer like conditions.

Procedure. A thin layer of fiber glass was put in the bottom of the 4 inch pots to keep the sand in. The pots were then filled to 1/8 inch of the top with fine quartz sand and seeded heavily with *Poa annua*. Forty pots were prepared thus, placed in the 60°F. day and 50°F. night greenhouse on April 8th, and subirrigated until well germinated.

Four weeks after planting, when the seedlings were about $\frac{1}{2}$ inch high, daily applications of a complete Hoagland's nutrient solution were begun. On May 11th the pots were clipped for the first time, and were then clipped every third day until the start of the treatments.

On June 10th the 8 poorest pots were removed. The remaining pots were divided into blocks based on the pre-treatment yields of clippings for June 1st and 5th. Block 1 was made up of the 8 highest yielding pots, block 2 included the 8 next highest in yield, etc.

A Sherer Controlled Environment Laboratory (growth chamber) was used during this experiment to provide 55 degree soil temperatures. This was set for a 14 hour day with the lights coming on at 7 A.M. There was 1200 foot candles of light at plant level. The air temperature was maintained at 60°F. in order to maintain a soil temperature of 55°F.

In the greenhouse at night the pots were covered with a heavy piece of clear plastic from 8 P.M. to 8 A.M. to eliminate the drop in surface temperature due to cold air temperatures.

Treatments. (1) 85°F. continuous soil temperature.

(2) nights at 55°F. and days at 85°F.

(3) every other night at 55°F. and remaining time at 85°F.

(4) every 4th night at 55°F. and remaining time at 85°F.

(5) every 7th night at 55°F. and remaining time at 85°F.

(6) nights at 85°F. and days at 55°F.

(7) 55°F. continuous soil temperature.

(8) reference plants harvested at the start of experiment.

Treatments were begun on June 10th when the plants were 2 months old.

Clippings were taken in the manner of earlier experiments every second day. The clippings were dried and weighed as before.

Whole plants were harvested at the end of the experiment by washing the grass free of the sand in a pail of water. Separation of tops and roots was not attempted because the quartz sand which remained made it very difficult to cut the roots from the tops. This quartz sand made it necessary to ash the plants to get a true value for plant weights.

Results and Discussion. The means of the plant weights for the 8 treatments were statistically analyzed by the Duncan's test (Steel

& Torrie, pg. 107). Plant weights and statistical analysis are given in Table 19. Plant weights are also shown in Figure 6.

The resulting plant weights for the treatments increased as the amount of time spent at a soil temperature of 55°F. increased. The treatments that resulted in the higher plant weights also had the better quality turf. (For pictures of resulting turf see Figures 8 and 9). The plants in treatments 1 and 5, which spent no nights and 1 night per week at 55°F. respectively, lost weight during the month of treatment. Their weights were statistically less than the weights of the reference plants. Treatment 2, which spent every night in the growth chamber at a soil temperature of 55°F., had heavier plants than any treatment spending less time in the growth chamber. A visual comparison of the roots of all 7 treatments after washing on a peg-board is given in Figure 10.

The clipping yields (Figure 7) were treated as a split plot in time (Steel & Torrie, pg. 242). These showed a significant difference between treatments (Table 20), and were, therefore, analyzed further by partitioning treatment of the sum of the squares (Steel & Torrie, pg. 217), (Table 21). This analysis showed that clipping yields and total plant weights increased with exposure to cool night temperatures.

A comparison of the 85°F. D.- 55°F. N. treatment with the reverse alternation of the temperatures (55° days-85° nights) shows that the plants at high night temperatures produced the least amount of clippings of all treatments while plants with the temperatures reversed produced the greatest of all clipping yields. Apparently the low night temperature rather than the mere alternation of the high and low temperatures, is necessary for best *Poa annua* growth in the summer.

Table 19. The weights in grams for the Poa annua plants harvested in Experiment V.

Treatment Number	Treatment	Plant Weight	Mean
1	Held constantly at 85°F. or above	0.818 0.849 0.873 0.728	0.817a
2	Days at 85°F., nights at 55°F.	1.338 1.367 1.329 1.510	1.386d
3	Every other night at 55°F.	1.005 1.061 1.120 0.998	1.046c
4	Every 4th night at 55°F.	1.047 0.776 0.954 0.984	0.940b,c
5	Every 7th night at 55°F.	0.875 0.862 0.895 0.912	0.886a,b
6	Days at 55°F. Nights at 85°F.	1.219 1.176 1.198 1.374	1.242d
7	Held constantly at 55°F.	1.945 1.778 1.780 1.911	1.854
8	Harvested at start	1.099 0.888 1.086 0.837	0.975c

a,b,c,d - Means having the same small letter are not significantly different at the five percent level.

Figure 6. Means of dry weights of whole *Poa annua* plants in Experiment V with the treatments arranged in order as to length of time spent at 55°F.

