

THE EFFECT OF VARYING SOIL MOISTURE,
FERTILIZATION, AND HEIGHT OF CUTTING
ON THE QUALITY OF TURF

By

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INTRODUCTION

Irrigation, mowing, and fertilization have been used with varying degrees of success in attempting to grow the type of fairway turf which golfers demand. Lack of knowledge concerning relationships of soil moisture, fertility, and height of cut to growth of fairway grasses and weed has often resulted in failure to produce the desired turf.

More knowledge is necessary in order to grow a thick, compact turf which will: (1) resist the invasion of weeds and undesirable grasses, (2) offer a minimum of resistance to the forward progress of a driven ball, (3) hold the ball at suitable heights above the soil surface and not interfere with the forward motion of the club-head in making shots, (4) afford the golfer a firm stance, and (5) present a pleasing landscape all season long. More information is needed to find how little water may be used in supplemental irrigation, its efficiency, and effects of various soil moisture levels on the growth of grasses.

The objectives of this investigation were to study the interactions of irrigation, height of cut, and fertility upon the growth of some grasses commonly grown on fairways in the northern humid regions. An effort was made to evaluate the influence of these practices on the quality of fairway turf.

REVIEW OF LITERATURE

The relationships that exist between soil moisture supply, height and frequency of cutting, fertility levels, and the growth of grasses have been studied in part by many investigators.

Wilson (27), Melton and Wilson (17), and Richards and Weaver (25) used the adsorption soil point method, developed by Livingston (15), to study soil moisture conditions under bluegrass and clover turf on golf courses and lawns. Melton and Wilson (17) showed that a soil permitting a sorption block to absorb 500 mg. water an hour contained sufficient water for good growth of lawn grasses.

The comparison of several methods of measuring soil moisture are given by Kelley, et al. (12) and Slater and Bryant (24). The former point out that two factors are of importance in moisture relations, the volume of water per mass and the availability of the moisture. Their conclusion was that the plaster of paris blocks were more adaptable for measuring soil moisture than other methods then available. This electrical resistance method developed by Bouyoucos and Mick (2,3,5,6,7) was used to study the effects of soil moisture on turf during this investigation.

Results of investigators on the physiological effects of differential cutting and fertilization agree very closely. Harrison (10) used bluegrass, fescue, and bent under three cutting heights, one-fourth, one and one-half, and three inches. He was able to reduce greatly the roots of the low-cut

grasses in 16 five-day periods of cuttings. Mineral fertilizers applied did not overcome this effect of low-cutting. Graber (9) points out that bluegrass may be closely clipped or grazed for one or two seasons with good results, but a decline in productivity is certain. Kuhn and Kemp (13) and Lovvorn (16) cut grasses at five heights relative to the leaf ligule and invariably found that frequent and close cuttings reduced the growth of foliage, roots, and rhizomes.

The importance of fertilizer use on turf has been well illustrated by Montieth and Bengtson (18) and Welton (26). They reported extensive tests on old fairways where recovery was due to fertilizers alone. The aggressiveness of bentgrass is shown by Musser (20) in a study of mixed turf under different pH and phosphorus ranges. Bluegrass and fescue were unable to compete with bent grass under conditions considered optimum for the slower growing grasses.

Bouyoucos (4), using plaster of paris blocks, found little moisture movement during a period of 30 days in soils having a moisture content below their moisture equivalent. He concluded that capillary rise in soil was of little importance to growing crops. In calibrating soil moisture blocks, Anderson and Edlefsen (1) found much less lag in the block readings when growing roots were present in the soil since a greater soil moisture gradient was established.

Soil compaction and physical conditions of soil water movement have received much attention, as related to turf management, especially in putting greens. Mott (19) states

that, in poorly aerated soils, a reduction of nitrates to ammonia occurs and plants lacking in oxygen cannot absorb potassium. Compaction studies of Lawton (14) confirm the idea that decreased potassium uptake occurs in compacted soils. Larger additions of potassium fertilizers were recommended under these conditions to increase uptake of this element. Physical analysis of soils such as those of Humbert and Grau (11) show that soil mixtures containing approximately 70 per cent sand are best for the putting green.

GREENHOUSE EXPERIMENTS

Methods

In December 1948 moisture studies were begun in the greenhouse using 60 three-gallon glazed jars. Fifteen cultures each of Astoria bent, Kentucky bluegrass, and Creeping Red fescue were started in Hillsdale sandy loam soil and fifteen cultures of Kentucky bluegrass were started on Brookston clay loam. Three cultures of each group were left as unfertilized checks and the remaining twelve fertilized. The twelve fertilized cultures of each group were divided into four soil moisture ranges with three replications of each. All unfertilized cultures were maintained in the high soil moisture range.

The Hillsdale sandy loam soil with a pH of 5.0 was relatively high in potash and medium in phosphorus content. The area from which this soil was taken had been in sod for several years and was farmed prior to that. The physical

structure of this soil was very good because of its coarse sand content and the aggregation due to previous grass growth.

The Brookston clay loam soil was very granular, had a pH of 6.8, and was well supplied in available nutrients. This heavy soil was used for contrast to the more sandy and open Hillsdale series, as soil type greatly influences moisture and aeration conditions.

Each culture contained 12 kilograms of screened soil, and the fertilizer was hand mixed into the soil at the rate of 1,500 pounds of 10-6-4 per acre. A Bouyoucos soil moisture block was placed on edge midway (four inches from the bottom) in each pot. Twenty-four nylon and thirty-six plaster of paris blocks were used. The nylon units were used in the extreme moisture ranges because they are more sensitive than the plaster of paris blocks.

On December 13 fescue and bluegrass were planted at the rate of one teaspoon of seed per culture. The bent grass which germinates faster, was planted on January 4, 1949 at the rate of one-half teaspoon of seed per culture. These grasses were permitted to grow until well established when the resulting turf was clipped to one and one-fourth inches.

A careful record was kept of the amount of water applied to each culture during the experiment. In most cases 1,200 ml. of water, equal to 10 per cent by weight of the soil, was applied at one time. Readings of the soil moisture blocks were taken periodically to determine the soil moisture available to the grasses. The reading of the individual block determined the amount of water and time of application

FIGURE 1. CALIBRATION CURVE FOR NYLON SOIL MOISTURE
BLOCKS IN HILLSDALE SANDY LOAM SOIL USED
IN GREENHOUSE AND FIELD PLOTS.
(SEE TABLE 1)

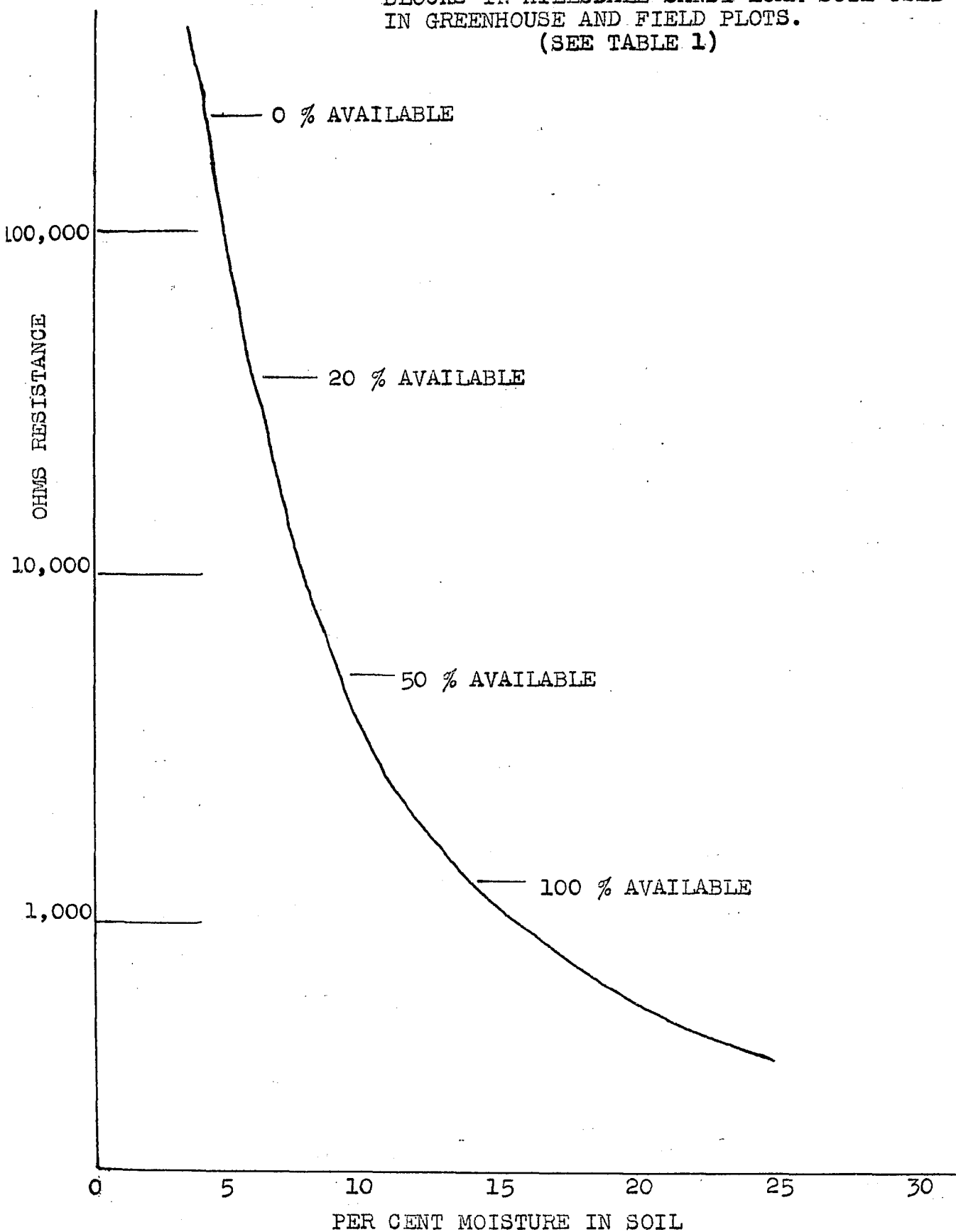


Table 1. Resistance of nylon blocks, per cent available soil moisture and soil moisture content in Hillsdale sandy loam.
Table based on calibration curve in Figure 1.

Ohms Resistance	Per cent Available	Per cent Moisture	Ohms Resistance	Per cent Available	Per cent Moisture
200	263	30.3	6000	45	8.5
250	245	28.5	6500	44	8.4
300	230	27.0	7000	43	8.3
350	220	26.0	7500	42	8.1
400	200	24.0	8000	41	8.0
450	185	22.5	8500	40	7.9
500	170	21.0	9000	39	7.7
550	160	20.0	9500	37	7.6
600	150	19.0	10,000	36	7.5
650	143	18.3	11,000	35	7.4
700	137	17.7	12,000	34	7.3
750	132	17.2	13,000	32	7.2
800	127	16.7	14,000	31	7.1
850	123	16.3	15,000	30	7.0
900	119	15.9	16,000	29	6.9
950	115	15.5	17,000	28	6.8
1000	110	15.0	18,000	27	6.7
1100	105	14.5	19,000	26	6.6
1200	100	14.0	20,000	25	6.5
1300	95	13.5	22,000	24	6.4
1400	90	13.0	24,000	23	6.3
1500	87	12.7	26,000	22	6.2
1600	84	12.4	28,000	21	6.1
1700	81	12.1	30,000	20	6.0
1800	79	11.9	35,000	19	5.9
1900	77	11.7	40,000	18	5.8
2000	75	11.5	45,000	17	5.7
2100	73	11.3	50,000	16	5.6
2200	71	11.1	55,000	15	5.5
2300	69	10.9	60,000	14	5.4
2400	67	10.7	65,000	13	5.3
2500	66	10.6	70,000	12	5.2
2600	65	10.5	75,000	11	5.1
2700	64	10.4	80,000	10	5.0
2800	63	10.3	85,000	9	4.9
2900	61	10.1	90,000	8	4.8
3000	60	10.0	100,000	7	4.7
3200	58	9.8	110,000	6	4.6
3400	57	9.7	120,000	5	4.5
3600	56	9.6	130,000	4	4.4
3800	55	9.5	140,000	3	4.3
4000	53	9.3	150,000	2	4.2
4200	52	9.2	175,000	1	4.1
4400	51	9.1	200,000	0	4.0
4600	50	9.0	240,000		3.8
4800	49	8.9	300,000		3.5
5000	48	8.8	400,000		3.3
5500	47	8.7	500,000		3.0

to a given culture in order to keep the available soil moisture within the desired range.

A modified Wheatstone bridge, Bouyoucos Soil Moisture Bridge, Model C (3), designed for testing the soil moisture blocks, was used throughout the experiment. The readings in ohms resistance were converted to per cent available moisture by calibrating duplicate samples as described by Bouyoucos and Mick (2,3). Supplementing these data were many weight-reading comparisons of actual conditions in cultures in the greenhouse. A total of 172 points was plotted for the curve for nylon blocks as shown in Figure 1. From this curve values such as 100, 50, 20 and 0 per cent available moisture were interpolated. The curve was used for 100 block locations both in the greenhouse and field plots, as a reference for all conditions and treatments on the Hillsdale soil. Variations were least in the mid portion of the curve and greatest at the low moisture end.

The calibration curve for the plaster of paris blocks, shown in Figure 2, was established similarly to that of the nylon block curve. Fifty-four readings were secured from greenhouse cultures to compare with the usual block calibration described by Bouyoucos and Mich (3). Figures 3 to 5 and 10 to 15 are based on these two curves.

Four ranges of soil moisture were maintained in the main experiment. The heaviest application of water was made to the "excess" soil moisture cultures in which the soil was maintained above 100 per cent available moisture after

FIGURE 2. CALIBRATION CURVE FOR PLASTER OF PARIS
SOIL MOISTURE BLOCKS IN HILLSDALE SANDY LOAM
SOIL USED IN GREENHOUSE. (SEE TABLE 2).