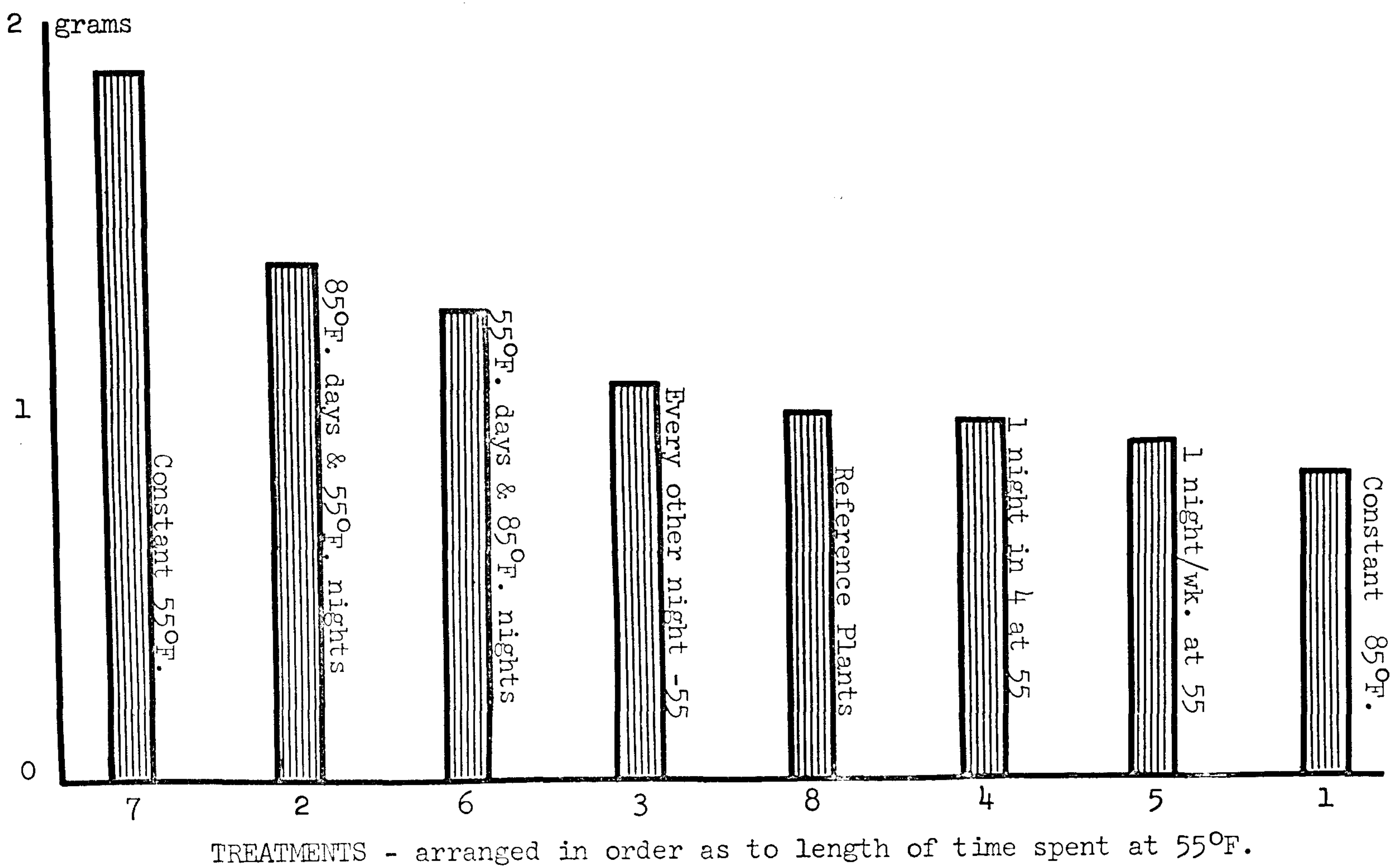

2 grams
1
0
Constant 55°F.
85°F. days & 55°F. nights
55°F. days & 85°F. nights
Every other night -55
Reference Plants
1 night in 4 at 55
1 night/wk. at 55
Constant 85°F.
7
2
6
3
8
4
5
1
TREATMENTS - arranged in order as to length of time spent at 55°F.

Figure 7. Means of clippings in milligrams plotted at 2 day intervals as harvested from *Poa annua* plants grown under different temperature treatments in Experiment V.

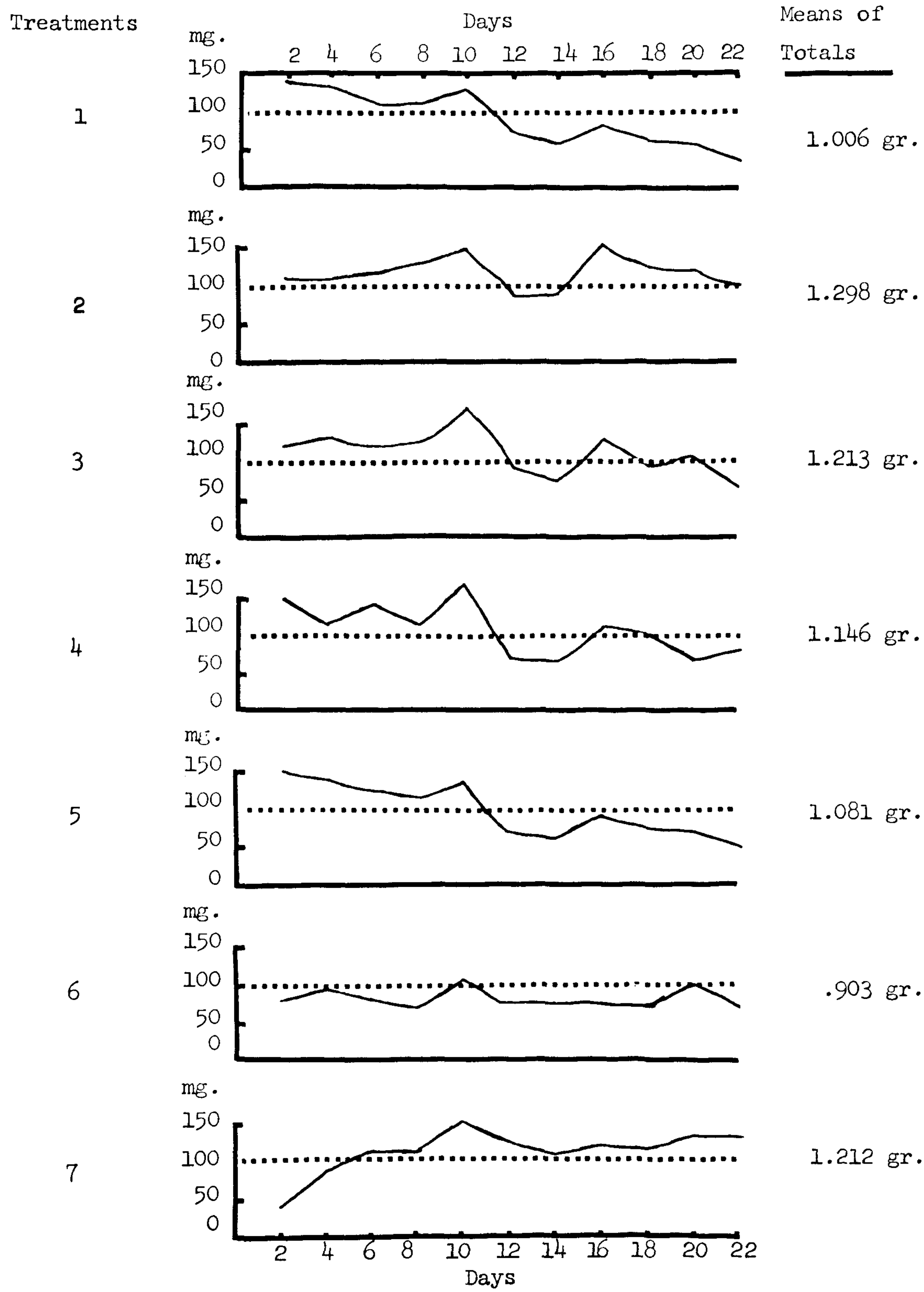

Treatments
Days
Means of Totals
mg.
150
100
50
0
2 4 6 8 10 12 14 16 18 20 22
1
1.006 gr.
2
1.298 gr.
3
1.213 gr.
4
1.146 gr.
5
1.081 gr.
6
.903 gr.
7
1.212 gr.
Days

Figure 8. Photograph of 2 pots per treatment for comparison of the quality of turf from selected treatments in Experiment V.
Treatment 1 = constant 85°F. soil temperature
Treatment 2 = 85°F. day and 55°F. night temperature.
Treatment 5 = 1 night per week at 55°F.
Treatment 4 = 1 night in 4 at 55°F.

Figure 9. Photograph of 2 pots per treatment for comparison of the quality of turf from selected treatments in Experiment V.
Treatment 1 = constant 85°F. soil temperature.
Treatment 2 = 85°F. day and 55°F. night temperature.
Treatment 7 = constant 55°F. soil temperature.
Treatment 6 = 55°F. day and 85°F. night temperature.


TREATMENTS
1
2
5
4


TREATMENTS
1
2
7
6

Figure 10. Photograph of Poa annua plants after washing on pegboards for comparison of the amounts of roots produced in different treatments in Experiment V.
Treatment 1 = constant 85°F. soil temperature.
Treatment 2 = 85°F. days and 55°F. nights.
Treatment 3 = every other night at 55°F.
Treatment 4 = 1 night in 4 at 55°F.
Treatment 5 = 1 night per week at 55°F.
Treatment 6 = 55°F. days and 85°F. nights.
Treatment 7 = 55°F. constant soil temperature.

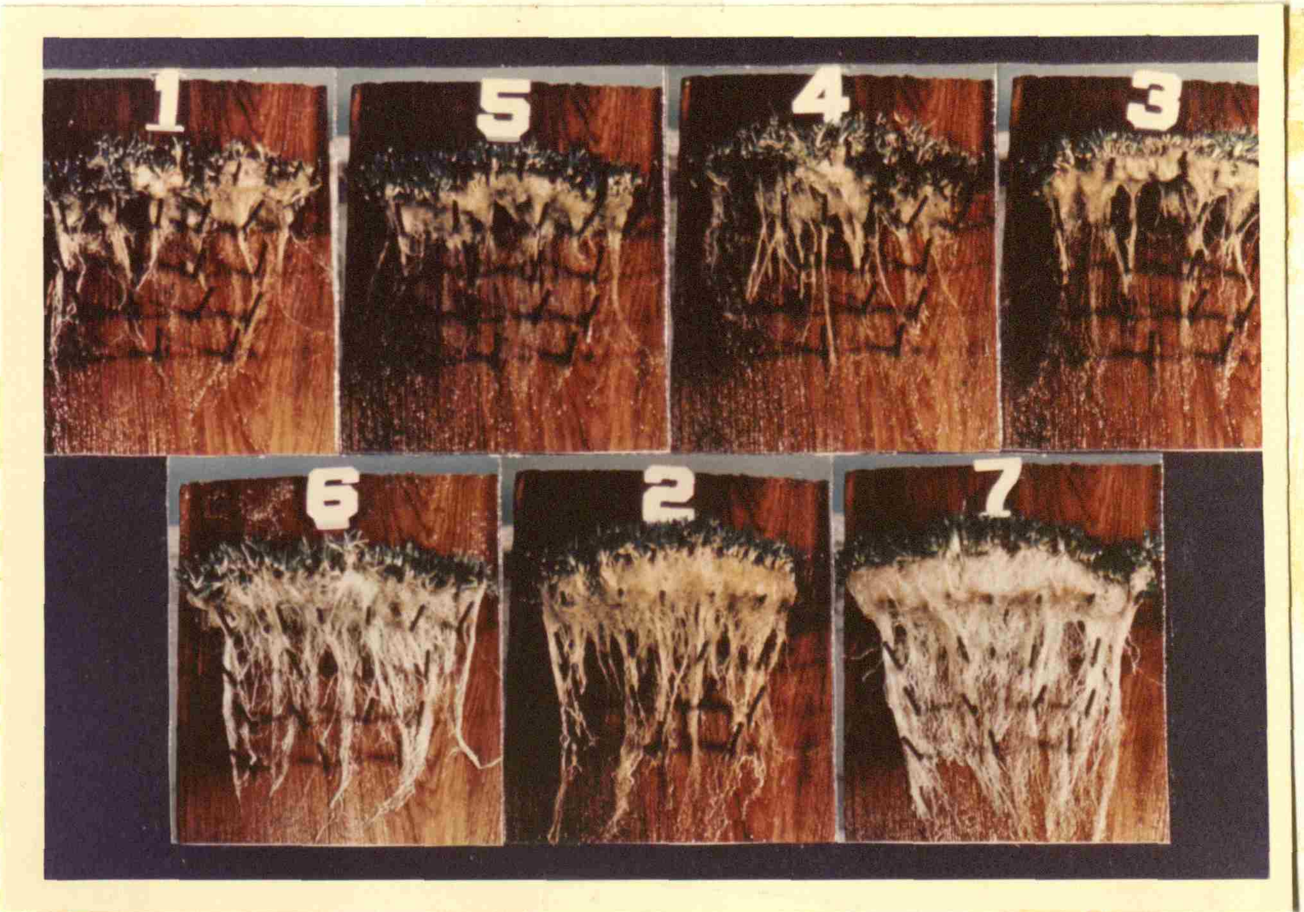

1
5
4
3
6
2
7

Table 20. Values of F from analysis of variance for the first through the 11th cuttings of Experiment V.

Source of variation	df	SS	MS	F
Correction term		3,237,360		
Blocks (B)	3	2,459	820	1.1
Treatments (T)	6	41,718	6,953	9.6**
Error (a)	18	13,017	723	
Whole units		57,194		
Cuttings (C)	10	118,401	11,840	84.0**
C x B	30	4,226	141	1.1
C x T	60	129,195	2,153	16.3**
Error (b)	179[c]	23,717	133	

** Significant at the one percent level.
[c]=Loss of one degree of freedom due to estimated missing value.

Table 21. Partitioning of treatment sum of squares for Experiment V.