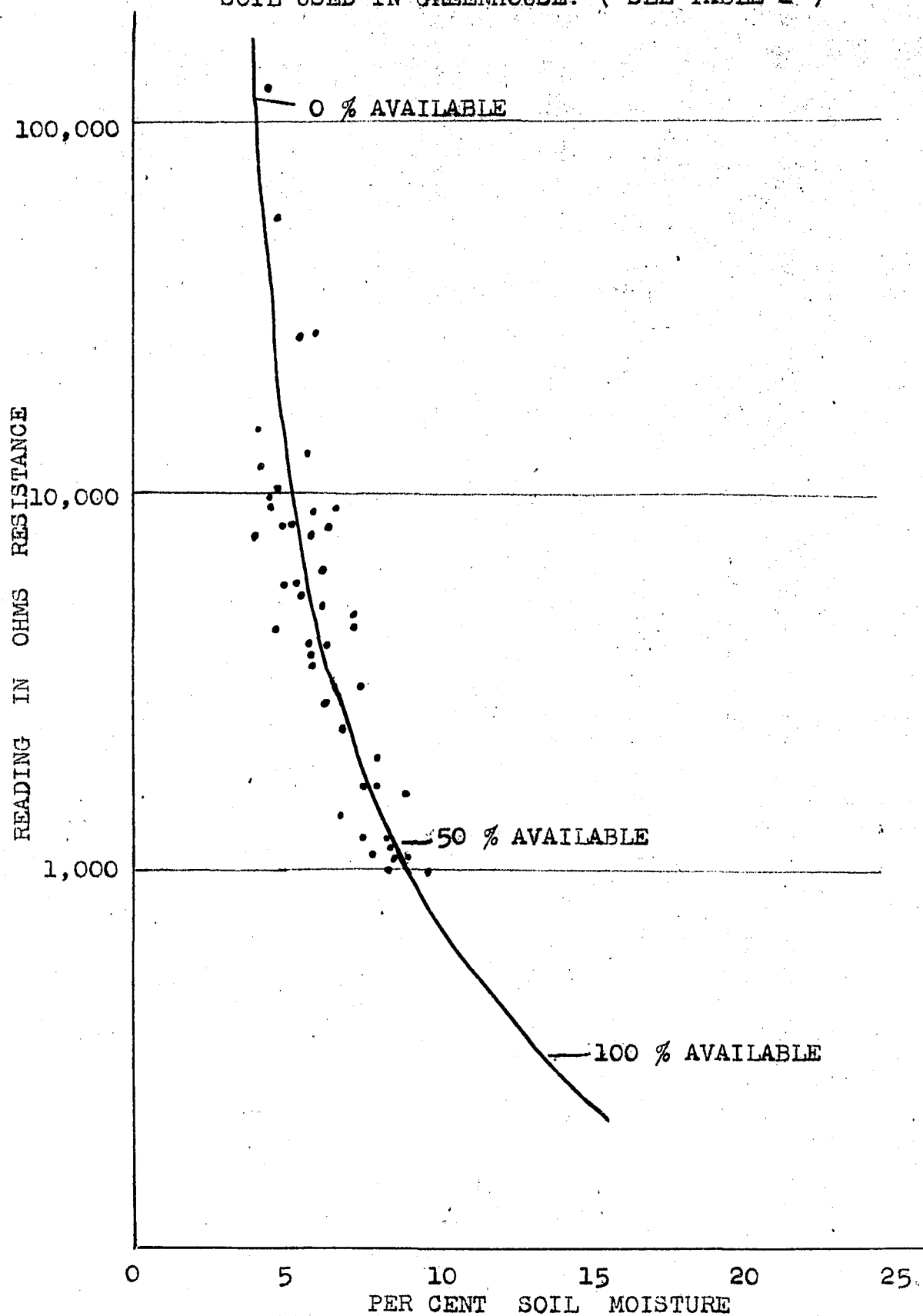


Table 2. Resistance reading of plaster of paris blocks, per cent available moisture and soil moisture content of Hillsdale sandy loam soil. Table based on calibration curve of Figure 2.

Ohms Resistance	Per cent Available	Percent Moisture	Ohms Resistance	Per cent Available	Per cent Moisture
200	120	16.0	2800	29	6.9
250	110	15.0	3000	28	6.8
300	100	14.0	3200	27	6.7
350	92	13.2	3400	26	6.6
400	85	12.5	3600	25	6.5
450	80	12.0	3800	24	6.4
500	76	11.6	4000	23	6.3
550	73	11.3	4400	22	6.2
600	70	11.0	5000	21	6.1
650	67	10.7	5500	20	6.0
700	64	10.4	6000	19	5.9
750	61	10.1	6500	18	5.8
800	59	9.9	7000	17	5.7
850	57	9.7	8000	16	5.6
900	55	9.5	9000	15	5.5
950	53	9.3	10,000	14	5.4
1000	52	9.2	11,000	13	5.3
1100	48	8.8	12,000	12	5.2
1200	46	8.6	13,000	11	5.1
1300	44	8.4	14,000	10	5.0
1400	42	8.2	16,000	9	4.9
1600	39	7.9	20,000	8	4.8
1700	38	7.8	22,000	7	4.7
1800	37	7.7	26,000	6	4.6
1900	36	7.6	30,000	5	4.5
2000	35	7.5	40,000	4	4.4
2200	33	7.3	50,000	3	4.3
2400	31	7.1	70,000	2	4.2
2600	30	7.0	90,000	1	4.1
			120,000	0	4.0

the beginning of the first growth period. This was increased to saturation, (Figure 3) and was completely saturated during the following growing periods. The latter conditions were maintained by the regular addition of small amounts of water.

The "high" soil moisture range varied from 150 to 50 per cent available soil moisture. This range has been shown by Schleusner, et al. (23) to be the most favorable for plants; it gave the greatest production and most succulent growth.

The "medium" soil moisture range was maintained between 120 and 20 per cent available soil moisture. This range was sufficient to keep the grass growing but tended to retard grass growth between the water applications. This range was planned as one requiring the least irrigation possible to maintain satisfactory turf growth.

The "low" soil moisture range varied from 100 to 0 per cent available moisture, which was from 14 to 4 per cent total soil moisture. Grass wilted (See Plate 1 and 2) to some degree for as much as five days between applications of water. Water was added frequently enough to prevent the grass from becoming dormant.

These variations of the soil moisture levels will be referred to as excess, high, medium, and low soil moisture ranges throughout the following discussion.

The response of the grasses to available soil moisture in the greenhouse study was measured in terms of height of growth, dry weight of clippings, water required to maintain the cultures, and water required to produce a unit of dry



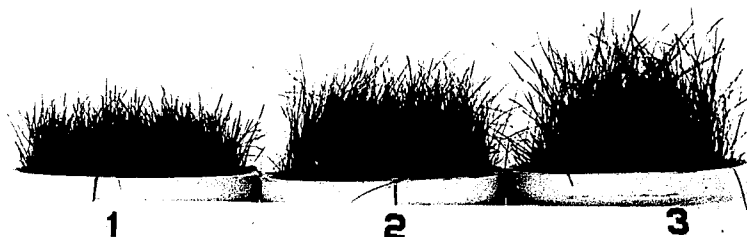
wilted recovered

Plate 1. Illustration of wilting occurring in low soil moisture range for bentgrass on Hillsdale soil. Culture on left had progressively wilted for three days at 70°F. and 40% relative humidity.



wilted recovered

Plate 2. Effect of wilting on appearance of bluegrass. Moisture content of clippings was 68% in wilted, 81% in normal grass.



Bentgrass Fescue Bluegrass

Plate 3. A comparison of three grasses at low moisture range.

matter. Harvest was made by clipping at one and one-fourth inches when a renewal of the moisture cycles occurred. The growth was measured following three growing periods of 27, 34, and 43 days, respectively.

Results and Discussion

Relation of growth to soil moisture ranges

First Growth Period-- This period was started after the turf was well established and extended from March 3 to March 30. During this time the greenhouse was thermostatically controlled at 65° to 75°F. The relative humidity varied from 30 to 100 per cent, but usually it was about 40 per cent. Changes in moisture levels were started March 3 at the same time as the designated first growth period. The responses of the grasses to moisture changes are shown in Table 3. The replications agreed very closely and only the average is reported.

Although the bentgrass grew less in height than the other grasses it produced the greatest dry weight of material. The large response of the bent to high soil moisture supports the results of Musser (20). Bent grass is a vigorous grass that responds to high fertilization and high moisture. The more fertile Brookston clay loam soil produced slightly greater yields of bluegrass than the Hillsdale sandy loam, but the height of growth was about the same. All three grasses in the low soil moisture range cultures produced nearly the same dry weight because they were limited in moisture and had been allowed to wilt on three occasions during the

Table 3. Effect of four soil moisture ranges on the height of growth, dry weight of clippings, and the amount of water applied to three grasses growing on two soils. Averages of three replications during first growth period.

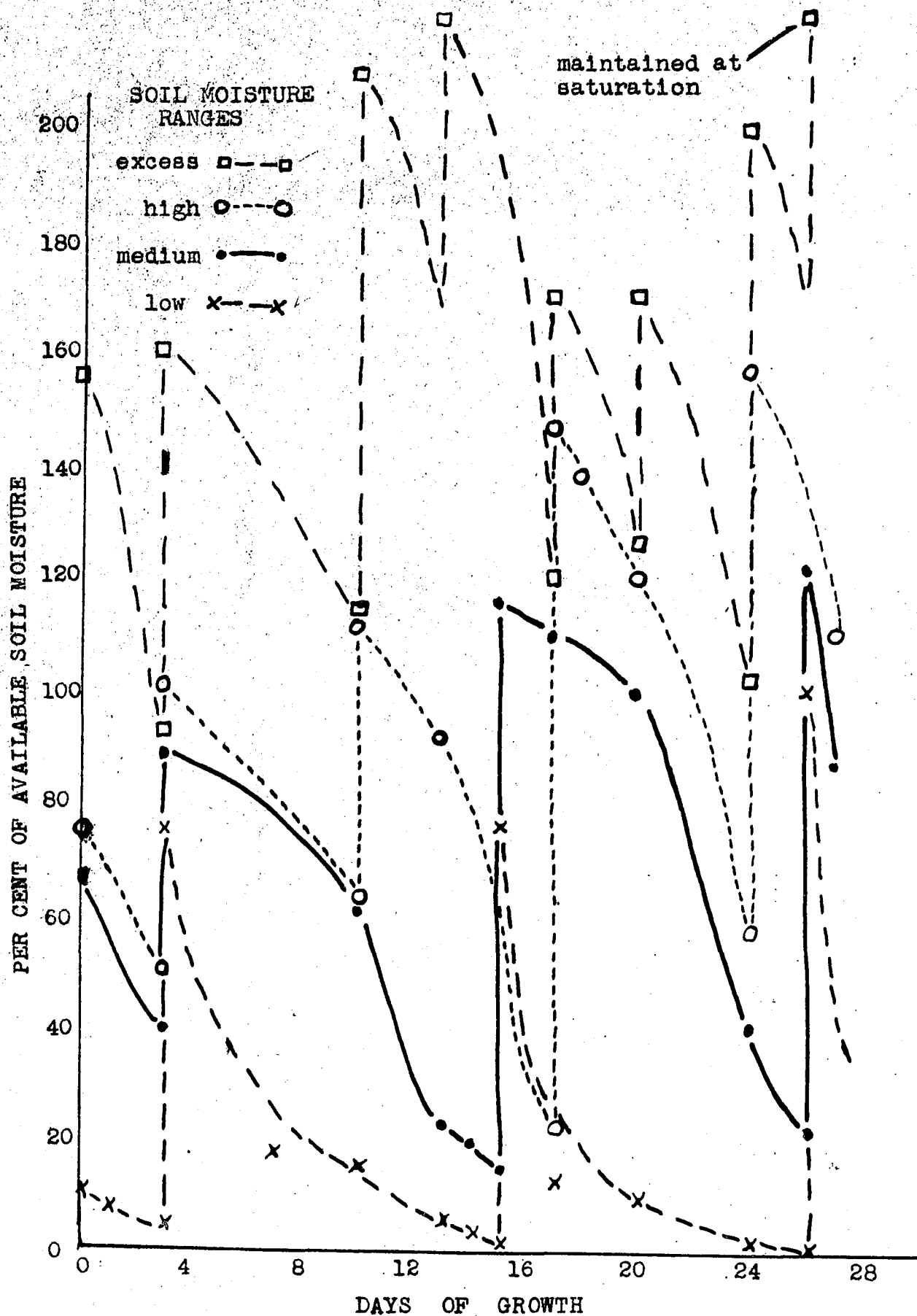
Grass	Soil series	Moisture Ranges			
		Excess	High	Medium	Low
<u>Height of Growth, cm.*</u>					
bentgrass	Hillsdale	21	16	14	11
fescue	Hillsdale	22	17	15	13
bluegrass	Hillsdale	22	20	17	17
bluegrass	Brookston	23	21	16	15
<u>Dry Weight of Clippings, gms.</u>					
bentgrass	Hillsdale	10.7	9.4	4.4	3.1
fescue	Hillsdale	7.7	5.2	3.7	3.4
bluegrass	Hillsdale	5.7	5.2	3.7	3.3
bluegrass	Brookston	6.7	5.7	3.9	3.5
<u>Water Added, liters</u>					
bentgrass	Hillsdale	7.0	3.6	3.0	2.9
fescue	Hillsdale	7.9	5.4	3.0	2.9
bluegrass	Hillsdale	7.4	3.6	3.0	3.2
bluegrass	Brookston	7.7	4.2	3.2	3.2
<u>Average of Above Grasses & Soils</u>					
Height of growth, cm.		22.0	18.0	15.6	14.0
Dry weight of clippings, gms.		7.7	6.4	3.9	3.3
Water applied, liters		7.5	4.2	3.1	3.1

* Clipped one and one-fourth inches above surface of soil.

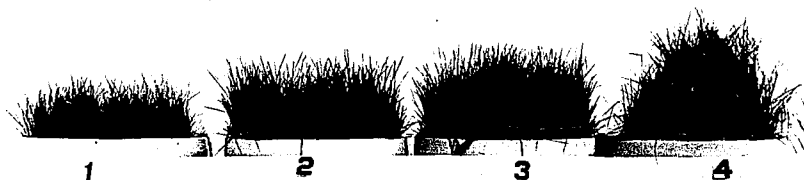
27 day growth period. Examples of such wilting are shown in Plates 1 and 2. As shown in Figure 3 the available soil moisture in the representative cultures was near zero between each water addition. The comparative growth rate is shown in Plate 3 where bent, fescue, and bluegrass were grown under uniform conditions.

Plates 4, 5, and 6 give a comparison of the relative growth response to the different moisture ranges as maintained during the first growth period. Culture 4 in the bentgrass produced the highest yield (10.7 grams) and culture 1 in the bent grass produced the lowest yield (3.1 grams).

FIGURE 3. PER CENT OF AVAILABLE SOIL MOISTURE IN FOUR MOIST. RANGES UNDER BENTGRASS CULTURES DURING FIRST GROWTH PERIOD



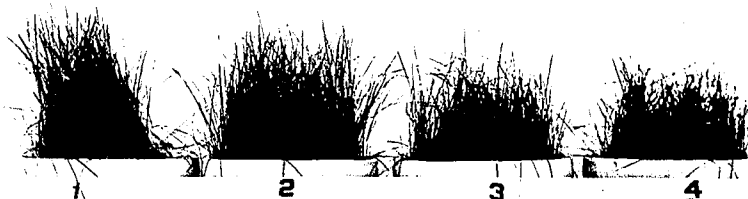
A comparative growth of three grasses during the first growth period on Hillsdale sandy loam soil. Moisture ranges are indicated below each picture.



low medium high excess
Plate 4. Bentgrass. Excess water applied did not reduce growth during this period.



low medium high excess
Plate 5. Fescue. Table 3 shows relative height and yield of these grasses.



excess high medium low
Plate 6. Bluegrass. Note variation in turf height for the different soil moisture ranges.

The gradual increase toward complete saturation of the soil in the excess soil moisture range cultures, shown in Figure 3, had not had time to reduce the yield of grass in the first period. However, examination of the soil in these jars showed that the roots, which formerly extended throughout the soil mass, had died back during the three weeks period, leaving roots only in the upper three inches of soil. Meanwhile, a concentration of new roots occurred at the surface of the soil and at the edges of the culture. It was these roots that enabled the turf to exist under the saturated moisture conditions of the later experiments. The large amount of water applied to the excess soil moisture range cultures is explained by the fact that they contained approximately 2 liters of free water at the end of the first growth period. They were maintained at this level until the end of the greenhouse experiment. Thus the water used by the plants was actually less than the seven and one-half liters listed for the first period.

Second Growth Period-- The second growth period extended for 34 days from March 30 to May 3. The first growth period was terminated after 27 days when there was a definite increase, to complete saturation, in the excess soil moisture range cultures. Following the first growth period all moisture levels were maintained uniformly to the conclusion of the experiments.

Table 4 gives an average of the three replications during the second growth period. In the excess soil moisture

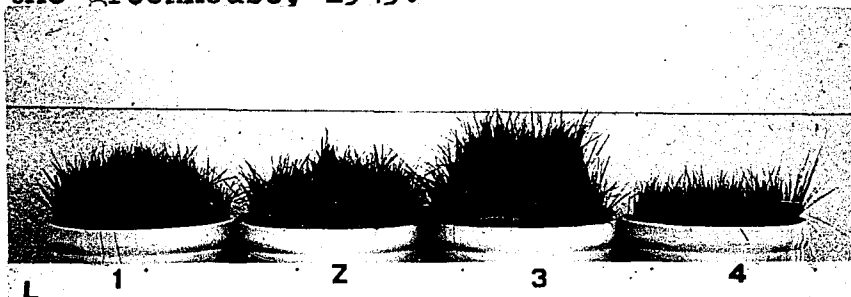
Table 4. Effect of four moisture ranges on the height and dry weight of grass clippings during second growth period.

Grass	Soil series	Soil Moisture Ranges			
		Excess	High	Medium	Low
<u>Height of Growth, cm.</u>					
bentgrass	Hillsdale	9	18	15	13
fescue	Hillsdale	12	15	13	12
bluegrass	Hillsdale	13	24	18	16
bluegrass	Brookston	10	21	17	16
<u>Dry Weight of Clippings, gms.</u>					
bentgrass	Hillsdale	3.3	8.2	7.2	6.0
fescue	Hillsdale	4.1	6.3	3.9	3.4
bluegrass	Hillsdale	2.9	8.8	5.1	4.6
bluegrass	Brookston	2.2	9.4	6.7	7.3
<u>Water Added, liters</u>					
bentgrass	Hillsdale	5.2	6.0	4.0	3.9
fescue	Hillsdale	5.1	6.4	4.4	4.3
bluegrass	Hillsdale	5.2	7.2	5.1	4.8
bluegrass	Brookston	4.5	7.5	6.7	5.7
<u>Ave. of Above Grasses & Soils</u>					
Height of growth, cm.		11	20	16	14
Dry weight of clippings, gms.		3.1	8.2	5.7	5.4
Water applied, liters		5.0	6.8	5.1	4.7

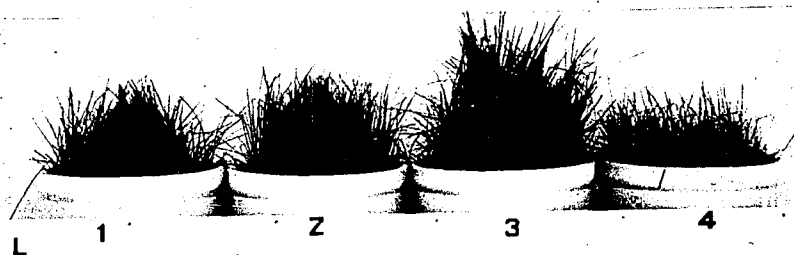
range cultures there was a sharp reduction of the growth accompanied by yellowing and lack of new leaf production. The most noticeable reduction was on the bluegrass on Brookston clay loam with only 10 cm. of growth. In contrast, bluegrass grew 13 cm. on the Hillsdale sandy loam. The fescue grew 10 cm. in the first fourteen days and only 2 cm. more in the last twenty days. In the first period the greatest growth occurred on the excess soil moisture range cultures. The greatest growth occurred on the high soil moisture range cultures during the second period. Plates 7, 8, and 9 show the growth response of the grass to four moisture conditions during this period.

The amount of water applied during this period was

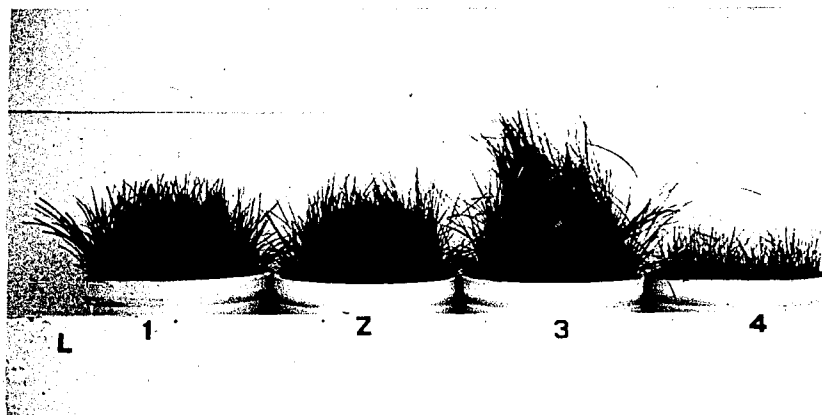
Response of three grasses to the indicated soil moisture ranges during the second growth period in the greenhouse, 1949.



low medium high excess
Plate 7. Bentgrass on Hillsdale sandy loam soil.
Compare with Plate 4 of first growth period.



low medium high excess
Plate 8. Bluegrass on Hillsdale sandy loam soil. Bluegrass
was taller, but less dense, than on Brookston soil.



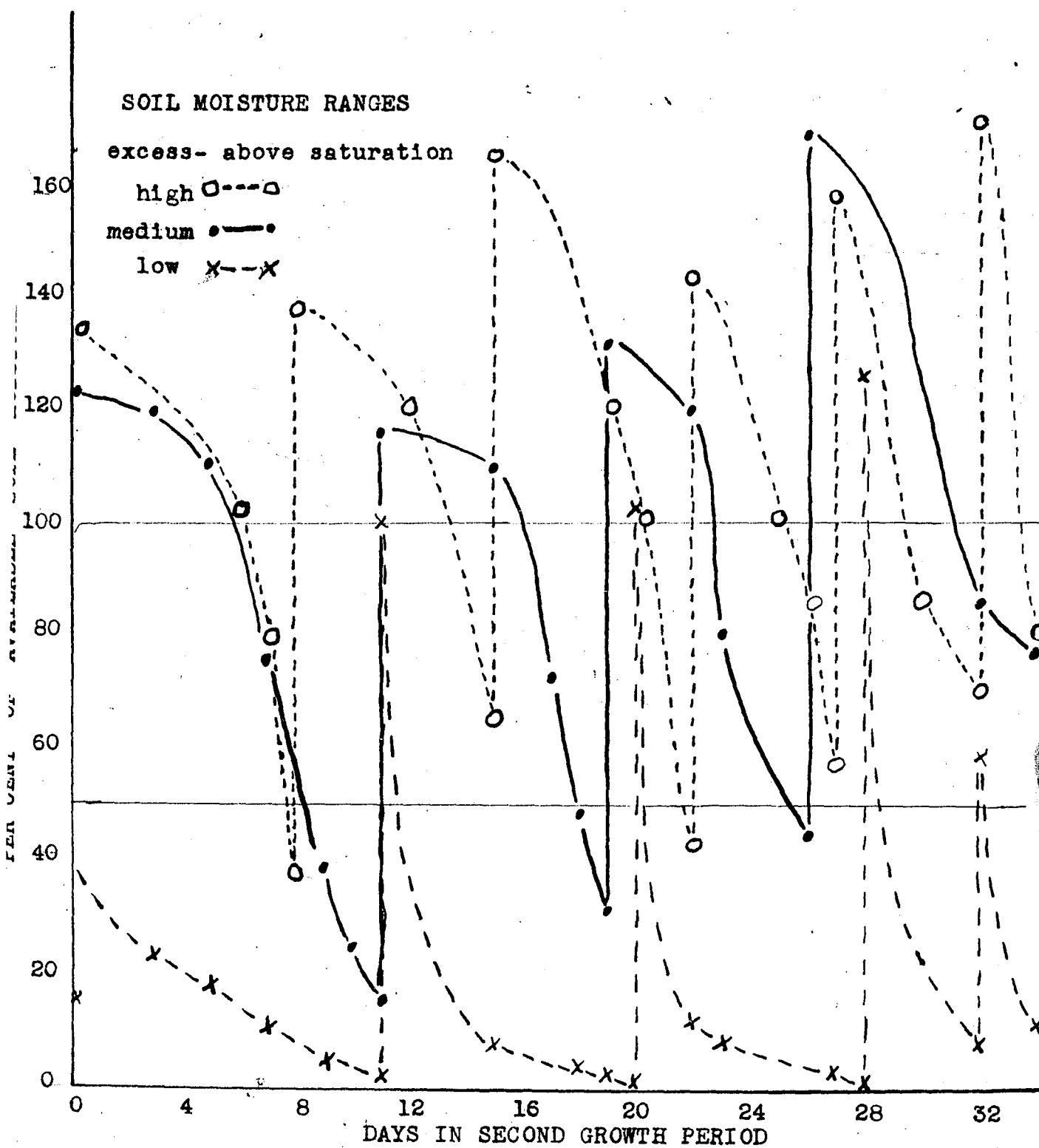
low medium high excess
Plate 9. Bluegrass on Brookston soil. Growth of bluegrass
reduced most by excess soil moisture.

probably the best indicator of the actual water relations in the three series. The excess soil moisture range cultures, with surface evaporation, used the same amount of water as the medium soil moisture range cultures where there was little surface evaporation and almost complete water utilization between each water addition. Meanwhile, low soil moisture range affected little economy in the amount of water used beyond that of the medium soil moisture range. The low range cultures rapidly used water after each addition and a low level of water availability was again quickly reached. Figure 4 follows the available moisture during this period for representative cultures of bentgrass. Cultures under the high range required six applications of water while those in the medium range required only four as shown in Figure 4.

The ability of the nylon soil moisture blocks to follow the available soil moisture at the lower ranges of availability is indicated in the low soil moisture range trends. This is shown in the "dashed" lower line of Figure 4. As the grass increased in size, increased frequency of water additions were necessary to maintain a given soil moisture level. For the bentgrass cultures maintained in the low soil moisture range there were 12, 9, and 8 days between water applications; for the medium soil moisture range cultures there were 11, 8, and 7 days and for the high soil moisture range cultures there were 8, 7, 7, and 5 days, respectively.

During this period the deepest roots in the excess soil moisture range cultures were reduced to a depth of less

FIGURE 4. PER CENT OF AVAILABLE SOIL MOISTURE DURING
SECOND GROWTH PERIOD OF BENTGRASS ON
HILLSDALE SANDY LOAM SOIL. GREENHOUSE '49



than two inches. The root system was largely a surface mat of roots with the greatest density at the edges of the cultures and some roots actually extended up the side of the containers as much as a half-inch. With no soil compaction and a constant high level of water, always near complete saturation, these surface roots enabled the grass to exist.