Source	df	SS	MS	F
Treatment SS	6	41,718	6,953	9.62**
1 vs others	1	6,289	6,289	8.70**
7 vs 2-6	1	1,799	1,799	2.49
6 vs 2-5	1	24,560	24,560	33.97**
2&3 vs 4&5	1	6,566	6,566	9.08**
2 vs 3	1	1,023	1,023	1.41
4 vs 5	1	1,481	1,481	2.05

** Significant at the one percent level.

FIELD OBSERVATIONS

Part 1. Studies of temperatures occurring under putting green turf.

Methods and Materials.

These studies were conducted on the 9,000 square foot experimental putting green of the Cornell University turf research plots on Dryden Road, Ithaca. The elevation of the putting green is 960 feet. The established grass species in the area used was Astoria bentgrass, *Agrostis tenuis*. The soil was Williamson silty clay loam, which had been modified somewhat by the addition of a small amount of peat to a depth of 3 to 4 inches. The peat was incorporated in the process of establishing the putting green in the summer of 1961.

Copper-constantan thermocouples attached to a Minneapolis-Honeyewell automatic recorder were used to measure the temperatures. The thermocouples were placed in the center of 10 by 10 foot plots which were replicated 4 times. In each plot 1 thermocouple was put at the soil surface, and 1 each at depths of 1 inch, 4 inches and 8 inches.

The temperature of the thermocouples was recorded at 2 minute intervals. The machine was programed to read the first 8 thermocouples twice in succession, then to read once the second 8 thermocouples, and then to repeat the cycle. The first 8 thermocouples were used for the soil surface and 1 inch depths for each of the 4 plots, while the last 8 consisted of the 4 and 8 inch depths for each plot. This arrangement of thermocouples allowed for more frequent readings where the temperature changed the most rapidly.

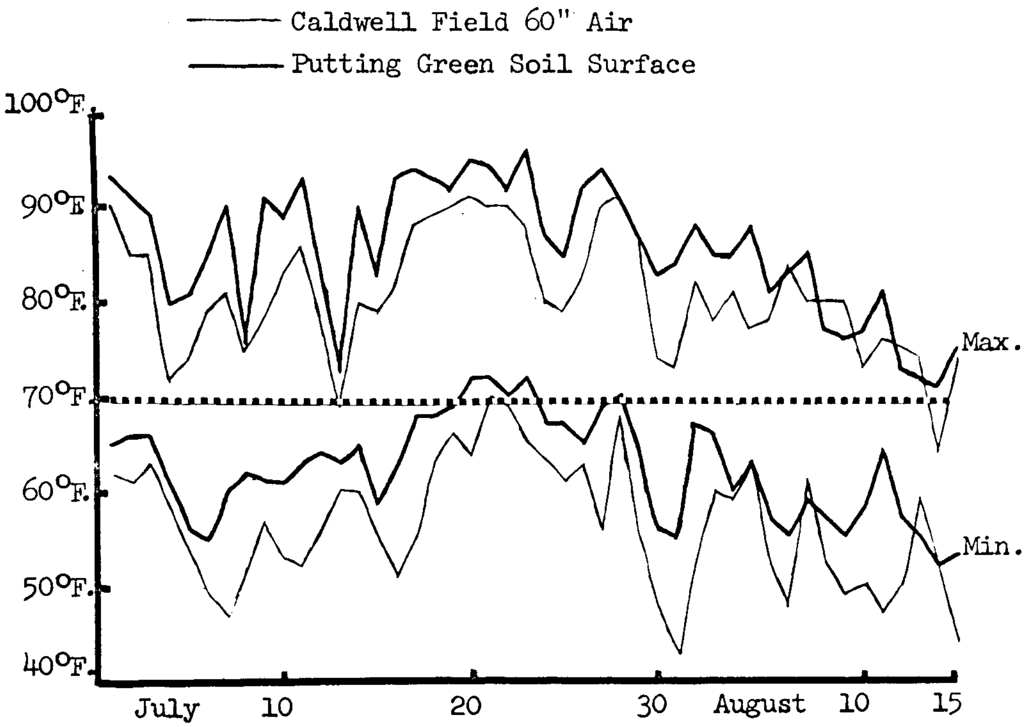
Since a United States Weather Station was located at Caldwell Field, Ithaca, 2000 feet to the north and at the same elevation, their meterological measurements were considered to apply to the test area and were not duplicated. They did have maximum-minimum soil thermometers at 4 and 8 inch depths under bluegrass sod mowed at normal lawn height (about 1½ inches), thus differing from our arrangement for these depths by the type of sod and height of cut of their cover.

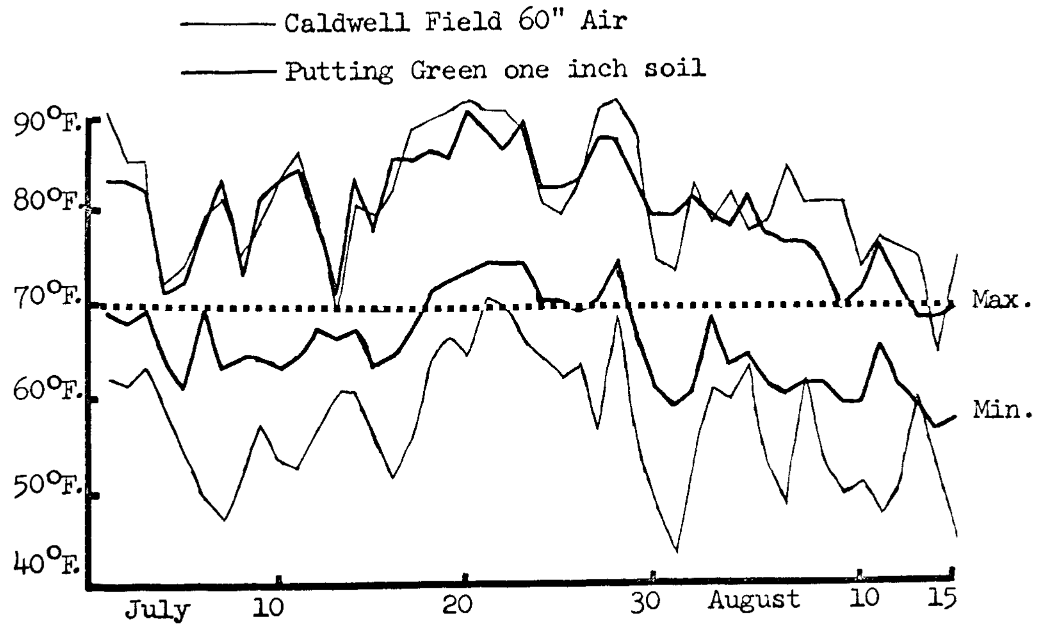
Results and Discussion.

The temperatures during the July and early August period of 1964 for which measurements were recorded were slightly above average for this time of year as reported by the Caldwell Field weather station. Maximum and minimum temperatures were taken for all depths for 24 hour periods beginning at 8 A.M. each day. The maximum and minimum for the soil surface and for the 1 inch depth are shown in Figure 11. The daily means only are given for the 4 and 8 inch depths for both Caldwell Field and the putting green. The soil temperature at these depths had only 6 and 3 degree average daily fluctuations respectively. The average daily fluctuations respectively. The average daily fluctuation at the putting green soil surface was 23 degrees, while that at the 1 inch depth was 14 degrees.

The maximum surface temperature occurred between noon and 3 P.M. The maximum temperature at the 4 inch depth occurred 1 to 2 hours after the maximum at 1 inch and the maximum at 8 inches another hour or two later than that at 4 inches. The minimum temperature for the surface occurred around 8 A.M., with the other minimums about one-half hour apart with increasing depth.

Figure 11. Graphs of the daily maximum and minimum temperatures at the putting green soil surface and 1 inch depth as compared with maximum and minimum 60 inch air temperatures.





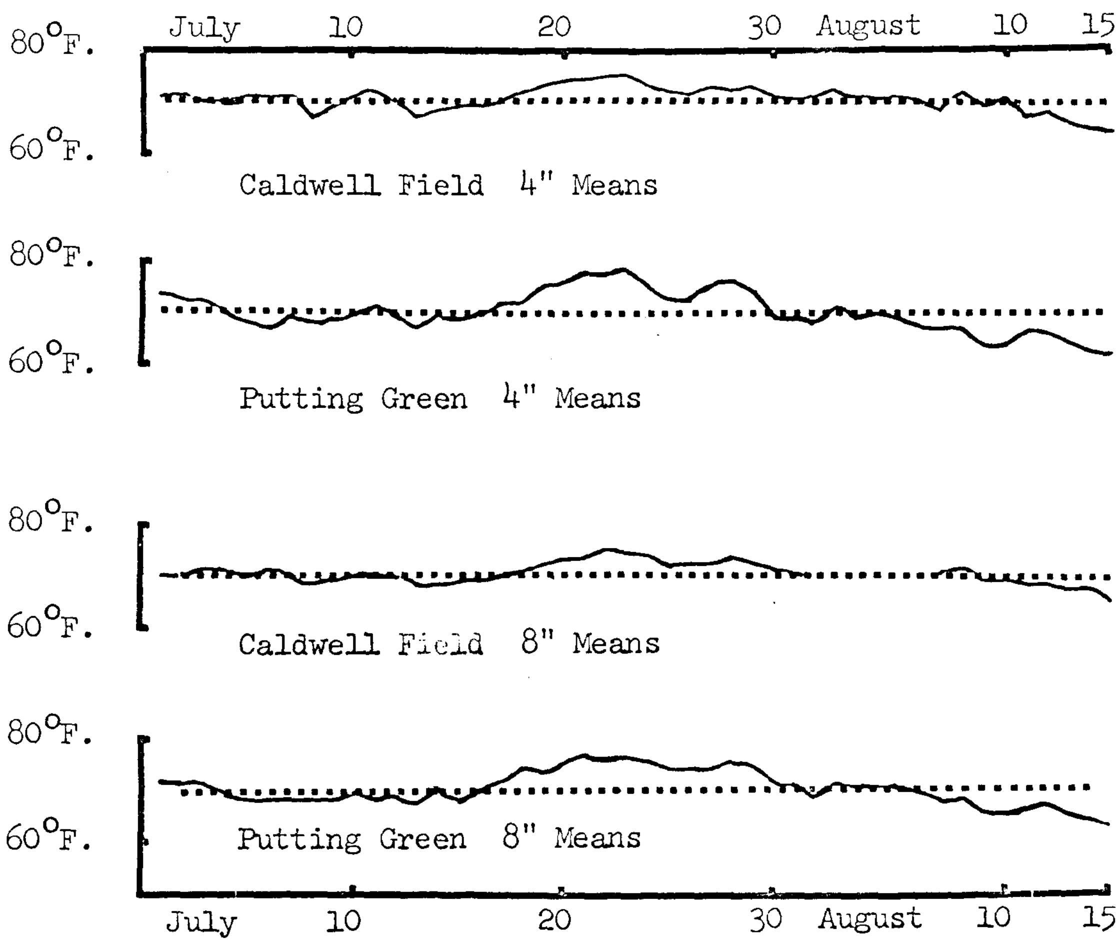
▪▪▪▪▪▪▪▪▪▪▪ Reference Line at 70°F. for comparison.

The surface temperatures of the putting green remained above the air temperatures at Caldwell Field (at 60") during the July-August period for which temperatures were taken. The putting green surface temperature averaged 4.8° higher for the maximum and 5.9° higher for the minimum as compared to the minimum and maximum air temperatures. The highest temperature recorded at the soil surface was 96°F. on July 23rd. Beard, 1959, recorded a high of 110°F. for mat temperature, but he did not give corresponding maximum air temperatures. Probably Beard's plots were at a higher air temperature, since his July-August mean air temperature was 10 degrees higher than that at Caldwell Field during the period of the measurements reported here.

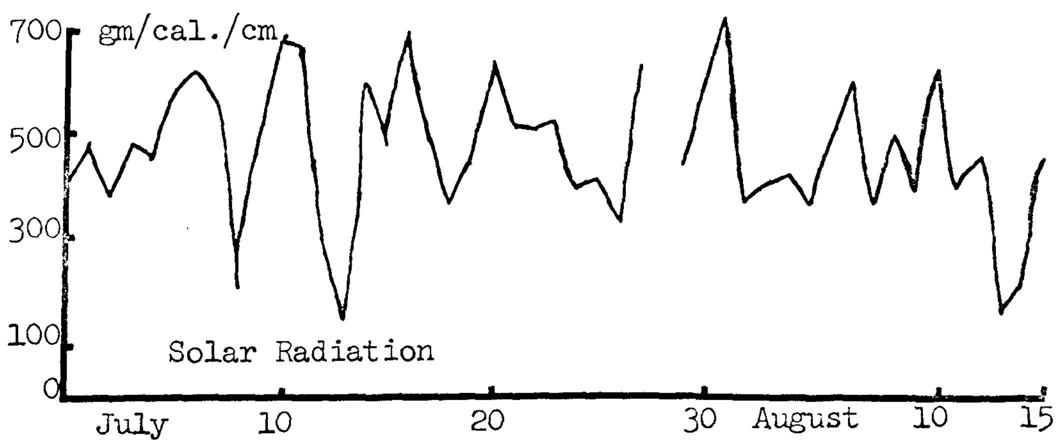
The mean temperature at the 1 inch depth was consistently higher than the air temperature (except in two cases, where routine irrigations lowered a day's average below that of the air temperature). The mean maximum soil temperature at the 1 inch depth for the period July 1 to August 15th on the putting green was 1.4° below that of the mean maximum air temperature, while the mean minimum was 8.8° above the mean minimum air temperature.