Third Growth Period-- During the third growth period in the greenhouse, May 3 to June 16, a period of 44 days, temperature and relative humidity conditions were less favorable. On bright sunny days the temperature sometimes reached 100°F. and the relative humidity went as low as 15 per cent; however, such days were relatively few. Midway through this growth period tissue tests, following the Spurway system (8), indicated that nitrogen from the original application of 10-6-4 at the rate of 1,500 pounds per acre was exhausted. An application of soluble fertilizer of one gram of actual nitrogen per culture was made. Ammonium nitrate was dissolved in water and a dilute solution applied to prevent salt injury to the grass. This small water application interrupted the moisture ranges as indicated in Figure 5 by the irregular moisture availability lines on the twenty-second day.

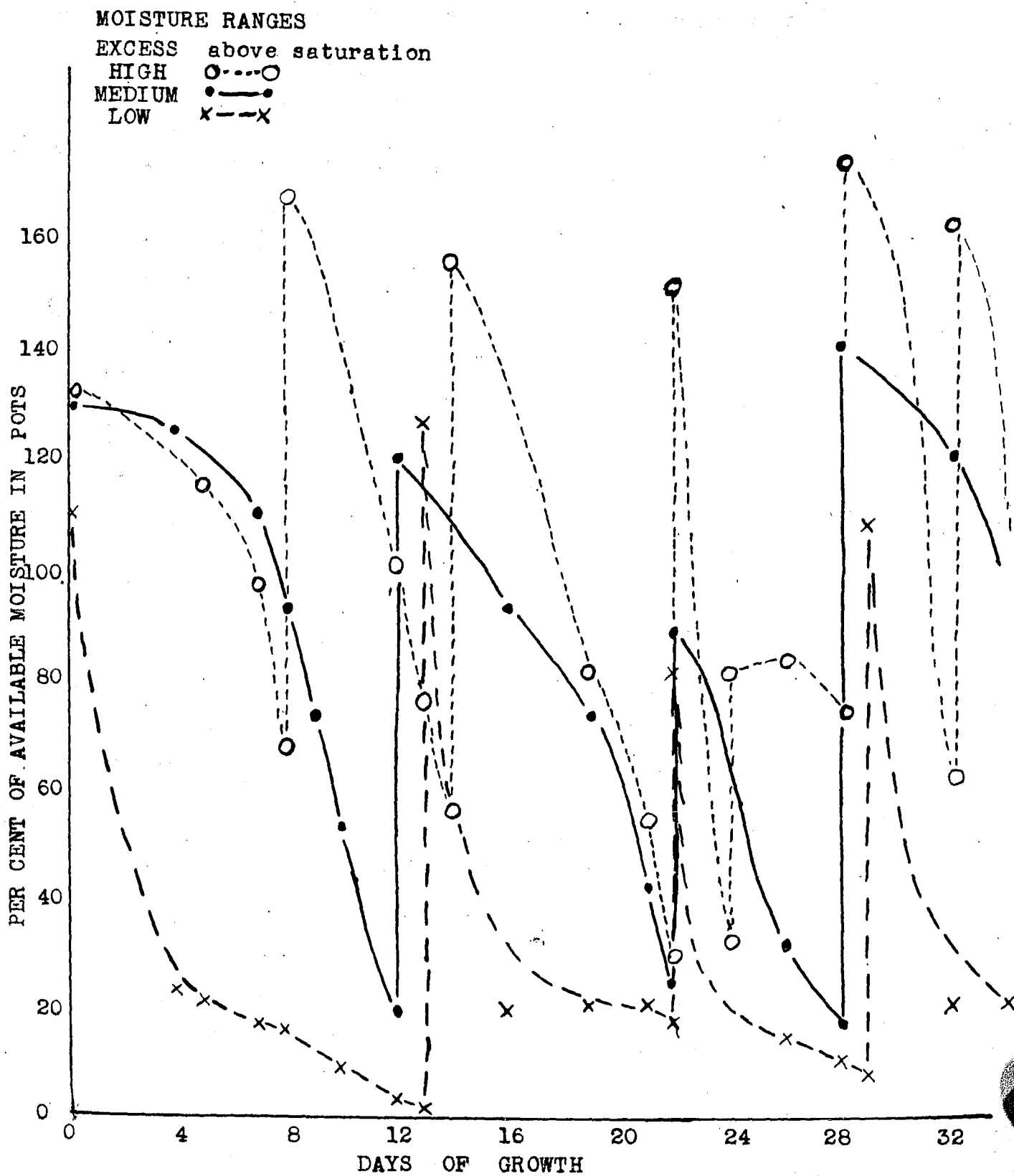
The height of the grass growth in the low soil moisture range cultures reported in Table 5, was about the same as that for the first growth period shown in Plate 3. Bent was lowest, 11cm., fescue was medium, 14 cm., and bluegrass was tallest, 16 cm. However, the dry weight of the average of three replications of each of these grasses is nearly

Table 5. Effect of four soil moisture ranges on the height and yield of grasses during third growth period. Each figure is an average of three replications.

Grass	Soil series	Soil Moisture Ranges			
		Excess	High	Medium	Low
<u>Height of Growth, cm.*</u>					
bentgrass	Hillsdale	13	18	13	11
fescue	Hillsdale	10	17	16	14
bluegrass	Hillsdale	20	25	20	16
bluegrass	Brookston	12	21	17	16
<u>Dry Weight of Clippings, gms.</u>					
bentgrass	Hillsdale	6.0	14.0	7.5	6.2
fescue	Hillsdale	5.5	9.3	7.5	6.1
bluegrass	Hillsdale	6.0	11.8	7.0	5.3
bluegrass	Brookston	5.0	11.1	9.3	9.3
<u>Water Applied, liters</u>					
bentgrass	Hillsdale	7.9	10.0	5.8	6.2
fescue	Hillsdale	7.2	8.6	6.6	4.9
bluegrass	Hillsdale	9.1	9.5	6.4	5.3
bluegrass	Brookston	6.5	9.3	6.5	6.7
<u>Averages of Above Grasses & Soils</u>					
Height of growth		14	20	17	14
Dry weight of clippings		5.6	11.6	7.8	6.7
Water applied		7.7	9.4	6.4	5.8

the same. In the excess soil moisture range cultures, the addition of nitrogen midway in the growing period stimulated new growth of a deeper green color for a short period of time. As a result the yield of grasses in the excess soil moisture range for this period was much greater than in the second period. Plate 13 illustrates the heavy top growth produced during this period, particularly, in the high soil moisture range cultures. These cultures were able to use the applied nitrogen to the best advantage because they had a good root system and ample moisture. There was much less variation in dry weights of grass produced in the medium and low soil moisture ranges. Higher yields from the medium and low soil

FIGURE 5. PER CENT OF AVAILABLE SOIL MOISTURE DURING THIRD GROWTH PERIOD FOR INDIVIDUAL BENTGRASS CULTURES.



moisture range cultures on the Brookston clay loam soil indicate its greater fertility over that of the Hillsdale sandy loam.

The amount of water applied in this growth period was particularly affected by the factors of evaporation and radiation mentioned by Livingston and Koketsu (15). High temperatures and greater evaporation increased the loss of water from the cultures receiving excess soil moisture. In the high soil moisture range cultures, both the moisture applied and resulting yields show that fescue responded less to the additional nitrogen than the other grasses.

Figure 5 shows the available moisture ranges for the third growth period. As in the second period, the use of water early in this period was much less than that later in the same period. This is partly a result of time required for new top growth to be initiated after the previous cutting. During this time the decreased amount of water lost by transpiration was important. The relative variations in the three moisture ranges for this soil is well illustrated in Figure 5. The fertilizer application on the twenty-second day and the addition of irregular amounts of water caused fluctuations in the soil moisture readings that were corrected by the next regular application of water.

Summary of Growth and Moisture Range Relations-- The great reduction in the yield of each grass culture receiving excess soil moisture after the first period is shown in Table 6. The totals for each grass show that bentgrass yielded 87.9 grams, the fescue yielded 66.1 grams, and the

Table 6. Summary of the clipping yields for three growth periods for each grass-soil condition. Each number is an average of three replications.

Grasses	Soil series	Soil Moisture Ranges			
		Excess	High	Medium	Low
<u>bentgrass</u>	<u>Hillsdale</u>				
First growth period		10.7	9.4	4.4	3.1
Second growth period		3.3	8.2	7.2	6.0
Third growth period		7.9	14.0	7.5	6.2
		21.9	31.6	19.1	15.3
<u>fescue</u>	<u>Hillsdale</u>				87.9
First growth period		7.7	5.2	3.7	3.4
Second growth period		4.1	6.3	3.9	3.4
Third growth period		5.5	9.3	7.5	6.1
		17.3	20.8	15.1	12.9
<u>bluegrass</u>	<u>Hillsdale</u>				66.1
First growth period		5.7	5.2	3.7	3.3
Second growth period		2.9	8.8	5.1	4.6
Third growth period		6.0	11.8	7.0	5.3
		14.6	25.8	15.8	13.2
<u>bluegrass</u>	<u>Brookston</u>				69.4
First growth period		6.7	5.7	3.9	3.5
Second growth period		2.2	9.4	6.7	7.3
Third growth period		5.0	11.1	9.3	9.3
		13.9	26.2	19.9	20.1
					80.1
		66.7	104.4	69.9	61.5
					303.5

bluegrass, on the same soil, yielded 69.4 grams. The more vigorous growth of the bentgrass was observed in various moisture ranges for each growth period. In the second growth period the fescue receiving medium and low soil moisture was not watered after cutting and the beginning of new growth was slower than for the other grasses for this period.

Higher yields were taken from the Brookston soil in almost every instance. This was particularly true in the third growth period where the greater fertility and more storage of available soil moisture allowed greater grass growth compared to the Hillsdale soil. Root samples examined at the close of the experiment showed that some root reduction

occurred in the high soil moisture range cultures on the Brookston soil. The highest yield attained from this treatment was only 11.1 grams which was less than the 11.8 grams for the Hillsdale soil in the same period. The difference in the total yield for bluegrass on the two soils, 10.7 grams, is attributed chiefly to the longer periods of growth between wiltings in the low soil moisture ranges on the Brookston soil.

The total yield for the high soil moisture range cultures, 104.4 grams, was much greater than any of the other three soil moisture range cultures. This high series, which fluctuated between 50 and 150 per cent available soil water, as plotted in Figures 3, 4, and 5, supplied sufficient moisture at all times and with the aid of the applied fertilizer the cultures produced a luxuriant growth. From the averages in Table 7 it was found that the medium soil moisture range cultures used only 72 per cent as much water and produced only 67 per cent as much growth as the grass receiving high soil moisture. The low soil moisture range cultures used 66 per cent as much water and produced 58 per cent as much top growth as the high moisture series.

Table 7 gives an average of the three growth periods as a basis for summarizing the results of the effects of different soil moisture ranges on the growth of turf grasses in the greenhouse. The height of the grass clippings removed varied only slightly in the different periods for the low, medium, and high soil moisture range cultures. However, excess soil moisture caused abundant growth, 22 cm., until

Table 7. Summary of the effect of different soil moisture ranges for three growth periods. Each figure is an average of 12 pots.

Growth period	Soil Moisture Ranges			
	Excess	High	Medium	Low
<u>Height of Clippings, cm.</u>				
First period, March, 27 days	22	19	16	14
Second period, April, 34 days	11	20	16	14
Third period, May, 43 days	14	20	17	14
<u>Dry Weight of Clippings, gms.</u>				
First period	7.7	6.4	3.9	3.3
Second period	3.1	8.2	5.7	5.4
Third period	5.6	11.6	7.8	6.7
<u>Water Applied, liters</u>				
First period	7.5	4.2	3.1	3.1
Second period	5.0	6.8	5.1	4.7
Third period	7.7	9.4	6.4	5.8
<u>Average of three periods*</u>				
Height of Clippings	15	20	16	14
Dry Weight of clippings	5.5	8.7	5.8	5.1
Water applied	6.7	6.8	4.9	4.5
Pounds of water applied per pound of dry grass	1232	778	840	883

* Each figure average of 36 cultures.

limited by a lack of available nitrogen at the beginning of the second growth period. In the second period the average height of growth was only 11 cm. for the excess soil moisture range cultures. This was much less than the 20 cm. growth of the grasses receiving high moisture during the same period. The heights and yields during the third period growth was affected by the nitrogen addition; they increased significantly above that of the second period. On the low soil moisture range cultures the height of growth was 14 cm. in each period, yet the dry weight of clippings increased in each period over that of the preceding one. This would be expected, due to the longer period of growth, and also the

thicker development of the turf as the grasses increased in age.

One of the purposes of this study was to determine the most economical range of soil moisture required to secure good turf growth. Thus, with a continuous measurement of the soil moisture and a record of the water applied, it was possible to determine the amount of water used to produce a given yield of clipped grass. The average yields for the high, medium, and low soil moisture range cultures are good indicators of the utilization of the water applied. When these figures are converted to the commonly used terms of pounds of water required for each pound of dry matter produced, the values at the bottom of Table 7 were obtained. These values fall within the range of 750-1,000 given by Noer (21) as a result of clipping trials on a putting green. The figure of 1,232 for the excess soil moisture range included that lost by evaporation from the moist surface, and some two liters of excess water left in the soil at the close of the experiment, as well as that used by the grass. The saving in water by allowing the plants to wilt, as in the low soil moisture range cultures, was not as large as expected. The water applied with this method was not the most efficient in producing growth in this moisture range. This might be explained by the rapid uptake of water after it was applied to the wilted cultures. There was a definite reduction in the daily use of water as the plants were allowed to approach wilting. The moisture curves in Figures 3, 4, and 5 show a

definite break at about 20 per cent available moisture.

Theoretically, the soil moisture should be allowed to approach this percentage before applying supplemental irrigation water in order to obtain the greatest efficiency of the water, to have the least amount of mowing, and yet, to maintain a satisfactory turf. Such a soil moisture range would allow root extension into all the soil area possible and would encourage the necessary aeration mentioned by Mott (19) and others.

Moisture and Nitrogen Relations

The marked influence of moisture on nutrient availability has been shown by several investigators. Lawton (14), for example, working on compacted soils in the greenhouse, showed that the availability of nitrogen and potash, particularly, may be limited by a reduction in aeration or excess moisture in the soil.

The greenhouse experiment made it possible to study the effect of a limited nitrogen supply in two different ways. First, twelve check cultures were not fertilized and were compared with those receiving fertilizer under similar moisture conditions. Second, some cultures that received fertilizer were completely saturated and the effect of this excess water on nitrogen availability noted. Nitrogen was applied in a soluble form and the grass response observed.

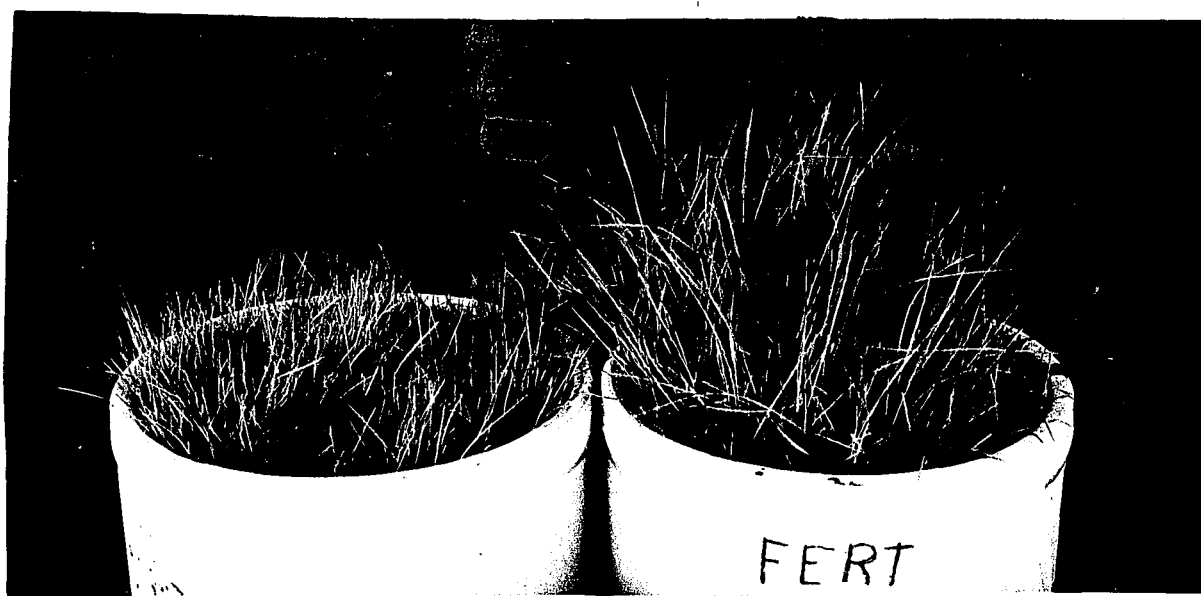
Yield of fertilized and unfertilized grasses-- The comparison of yields of the fertilized and unfertilized grass is given in Table 8. During the first growth period

Table 8. The yields of three grasses on fertilized and unfertilized soils when maintained within the high soil moisture range. Average of three replications in the greenhouse, 1949.

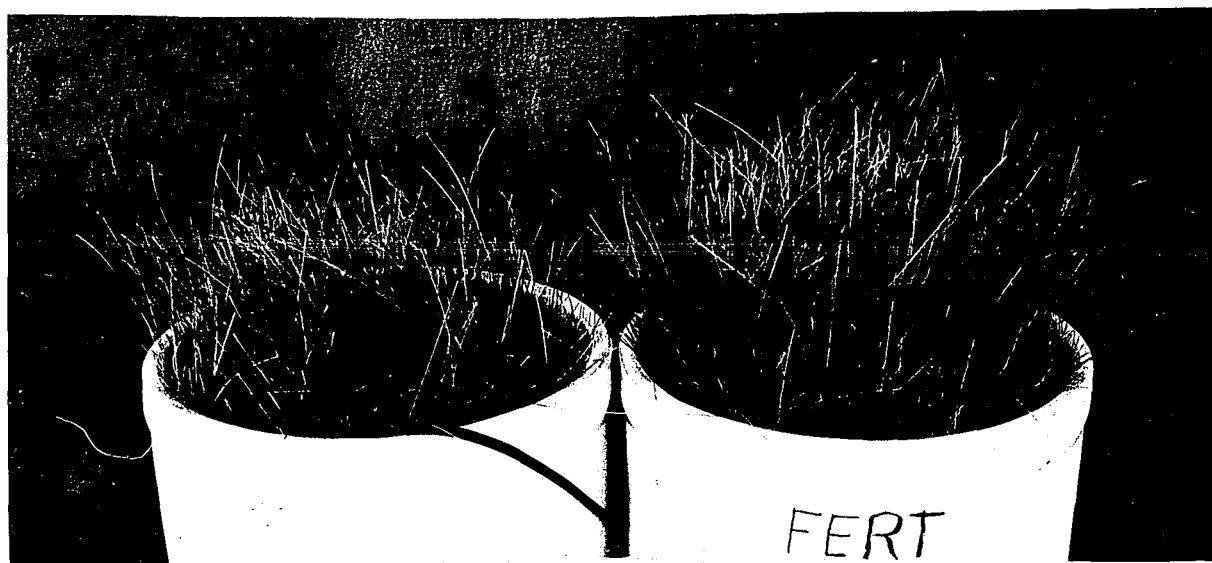
Grass	Soil series	Dry weight in grams	
		fertilized	unfertilized
<u>First Growth Period</u>			
bentgrass	Hillsdale	9.4	4.4
fescue	Hillsdale	5.2	4.2
bluegrass	Hillsdale	5.2	4.3
bluegrass	Brookston	5.7	4.4
		<u>25.5</u>	<u>17.3</u>
<u>Second Growth Period</u>			
bentgrass	Hillsdale	8.2	3.8
fescue	Hillsdale	6.3	3.8
bluegrass	Hillsdale	8.8	4.9
bluegrass	Brookston	9.4	6.7
		<u>32.7</u>	<u>19.2</u>
<u>Third Growth Period</u>			
bentgrass	Hillsdale	14.0	4.8
fescue	Hillsdale	9.3	2.6
bluegrass	Hillsdale	11.7	2.9
bluegrass	Brookston	11.1	4.0
		<u>46.1</u>	<u>14.3</u>
<u>Total of All Growth Periods</u>			
bentgrass	Hillsdale	31.6	13.0
fescue	Hillsdale	20.8	10.6
bluegrass	Hillsdale	25.7	12.1
bluegrass	Brookston	26.2	15.1
		<u>104.3</u>	<u>50.8</u>
Pounds of water applied per pound of clipped grass*		778	1348
Liters of water required for each culture*		20.3	17.2

* Average of 12 cultures.

the recently potted soils were able to supply some nitrogen to the grasses and the differences in yields of 17.3 grams for unfertilized and the 25.5 grams for the fertilized is not as great as that in the later periods. Tissue tests on the leaf blades of the unfertilized grasses gave a low nitrogen test during the first growth period. At the



no fertilizer 1500 lbs./acre of 10-6-4
 Plate 10. Growth of bentgrass at high soil moisture range
 for both cultures during second growth period.



no fertilizer 1500 lbs./acre of 10-6-4
 Plate 11. Growth of fescue at high moisture range for
 second period.

beginning of the second growth period these plants tested blank in nitrate nitrogen. The greatest deficiency of nitrogen and the least growth occurred during the third growth period. The total yield of the unfertilized cultures was less than one-third of that for the fertilized. The relative size of the grasses in Plates 10, 11, and 12 shows a continuing reduction in the original soil fertility from that indicated during the first growth period.

The unfertilized bent grass, which was the most dense of the grasses, yielded the same as other unfertilized grasses. However, when bentgrass was fertilized it yielded more than either of the other fertilized grasses. A comparison of the relative amounts of growth of the fertilized and unfertilized bentgrass is shown in Plate 10. The Kentucky bluegrass yielded more in the second period than any other grasses in both the fertilized and unfertilized groups. The greater fertility of the Brookston in comparison to the



fertilized unfertilized
Plate 12. Response of bentgrass to added nitrogen during
the third growth period.

Hillsdale soil is indicated by the data in Table 8 for bluegrass for the second growth period. Fescue, in both the fertilized and the unfertilized soil had the lowest yield of clippings of the three grasses under greenhouse conditions.

The comparison of unfertilized and fertilized cultures in the high soil moisture range shows that it required 173 per cent more water to produce a pound of grass without than with fertilizer. However, only 85 per cent as much water was required to maintain the high soil moisture range where no added fertilizer was used.

Nitrogen availability in the excess soil moisture range-- Nitrogen deficiency also occurred in the cultures receiving excess soil moisture. This lack of available nitrogen began to occur early in the second growth period and quickly became severe. One culture in each of the three excess moisture range replications was treated with a dilute solution of one gram of sodium nitrate to test the response of the grasses to available nitrogen under these conditions.

Tissue tests on the grass blades two days later indicated that nitrogen was being taken in by the plants, as shown by a high test for nitrates. A greener color was apparent in the grass four days after the application of nitrogen and an increased rate of growth occurred. Table 9 shows that the nitrogen added midway in the second period increased the yield from 12.5 to 21.6 grams for the four grasses in a period of 15 days. Midway in the third growth period nitrogen was applied to all cultures. This gave a yield of 22.1 grams for those cultures fertilized during the third period

only and 28.4 grams for those fertilized in both the second and third periods.

Table 9. Effect of an addition of soluble nitrogen on the yield of grasses under excess soil moisture range conditions.

Grasses	Soil series	Dry Weight in Grams	
		Nitrogen added	No supplemental nitrogen added
<u>Second Growth Period*</u>			
bentgrass	Hillsdale	5.7	3.3
fescue	Hillsdale	5.6	4.1
bluegrass	Hillsdale	5.7	2.9
bluegrass	Brookston	4.6	2.2
		<u>21.6</u>	<u>12.5</u>
<u>Third Growth Period**</u>			
bentgrass	Hillsdale	6.9	6.0
fescue	Hillsdale	7.0	5.1
bluegrass	Hillsdale	9.5	6.0
bluegrass	Brookston	5.0	5.0
		<u>28.4</u>	<u>22.1</u>

* 1 gm. NaNO_3 applied April 16, 17 days before second harvest

** 1 gm. Nitrogen, as NH_4NO_3 , applied to all cultures 22 days before harvest.

Root growth in relation to moisture supply

The roots of the grasses receiving excess soil moisture were very matted at the surface and extended only about one inch into the soil (Plate 13). However, the constant high water level and the lack of compaction with rather frequent water additions allowed the root system to take up the added soluble nitrogen. Tissue test showed a high content of soluble phosphorus and potassium but gave a blank in nitrate nitrogen prior to addition of the nitrogen fertilizer. Two weeks after the nitrogen application, tissue tests showed a high nitrate, a low phosphorus, and a medium potassium content.

The relative extent of root growth is shown in Plate 13.



excess high medium low
 Plate 13. Roots from bluegrass on Hillsdale sandy loam soil, showing root location and block position. More rhizomes were produced in high and medium moisture range cultures.

In contrast to the shallow roots produced under excess moisture conditions, the high range cultures had roots distributed throughout the soil. However, they did not have as many roots in the bottom two inches of the jars as the medium and low moisture range cultures. The medium moisture range had an excellent root distribution with a large concentration at the bottom of the culture.

Large white rhizomes developed in the cultures maintained at high and medium moisture ranges as illustrated in Plate 13. The low moisture range soil contained some rhizomes but they were small and brownish in color.

The roots of representative cultures from each replication were partially washed from the soil at the close of the experiment. Complete separation of the roots from the soil was not possible, so the roots, crowns, and attached

Table 10. Effect of soil moisture ranges on the weight of roots from representative cultures at the end of the greenhouse experiment.*

Grass	Soil series Moisture Ranges	Total Weight in Grams	
		Roots	Clippings
<u>bentgrass</u>	<u>Hillsdale</u>		
	excess	18.5	21.9
	high	30.5	31.6
	medium	19.2	19.1
	low	<u>14.8</u>	<u>15.3</u>
		83.0	87.9
<u>fescue</u>	<u>Hillsdale</u>		
	excess	12.6	17.3
	high	27.6	20.8
	medium	19.1	15.1
	low	<u>16.2</u>	<u>12.9</u>
		75.5	66.1
<u>bluegrass</u>	<u>Hillsdale</u>		
	excess	14.4	14.6
	high	24.8	25.8
	medium	20.3	15.8
	low	<u>19.1</u>	<u>13.2</u>
		78.6	69.4
<u>bluegrass</u>	<u>Brookston</u>		
	excess	11.6	13.9
	high	22.2	26.2
	medium	22.8	19.9
	low	<u>20.6</u>	<u>20.1</u>
		77.2	80.1
		<u>304.3</u>	<u>303.5</u>

* Root weight includes crowns

soil were oven dried, weighed, and placed in a muffle furnace at a temperature of 450°C. to determine the loss of organic matter by ashing. Because the ash from the roots remained in the soil, six per cent more than that weight lost by ashing was considered as the weight of the roots.

Pinck and Allison (22) found that roots of unclipped sudan grass averaged one-third of the total plant weight at three different stages of harvest. In the present experiment, with three monthly clippings, the weight of roots was about the same as the weight of tops. Bentgrass produced

greatest weight of roots and also of clippings. The high soil moisture range cultures yielded the highest weight of roots, 30.5 grams, of any cultures. Although the low soil moisture range cultures had a good distribution of roots, their weight was only 14.8 grams, about half that of the high soil moisture range.

In earlier sections, it was shown that the limited available nutrients in the soil that was unfertilized greatly reduced yields of clippings and, to a lesser extent, the water required for growth. The weights of roots of cultures from fertilized and unfertilized soil are listed in Table 11.