Figure 12 shows the daily mean temperatures at the 4 and 8 inch depths under the putting green and at Caldwell Field. The difference in temperature between the 4 and 8 inch depths under the putting green and at Caldwell Field. The differences in temperature between the 4 and 8 inch depths at the putting green as compared to the temperatures at those depths at Caldwell Field appear to be due to 2 things: Lower temperatures under the putting green than at Caldwell Field can be related to periods of irrigation of the putting green; higher readings at the putting green during periods of warm

Figure 12. Graphs of the daily mean 4 and 8 inch soil temperatures at Caldwell Field and the putting green; also, graph of solar radiation of the same period for comparison.



.... = 70°F. Line, put there to facilitate comparisons



sunny weather when the putting green was not being watered can be related to relatively less shading by vegetation on the putting green.

Figure 12, showing the mean temperatures at the 4 inch depth on the putting green, has a sharp drop in temperature on July 29th and a definite drop on the 9th of August. These drops in temperature were due to irrigation. The July 19th to July 29th period was one of warm weather when the putting green was not irrigated. During this period the temperatures at the 4 and 8 inch depths rose several degrees above the Caldwell Field temperatures for these depths. The shorter turf cover and the greater heat conductivity of the more moist soil under the putting green were probably responsible for the higher soil temperatures at these depths.

The mean temperatures for the 6 weeks for which temperatures are recorded are the same for the 4 and 8 inch depths at both locations (Table 22). However, the range between minimum and maximum temperatures for the period is greater under the putting green. This greater range is probably due to the ability of the thermocouples to register changes more quickly than could the maximum-minimum thermometers used at Caldwell Field.

Table 22. Means of weather data from Caldwell Field and putting green for the period of July 1, to August 15, 1964.

Location	Maximum	Minimum	Mean
C.F. 60" air	80.8	56.5	68.6
C.F. 4" soil	72.9	67.9	70.4
C.F. 8" soil	72.0	68.7	70.3
C.F. Solar radiation			470.2
P.G. Soil surface	85.6	62.4	74.0
P.G. 1" soil	79.4	65.3	72.4
P.G. 4" soil	73.7	66.4	70.0
P.G. 8" soil	71.8	68.0	70.0

Part 2. A study of the changes in soil surface temperatures caused by the practice of syringing.

Methods and Materials.

It is a common practice to syringe putting greens during hot summer days in the belief that this will maintain *Poa annua* by reducing transpiration and soil temperatures. Beard, 1959, reported only slight cooling by this practice. To check this observation under Ithaca conditions with known amounts of water at a known temperature, 2 of the 4 plots used in recording soil temperatures were syringed on hot days.

Syringing was by watering a plot with a rose nozzle on the end of a 1 inch hose for 30 seconds. This put about 7 gallons of water on the 100 square foot plot, or a little more than one-tenth of an inch. The temperature of the water was 67°F.(± 1°). Plots were syringed between 11:30 A.M. and 3:00 P.M. on various hot days through-out the period for which soil temperatures were recorded.

On one occasion the plots were syringed for one minute each, and on two occasions 100°F. water was applied with a watering can to 2 of the plots.

Results and Discussion.

Four readings at the soil surface within 2 minutes of syringing gave an average cooling of 8°F. The temperature at the time of syringing ranged from 88°F. to 93°F. On syringed plots 6 temperatures recorded between 6 and 10 minutes after syringing averaged one and one-half degrees cooler than the check plots. All syringed plots returned to normal within 15 to 30 minutes. The slight amount of cooling obtained confirms in general Beard's 1959 observations.

Beard, reported a longer cooling effect of from 30 to 60 minutes, and also reported that the maximum soil temperature was reduced for the day on syringed turf. He did not give the amount or temperature of the water used so no explanation for observed differences can be offered.

The application of two-tenths of an inch rather than one-tenth of water did not have an appreciably greater cooling effect. The use of 100°F. water did not change the surface temperatures in the 2 trials in which this water was used. (The soil surface was 92°F. and 96°F. for these 2 trials.)

On the basis of these observations it would seem that under these conditions syringing does little cooling of the soil under putting green turf.

Part 3. A study of soil cooling with crushed ice.

Methods and Materials.

Two trials were conducted to see how much cooling could be obtained by the use of cold water. An earlier greenhouse trial has suggested that a marked cooling could be obtained if ice was watered in. In the greenhouse trial, little cooling of the soil occurred if ice was merely placed on top of the grass.

At 8:15 P.M. in the evening of July 23rd, crushed ice at approximately 100 pounds per 1000 square feet was spread over one plot and watered in with 28 gallons of water or 0.44 of an inch. Crushed ice was applied to a second plot at the rate of 500 pounds per 1000 square feet on the center 20 square feet. The whole 10 by 10 foot plot was then watered as the first plot was. This small amount of water on a larger amount of ice in this second plot left about 20 percent of the ice unmelted.

Results and Discussion.

Figure 13 shows the large amounts of cooling obtained at the soil surface and at a 1 inch depth on the 2 plots which were treated. Twice as much cooling was obtained in the second plot on which the ice was applied at 5 times the rate used on the first plot. Also, as indicated by the data shown in Figure 12 and by that obtained at the 4 and 8 inch depths, the total degrees that the soil was cooled became less as depth increased but, the length of time that the soil was cooled became longer.