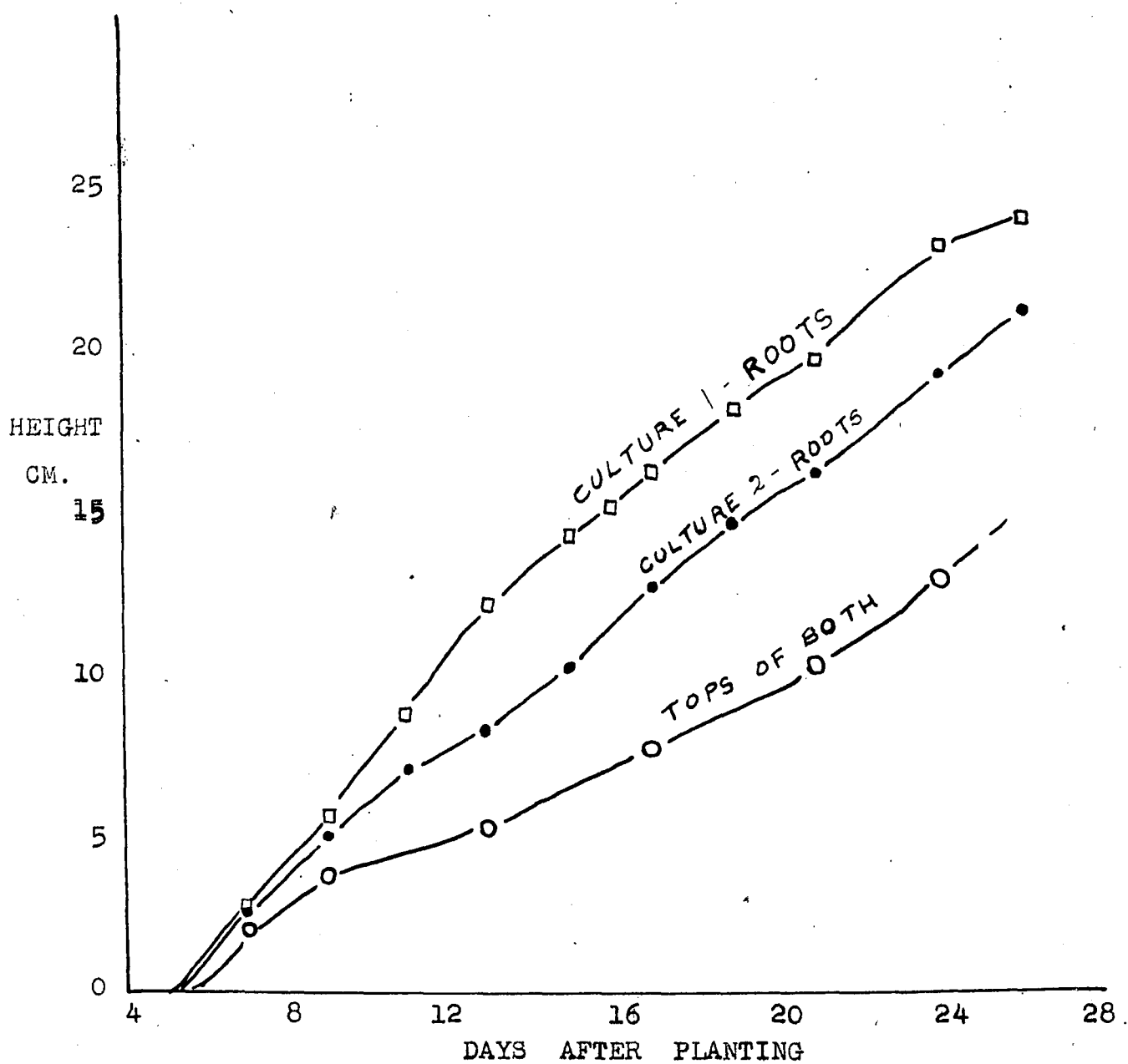
Table 11. Effect of fertilizer on weight of roots in the high moisture range. Each number represents one culture.

Grass	Soil series	Total dry weight in grams	
		fertilized	unfertilized
bentgrass	Hillsdale	30.5	19.6
fescue	Hillsdale	27.6	22.1
bluegrass	Hillsdale	24.8	19.7
bluegrass	Brookston	22.2*	11.1*
		<u>105.1</u>	<u>72.5</u>

* Roots were pruned due to lack of aeration.

In every case the cultures grown in unfertilized soil had a smaller root system. The high soil moisture caused a reduction in the roots in the cultures growing in Brookston soil and the lower portion of the soil was essentially free of roots. The weight of the roots, 72.5 grams, from the cultures receiving no fertilizer was considerably greater than that of the tops, 50.8 grams. In the fertilized cultures the weight of the tops for three cuttings, 104.3 grams, was almost equal to that of the root weight, 105.1 grams.

FIGURE 6. RELATION OF ROOT PENETRATION TO TOP GROWTH
FOR CREEPING RED FESCUE ON HILLSDALE SANDY
LOAM SOIL



Root-top ratios of seedlings

An experiment was set up in the greenhouse to determine the relative root-top growth of seedlings of Creeping Red fescue when grown in thirteen inch glass pots on fertilized Hillsdale sandy loam soil. Nylon and plaster of paris blocks were placed on edge, two inches from the top and two inches from the bottom of the soil. Masking tape held heavy brown paper around the jars except during the time of the daily root growth observations. Root penetration was uniform throughout the soil since the soil was loose and sandy. A wax pencil was used to mark the daily advance of the roots. These data are plotted in Figure 6. The growth in root length exceeded that of the tops at all times. Twenty days after germination, the roots had extended to the bottom of the pot, 24 cm., for an average growth rate of 1.2 cm. per day. In the same time the tops had grown only 13 cm. for an average of .65 cm. per day. However, the dry weight of the tops above soil level averaged 4.7 grams while the roots averaged 4.1 grams two months after germination.

The expansion of the root system was also followed by changes in the moisture block readings. Bouyoucos (4) had shown that there is little moisture movement in the lower ranges of available soil moisture. Moisture absorption by the roots was indicated by changes in the block readings only when the roots were within an inch of the soil moisture blocks. At that time the soil was at field capacity and some moisture movement toward the roots could take place.

The upper soil moisture block indicated a geater removal of moisture in all five periods. This was particularly true during the earlier growth when the roots had not reached the lower block area. As the root system expanded, less variation was noted between the reading of the lower and upper blocks. At the end of two months growth, the lower soil moisture blocks indicated less than 10 per cent more in the lower part of the soil column than in the upper. From this experiment it was concluded that one block placed midway in the soil column was an adequate measure of soil moisture conditions.

FIELD EXPERIMENTS

Methods

The turf plots were located on Hillsdale sandy loam soil at the College River Farm, two miles southeast of Okemos, Michigan. Below the twelve inch surface layer of this brownish sandy loam was a fourteen inch layer of yellowish sandy loam which was an open leached layer. For several years the area had been in grass. It was fall plowed in 1947 and cultivated twice in 1948 prior to the preparation of the experimental plots. In September 1948 an area 36 by 180 feet was plowed, harrowed, and hand raked several times to remove the gravel and stones and to level the area.

Fifteen pounds of 10-6-4 fertilizer and five pounds of lead arsenate were applied broadcast to each 1,000 square feet and raked prior to seeding. On September 13, 1948 Creeping Red fescue (*Festuca rubra*) and Kentucky bluegrass (*Poa pratensis*) were seeded on parallel strips, 18 by 180 feet, at the rate of one and one-half pounds seed per 1,000 square feet. Germination was rapid and growth reached approximately two inches during the mild and late fall.

Fifteen pounds of 10-6-4 and one additional pound of seed were applied per 1,000 square feet on April 10, 1949. On May 24, 2,4-D, as an ester in oil, was applied at the rate of one and one-half pounds per acre. Until July 1 both grasses were mowed only eight times, so that a good root system and top growth was secured before the differential moisture and cutting treatments were begun July 1.



Plate 14. Illustration of block locations and the instrument used for reading block resistances. Paper arrows show block locations at four inch depth for three cutting heights and string indicate wire leads going to central post where clamps connect the meter for readings. Strings in background delineate different moisture range plots.

Bouyoucos nylon soil moisture blocks were placed in sixty, 6 by 18 feet plots at a four inch depth. These were installed by using a cup cutter to remove soil to a depth of about five inches. The soil surrounding the block was cleared of stones and large gravel and the block packed into position, then the cup of grass was replaced and pressed into position. In ten plots, additional soil moisture blocks were placed at a ten-inch depth immediately below the four inch block for comparison with the upper portion of the same soil layer. Plate 14 illustrates how the six foot wire leads radiated from a central post to the three blocks located under the grass plots cut at different heights;



Plate 15. Turf plots showing fescue on right and bluegrass on the left half. The nonirrigated plot is delineated in foreground by string while sprinklers are in operation on the excess watered plots.

thus several blocks were read at one position and the blocks and posts did not interfere with mowing.

Each plot was 18 feet long, east and west, and the three heights of cut, one-half, one, and one and one-half inches, were varied in this direction. The irrigations were applied north and south, thus six plots were watered by one sprinkler unit. Five Nelson square sprinklers, each of which gave an 18 by 18 foot coverage at twenty pounds pressure, were mounted nine feet apart on a one-half inch galvanized pipe so that a complete overlap of spray was secured. Plate 15 gives a west to east view of the plots with the fescue on the right.

Two replications of five soil moisture ranges were

maintained. The plots which were maintained at a "very high" soil moisture level, plots 3 and 8, received twenty, three-fourths inch irrigations plus twenty rains, each of which was more than one-third inch, during the three months period from July 1 to October 1, 1949. These frequent moisture additions maintained the soil at near field capacity. From July 26 to August 25, the soil averaged 106 per cent available moisture. It was not possible in this sandy loam soil to produce poor aeration by excess irrigation due to fast infiltration. In order to avoid leaching light irrigations were made.

The plots in which a "high" soil moisture range was maintained received four one-inch irrigations each of which was applied when the blocks indicated a reduction in the available soil moisture to near 50 per cent. Such a procedure is recommended by Bouyoucos (3, 7) for shallow rooted field crops on sandy loam soils. The average available soil moisture for this range during a measured period was 78 per cent.

The plots maintained in the "medium" soil moisture range received two, 2-inch irrigations which were applied when the soil moisture blocks indicated a depletion, to about 20 per cent, of the available soil moisture in the surface layer. These applications kept the grass growing and the dryness of the soil permitted a large application of water to be retained in the soil. The average available soil moisture for this period was 59 per cent.

Two 0.75-inch irrigations were sufficient to keep the plots within the "low" soil moisture range. These additions were made when the soil moisture at the four-inch depth indicated that the available soil moisture approached zero, and when the grass was just beginning to wilt. This timing of applications kept the grass growing, yet slowed it down so that it was not vigorous. The small water application to a dry soil, moistened only the upper part of the profile as indicated by the ten-inch moisture block.

The plots, which were maintained in the "very low" soil moisture range, received no supplemental irrigation. The relation of the soil moisture ranges to the number, frequency and rate of irrigations, and the amount of water applied is given in Table 12.

Table 12. Relative soil moisture ranges on the turf plots for the 1949 growth period.

Soil moisture ranges	% available moist. for Jul.26-Aug.25*	Irrigation applied			Inches of water app. in 3 mo.
		Number	Inches	Total	
very high	106	20	.75	15	23.6
high	78	4	1.0	4	12.6
medium	59	2	2.0	4	12.6
low	39	2	.75	1.5	10.1
very low	11	0	.0	0	8.6**

* Period during the season when moisture was controlled by irrigation

** Total rainfall in six months, 18.86 inches, was more than normal and well distributed.

Results and Discussion

Soil moisture conditions

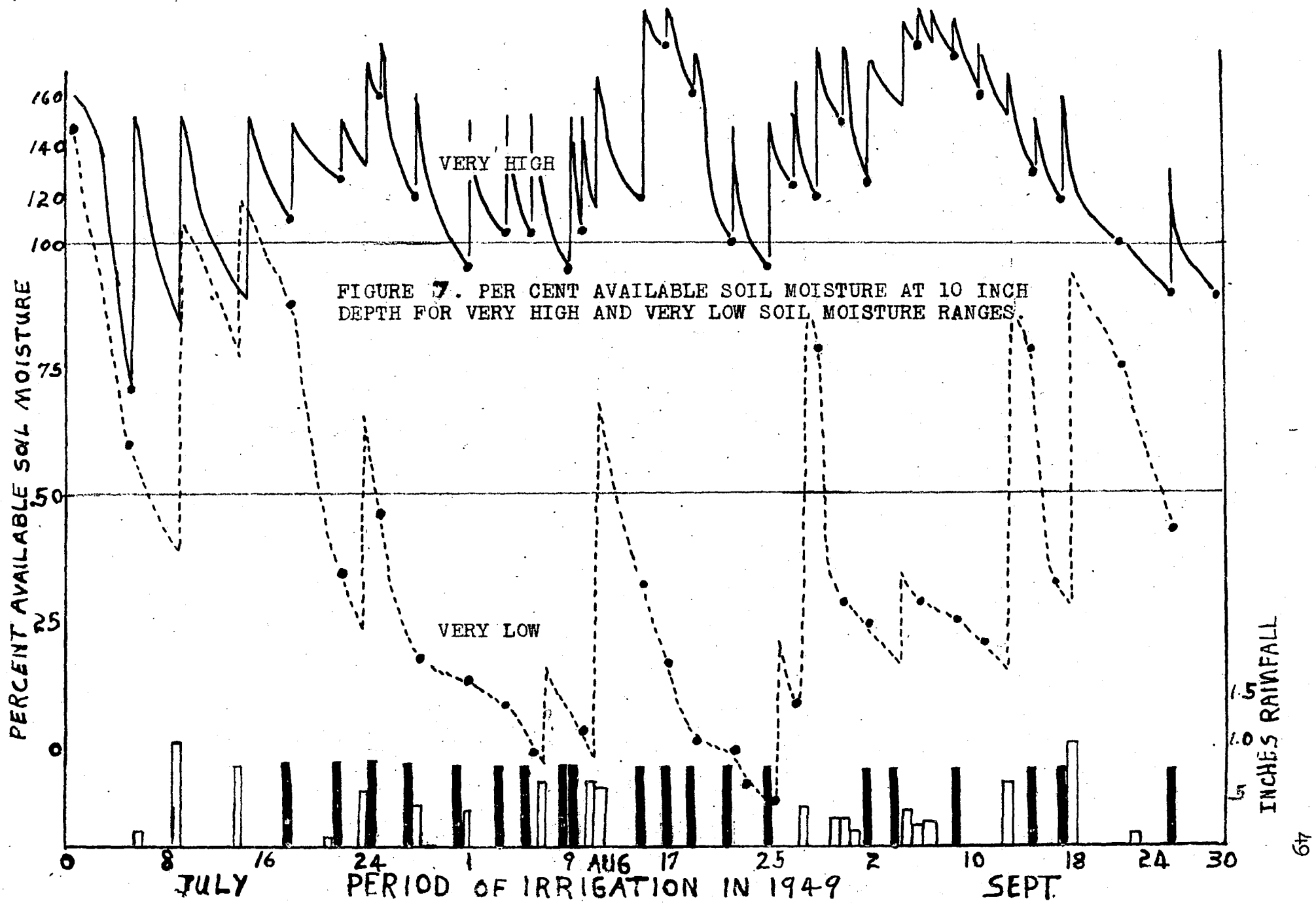
Seasonal conditions during irrigation period-- In a one season irrigation experiment the influence of weather assumes great proportions. However, the comparison of this season with that normally expected permits an interpretation of the data secured for other seasons. The total rainfall for the year was 34.3 inches, 110 per cent of normal. July, August and September had slightly more than normal rainfall with very good distribution. The rainfall scale on the base of the soil moisture charts, Figures 7 to 11 give the actual time and amount of rainfall represented by open bar lines. In April, temperatures were above normal and the low rainfall favored early season growth. Then a heavy June rainfall delayed the beginning of irrigation on the plots and made ample moisture available until mid-July. During August, ending about August 5 and 25, there were two dry spells that depleted the soil moisture in unirrigated plots and allowed controlled moisture ranges. In early September several series of cool cloudy days and light precipitations cut the irrigation season short. The charts for the high, medium, and low soil moisture present at the beginning of September in those plots was sufficient, when aided by the cool weather and light rains, to maintain the desired soil moisture ranges to the end of the growing season without further irrigation.