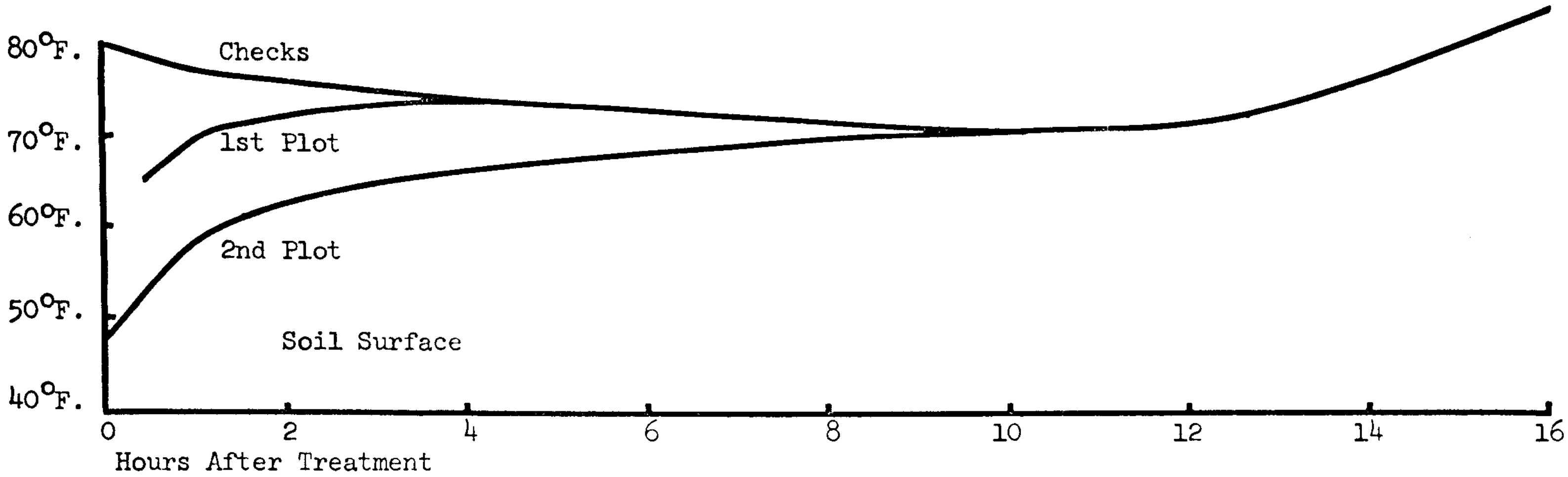
The soil at the 4 inch depth in both plots underwent a gradual cooling which lasted for about 3 hours. In this period the soil was cooled from 80°F. to 73°F. while the check plots dropped to 78°F. The first plot took almost 2 days to return to normal and the second plot took 2½ days to return to normal. The longer time required for the second plot is probably due to a greater amount of cooling in this plot at lower soil depths.

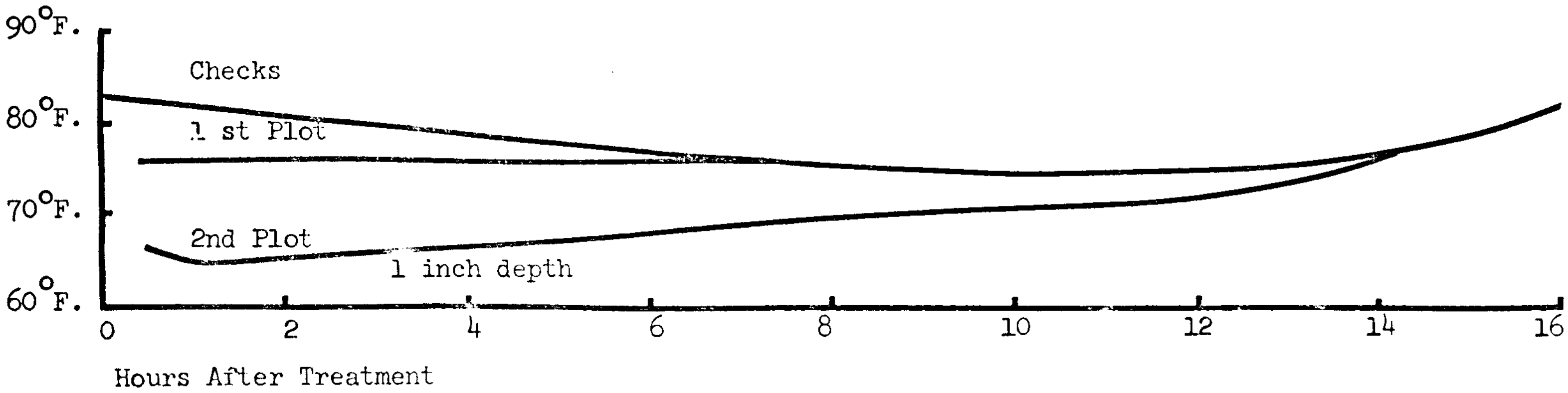
At the 8 inch depth only 1 degree of cooling was noted in the first plot and this was not obtained until 4 hours after the start of the treatment. This 1 degree cooler soil temperature only lasted for 1 day. The second plot was cooled a full degree in 3 hours, and 2 degrees in 5 hours. After 1 day this plot was only 1 degree cooler than the checks and returned to normal at the end of 2 days.

The only difference in the turf noted on these 2 plots was the formation of dew on the treated plots the morning after treatment.

Although considerable cooling was obtained on the treated plots, the large amounts of ice required makes it impractical even if it were found highly desirable to cool the soil during periods of high temperature.

Figure 13. Graphs showing the amounts of cooling occurring at the soil surface and at the 1 inch depth of the putting green after the turf was watered with cold water.


80°F.
70°F.
60°F.
50°F.
40°F.
Checks
1st Plot
2nd Plot
Soil Surface
0
2
4
6
8
10
12
14
16
Hours After Treatment


90°F.
80°F.
70°F.
60°F.
Checks
1 st Plot
2nd Plot
1 inch depth
0
2
4
6
8
10
12
14
16
Hours After Treatment

SUMMARY

Greenhouse Experiments.

Experiment I. *Poa annua* plants, ($3\frac{1}{2}$ months old) were grown in 10 degree intervals at soil temperatures from 55°F. to 95°F. to study effects of soil temperature on this plant. The plants were cut back to one-quarter inch at the start of the temperature treatments after being allowed to grow uncut for 3 weeks. Plants were harvested at 2 week intervals and the dry weights of roots and tops used for the primary measure in determining the optimum temperature for growth.