Soil moisture ranges-- Figures 7 to 11 are records of the available soil moisture data for five individual plots which represent the conditions in all plots receiving similar irrigation treatment.

Figure 7 gives the range of available soil moisture at the ten-inch depth for plots maintained in both the very low and very high soil moisture ranges. The dotted line representing the very low soil moisture range goes below zero per cent available soil moisture at two periods. After each of these periods, the first rainfall was insufficient to move moisture in large amounts through the dry upper layers and into the ten-inch soil layer. Then the second addition of rain increased the soil moisture content sufficiently for movement to occur into the ten-inch soil zone.

Under the very high soil moisture range conditions the soil at the ten-inch depth was slower returning to field capacity than that at the four-inch depth. This is indicated by a higher per cent available soil moisture shown as the base of the very high soil moisture line for the ten-inch layer.

The excess water during and at the close of irrigation was well above 100 per cent. However, readings from the blocks at hourly intervals following irrigation showed that the soil permitted the excess water to pass downward readily and the sandy soil was again near field capacity after three hours. The field capacity was not completely reached until approximately one day after irrigation at the four-inch

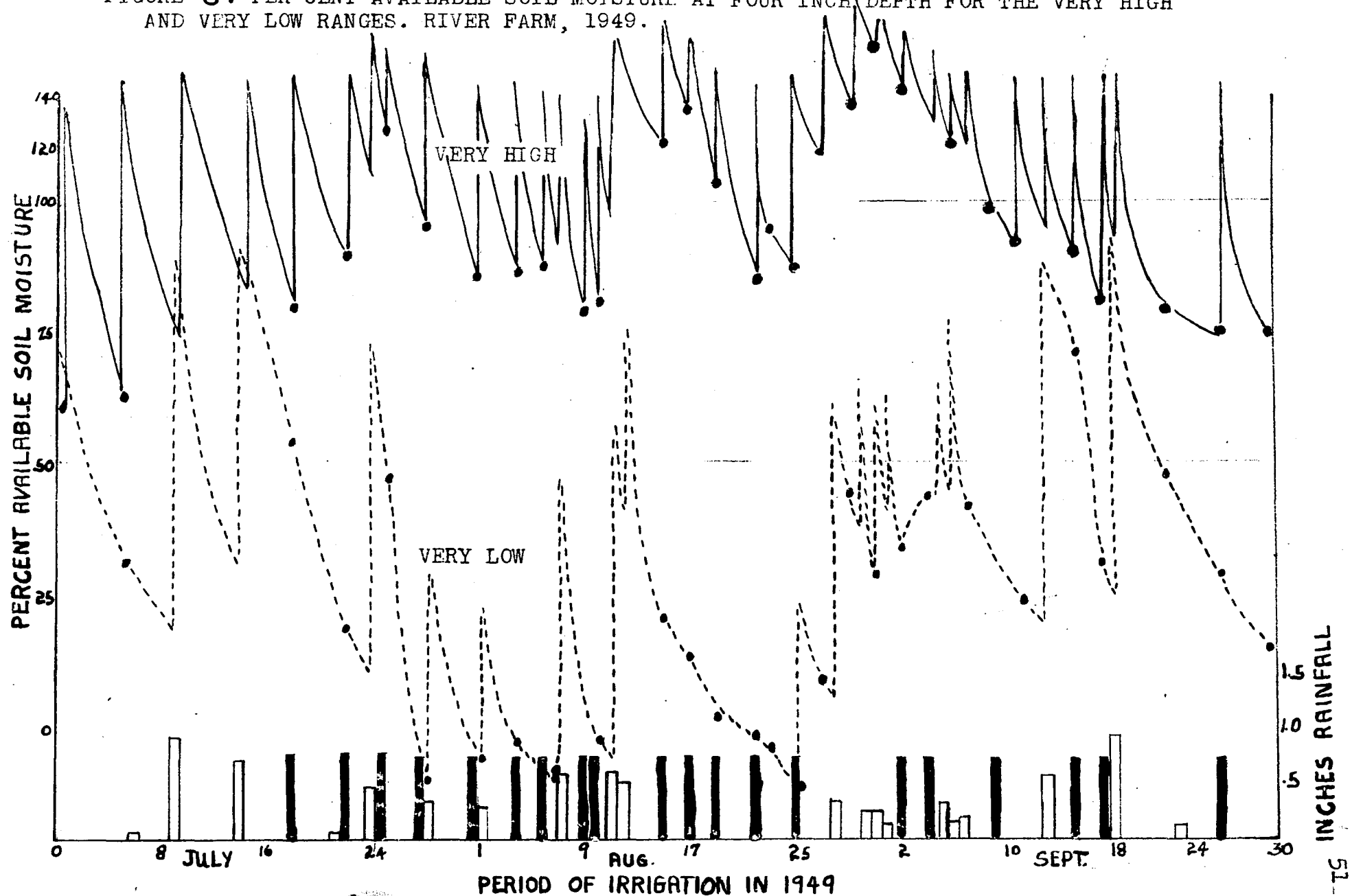


zone while in the ten-inch zone more time was required. Thus, the slope of the per cent available soil moisture curve is very steep on the drying cycle from the time of irrigation until the field capacity was approached, then the curve levels off as the excess moisture is removed. After this short leveling period, a rather uniform downward gradient was found as the per cent available soil moisture decreases from 100 toward 20 per cent. At slightly below 20 per cent, the plant was less able to withdraw moisture from the soil and the slope again levels off as zero is approached as was shown in the moisture curves of the greenhouse experiments and was indicated also in the unirrigated plots in the field.

The increased conductivity as determined by the nylon blocks, due to the addition of chemical fertilizers on August 11 and 23, reached a peak on August 17 and again on September 6. Removal of the fertilizer salts by leaching, under excess irrigation, was relatively rapid. In other plots, not excessively irrigated, the removal of the salts was much slower.

In Figure 8 the available moisture at the four-inch depth for the very high and very low soil moisture ranges is shown. Here the nearness to the surface is indicated by the greater variation of the high and low points on the available soil moisture lines. The light rains on the unirrigated soil were sufficient to cause an increase in the soil moisture content at the four-inch depth although a

FIGURE 8. PER CENT AVAILABLE SOIL MOISTURE AT FOUR INCH DEPTH FOR THE VERY HIGH AND VERY LOW RANGES. RIVER FARM, 1949.

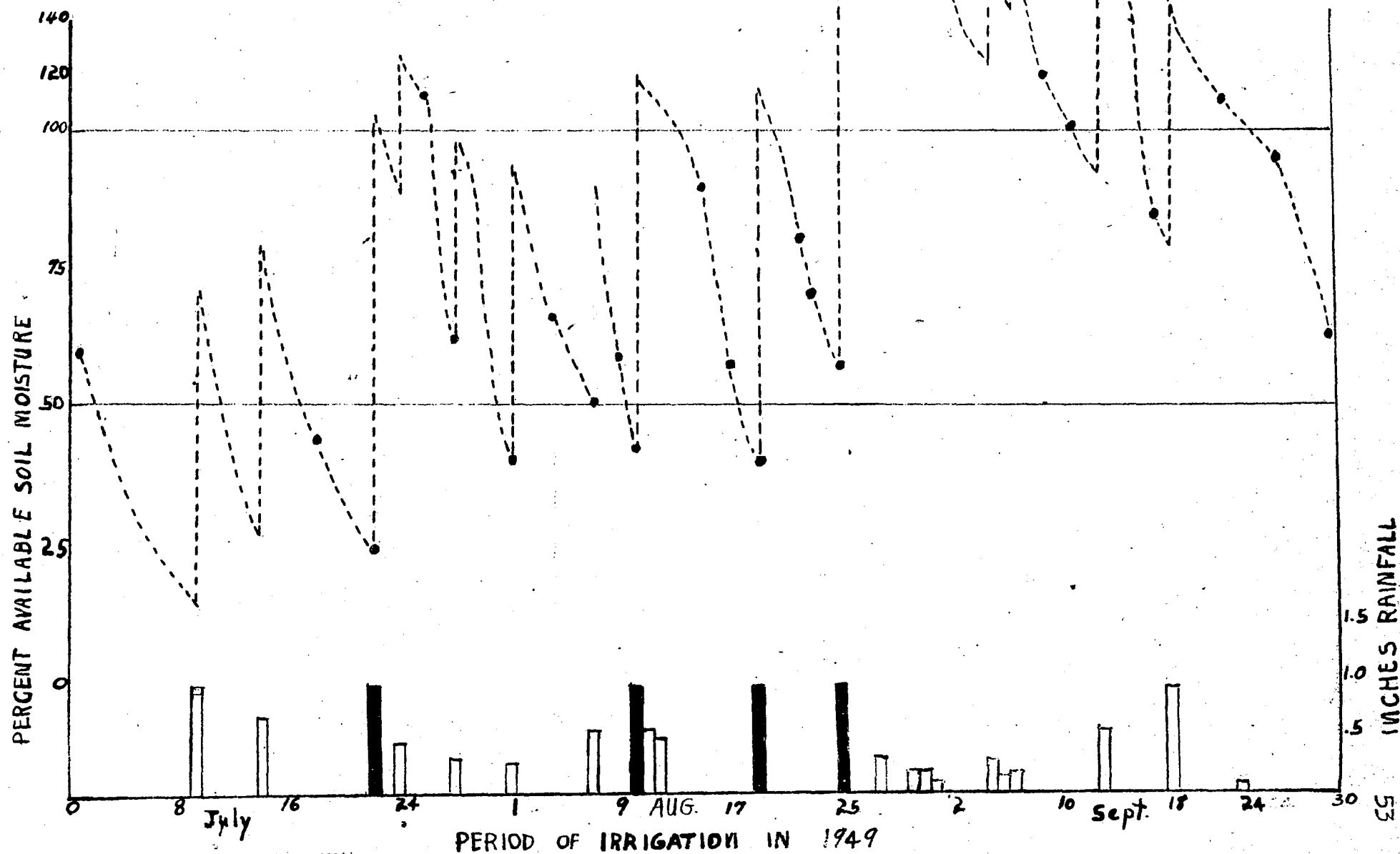


dry condition was soon re-established.

Figure 9 shows that four irrigations were sufficient to maintain the soil above a minimum, approximately 50 per cent, available soil moisture during July and August, with an average of 78 per cent available during that period. In September, cooler weather and eight rains kept the soil at a relatively high soil moisture content and no irrigations were required. Here the fertilizer salts were gradually moved downward, slower than in the plots, which were maintained in the very high soil moisture range, and the ten-inch block in this plot indicated that the salts were not leached below that zone.

The soil moisture blocks were read during the summer only as a means of determining when to irrigate the plots to keep them within the desired soil moisture range and determine how deep the water penetrated into the soil. However, in Figure 10, which is an example of the plots which were maintained in the medium soil moisture range, the height of the upper points of the lines illustrates the wide variation occurring in the soil moisture. A minimum of about 20 per cent available soil moisture was reached on two occasions. Two heavy irrigations of two inches each on the dry soil were able to supply water throughout the soil column to a depth of at least 10 inches, and with following rains, to give a more lasting moisture increase where only small additions were made. In the plots of medium soil moisture, the fertilizer salts from both the August 13 and 23 applications were concentrated in the

FIGURE 9. PER CENT AVAILABLE SOIL MOISTURE,
RAINFALL, TIME AND AMOUNT OF IRRIGATIONS
AS AN EXAMPLE OF HIGH SOIL MOISTURE RANGE.