The dry weight of tops were statistically the same for plants grown at 55°F., 65°F. and 75°F. for the first 6 weeks, while those at 85°F. and 95°F. were significantly less. After 8 weeks the tops at 55°F. weighed more than those at 65°F. and 75°F., thus indicating 55°F. to be the optimum temperature for top growth under these conditions. The weight of roots at the final harvest was greater at 55°F. than at 75°F., but not different than the weight of roots at 65°F.

Temperatures showed an effect on maturity, in that after 4 weeks of growth more infloresences were present at temperatures of 65°F. and above than at 55°F. After 4 weeks root length and top height were both less at 85°F. and 95°F. than at cooler soil temperatures.

Color of roots and tops was also affected by soil temperatures. Roots at 55°F. and 65°F. were thick and white, those at 75°F. were thinner and light brown in color, while those at 85°F. and 95°F. were very thin and brown. There were many dead and yellow leaves at 85°F. and 95°F. and a few at 75°F., while leaves at 55°F. and 65°F. were all dark green.

Experiment II. As in Experiment I, $3\frac{1}{2}$ month old *Poa annua* was grown at soil temperatures of 55°F. to 95°F., but the grass was clipped every 3 days to $\frac{1}{4}$ inch and had been kept at this height for the $3\frac{1}{2}$ months prior to the start of the treatments. Yields of clippings were used as a measure for determining the optimum temperature for growth.

After 1 month at the experimental temperatures it became quite clear that *Poa annua* could not tolerate soil temperatures above 75°F. After 2 months yields of clippings were greatest at 55°F.

Tillers of the plants at the cooler soil temperatures had a horizontal growth while those at higher temperatures grew more upright.

Experiment III. *Poa annua* was grown at the same day temperatures as used in the previous experiments, only with night temperatures 10 degrees cooler than day temperatures. The grass was clipped every third day to $\frac{1}{4}$ inch and dry weight of clippings was used as a measure of growth.

Again plants at 85°F. and 95°F. failed to tolerate these temperatures. Sod at 75°F. day and 65°F. night temperatures grew well for a month and one-half but, failed to respond to increased light intensity after this length of time. Yields for plants at 65°F. day and 55°F. night were not different than those of plants grown at 55°F. day and 45°F. night after 2 months at these temperatures.

Experiment IV. Three sets of Penncross bentgrass were grown at soil temperatures ranging from 45°F. to 95°F. for different lengths of time for the purpose of comparison with *Poa annua*. One set of pots containing *Poa annua* was grown at the same time for direct comparison. Mature sod of both grasses was used for this experiment.

Dry weights of tops and ash weights of roots were used as measures of plant response to temperatures.

There were 3 distinct differences between the top growth of bentgrass and Poa annua in response to temperature differences. Tops of Poa annua grew well at 45°F., while tops of Penncross made almost no growth at this temperature. While 55°F. was found to be the optimum for tops of Poa annua, the optimum for tops of Penncross bentgrass fell between 65°F. and 85°F. Penncross bentgrass tolerated soil temperatures of 85°F. and 95°F. much better than did Poa annua, and bentgrass grew better than Poa annua at 65°F. and above.

Bentgrass root production was relatively greater than that of Poa annua at temperatures from 55°F. to 85°F., while both had relatively similar yields of roots at 45°F. and 95°F.

Experiment V. To determine what extent the exposure of Poa annua to high temperatures might be counteracted by periods of low temperatures, Poa annua was grown for one month at constant soil temperatures of 85°F. and 55°F., and for various numbers of nights per week at 55°F. with days at 85°F. The grass was cut every second day at $\frac{1}{4}$ inch. Dry weight of clippings and ash weight of plants were used as measurements.

There was a gradual decrease of the dry weights of plants with the increase in time plants spent at 85°F. The weight of plants in pots spending less than every fourth night at 55°F. was lower than that of the plants harvested at the beginning of the temperature treatments and the sod was inferior to that of pots spending more time at 55°F.

Clipping yields decreased with increasing time spent at 85°F.

The largest amounts of clippings were produced by plants spending every night, every other night at 55°F., and those held constantly at 55°F. The quality of the resulting turf was the best with the latter treatment. Plants spending their nights at 85°F. and their days at 55°F. produced clippings at a slow, but steady rate. Although plants under this alternation of high night and low day temperatures produced the least amount of clippings (even less than those plants held constantly at 85°F.) ash weights of the resulting sod were equal to those produced by plants at the reverse alternation (high days and low nights).

Field Experiments.

Part 1. Studies of temperatures occurring under putting green turf: An automatic recording instrument and thermocouples were used to take soil temperatures during July and August at the soil surface, 1 inch, 4 inch, and 8 inch depths. These readings were compared to air temperatures and soil temperatures at the 4 and 8 inch depths of a nearby weather station.

The mean soil surface temperature of the putting green was 5°F. higher than the mean air temperature. The mean maximum soil surface temperature was 5°F. higher than that of the air, and the mean minimum temperature of the soil surface was 6°F. higher than the mean minimum temperature of the air. At the 1 inch depth of mean temperature on a particular day was about 4°F. higher than the mean air temperature. This higher mean for the 1 inch soil temperature was due to a 9°F. higher mean minimum soil temperature over the mean minimum air temperature. The means for soil temperatures at the 4 and 8 inch depths were 1°F. higher than the mean air temperature and equal to the means for these depths at the nearby weather station.

Part 2. A study of the changes in soil surface temperatures caused by the practice of syringing: Syringing was done with one-tenth of an inch of water at 67°F. (± 1°), with two-tenths of an inch of the same temperature water, and with one-tenth of an inch of 100°F. water at various times during July and August. The changes in soil surface temperature were recorded with an automatic recorder.

With one-tenth inch of 67°F. water the soil surface was cooled an average of 8 degrees within 2 minutes after syringing. Six to 10 minutes after syringing the syringed plots were only 1½ degrees cooler than the check plots at the soil surface. Fifteen to 30 minutes after syringing the temperature of syringed plots equalled that of unsyringed plots.

Doubling the amount of water used in syringing did not substantially increase the amount of cooling. The use of 100°F. water did not change the temperature of the soil surface. Thus syringing did not greatly cool the soil surface to an important extent under these conditions.

Part 3. A study of soil cooling with crushed ice: Crushed ice at 100 pounds per 1000 square feet and at 5 times this rate was watered in to see how much cooling of the soil this would provide. Soil temperatures were recorded with an automatic recorder.

When the greatest amount of crushed ice was used the soil surface was cooled 30°F. for a short time. The most cooling was at the surface, but the greatest duration of cooling was at the 4 inch depth.

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