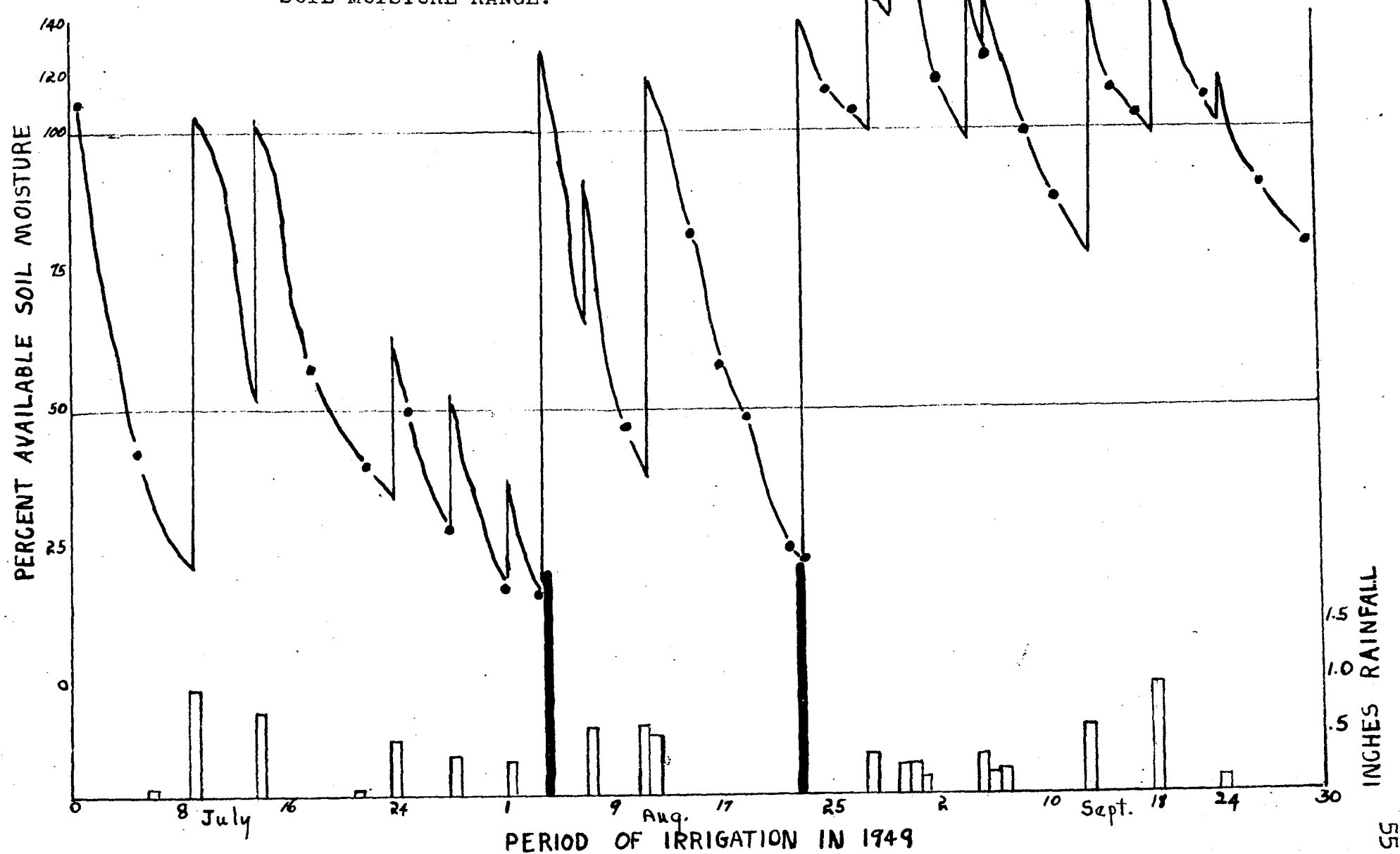


4-inch block area. Here the salt effect was noted until the last of September.

The value of small amounts of irrigation water applied at critical times is well illustrated in Figure 11. Here, two small, three-fourths inch, irrigations applied when the grass had just begun to wilt, prevented the grass from becoming dormant and carried it through until light fall rains could maintain the turf. Although these irrigations preceded rains by only a few days, the protection of the grass from drought damage preceding the rains produced a much better turf during the season. When the light fall rains began, the grass in the plots with very low soil moisture recovered very slowly because a drought condition had been established. Thus correct timing of the irrigation becomes very important if a minimum amount of water is to be applied during a season. In the plots with the low soil moisture, the light irrigations did not leach out the salts.

Generally, the soil in the low moisture range plots was drier at the ten-inch depth than at the four-inch depth since the small irrigations and rains would wet only the upper area. Such a soil moisture condition is often critical. If moisture is not applied when the upper layer is depleted the turf will rapidly become dormant because it does not have a moisture reserve in the sub-soil layers. In contrast, the two heavy irrigations applied to the plots maintained in the medium soil moisture range gave a renewed subsoil supply that supported the grass for a much longer time and was depleted less rapidly.

FIGURE 10. THREE MONTHS TREND IN THE AVAILABLE
SOIL MOISTURE AS AN EXAMPLE OF THE MEDIUM
SOIL MOISTURE RANGE.



Yield of clippings

The yields were taken from the sixty field plots during a period of twenty days. The harvesting dates were August 16, 22, 26, and 31. Clippings were taken on those days when changes in fertility or moisture levels were made. A hand mower with a close fitting apron was used to collect the clippings from the entire plot. The green and oven dry weights were obtained. Four successive yields were taken from each plot to allow for variations in the mower settings and changes within each soil moisture range.

Tables 1 and 2 of the Appendix give the individual plot yields for the four cuttings. Table 13 is a summary of data for the five soil moisture ranges. Each figure represent the total yield of six plots.

After the clipping of August 11, all plots were fertilized with fifteen pounds of 10-6-4 per 1,000 square feet. A one-half inch rain fell shortly after this fertilizer treatment. The bluegrass yielded 4,085 grams dry weight at the next clipping whereas, the fescue yielded only 2,291 grams. During the following periods the yield of fescue was about three-fourths that of bluegrass.

From August 16 to 22 the soil continued to dry out and yields from the plots showed a definite relationship to the available soil moisture. Yields were reduced on the unirrigated areas and the moisture in the green clippings decreased to 55 per cent. The grasses from the irrigated areas contained about 80 per cent moisture and the dry

FIGURE 11. THE THREE MONTHS TREND IN THE AVAILABLE SOIL MOISTURE AT FOUR INCH DEPTH OF THE LOW SOIL MOISTURE RANGE UNDER HIGH CUT FESCUE, PLOT 5.

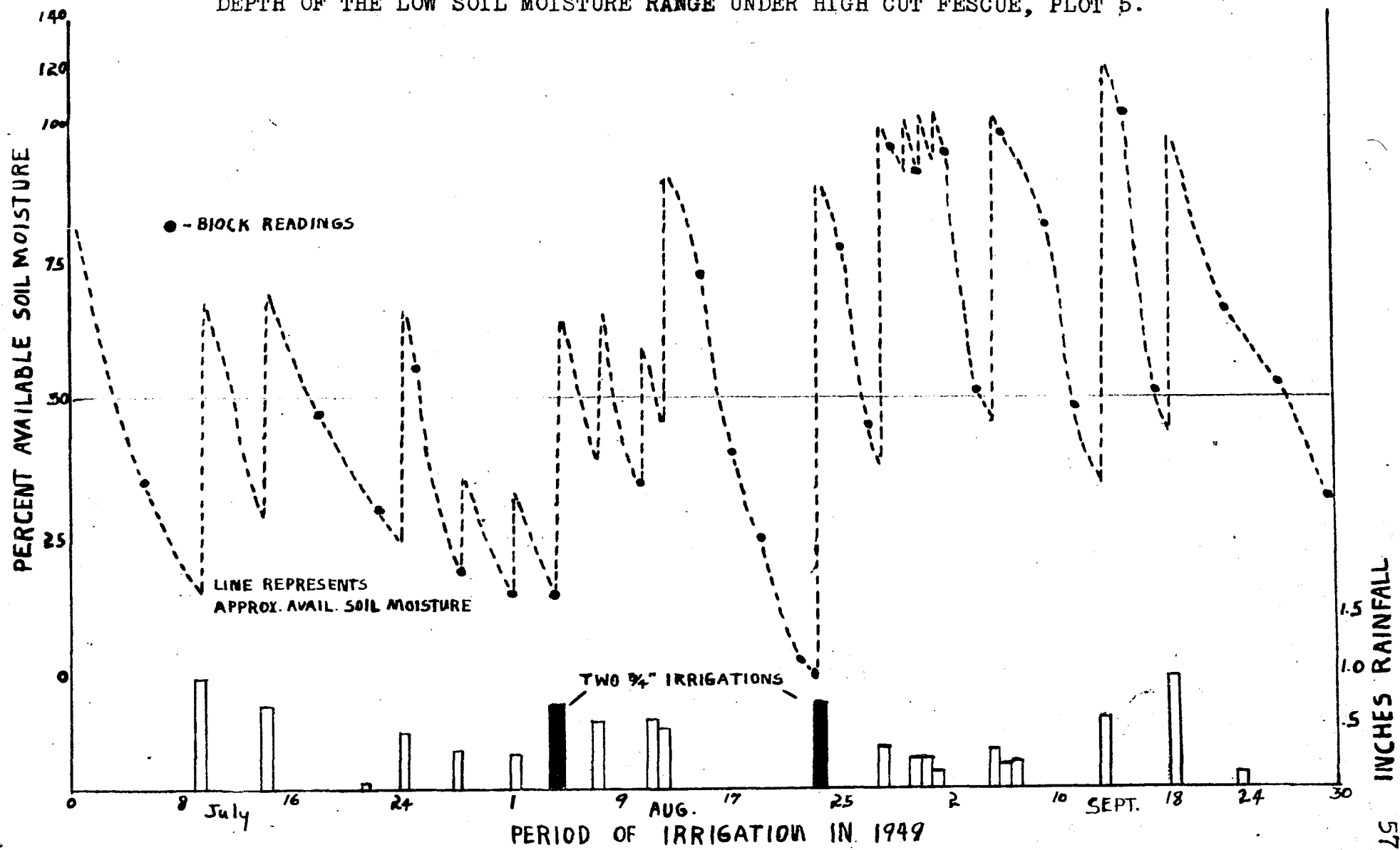


Table 13. Summary of the yield of clippings from the turf plots as affected by available soil moisture ranges.*

Available soil		Dates of harvest in August			
moisture range	16	22	26	31	Total
Creeping Red Fescue					
very low	298	273	160	285	1016
low	362	500	391	607	1860
medium	437	658	601	859	2555
high	566	905	612	936	3019
very high	628	982	646	976	3232
Total by dates	2291	3318	2410	3663	11,682
Kentucky bluegrass					
very low	327	341	146	355	1169
low	783	750	515	784	2835
medium	786	785	784	1067	3412
high	970	1265	806	1128	4169
very high	1219	1251	937	1155	4662
Totals by dates	4085	4492	3188	4489	16,244

* Each figure is the sum of six plots; individual plot yields are given in Tables 1 and 2 in Appendix.

weight yields increased over that of the preceding clipping. The clippings on August 26 were taken during a very dry period. The low yield of clippings for the unirrigated turf was due to the lack of available soil moisture throughout the root zone. During this time the unirrigated grass turned brown and the green clippings had a high percentage of dry matter.

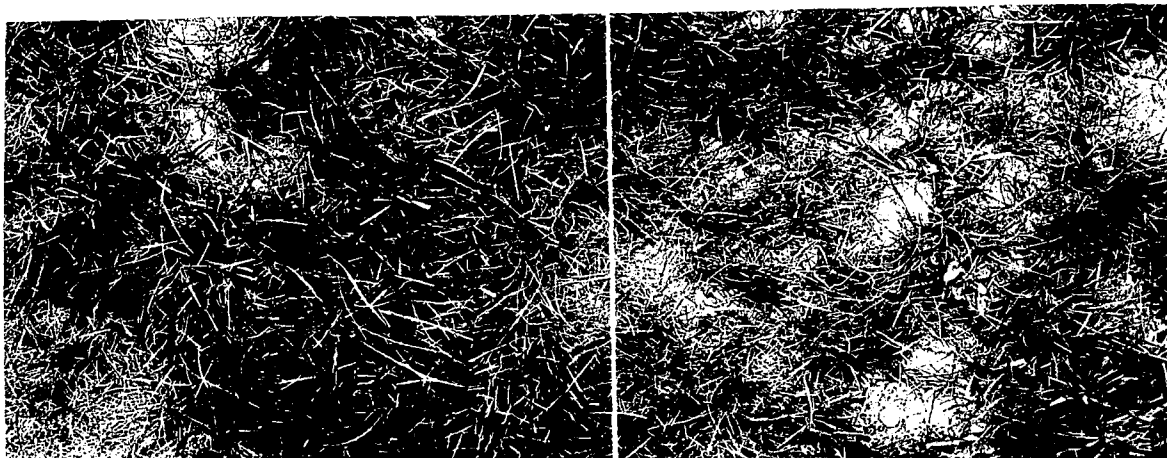
Following the clipping on August 26, tissue tests indicated that insufficient nitrogen was available. An application of five pounds of ammonium sulfate per 1,000 square feet was applied at this time. The plots were then watered, (Note soil moisture range charts, Figures 7 to 11.) The grasses responded favorably to the application of nitrogen and also to the high available soil moisture as they did during the first and second periods. Although fescue

yields increased more on a percentage basis than the bluegrass, its total yield was only about three-fourths that of the bluegrass.

The progressively greater yield for each increase in available soil moisture illustrates that, on this very open soil, excess application of moisture was not detrimental. The greenhouse experiment showed also that larger yields are obtained under a high percentage of available soil moisture. However, the yield of the grass under the medium soil moisture range conditions appeared as satisfactory as that of a higher soil moisture. This is significant in considering the economic aspects of turf maintenance.

Turf ratings

Three monthly ratings of the turf were made after the soil moisture ranges and cutting heights had been maintained for forty-five days. They were rated 1 to 10, with 10 considered a perfect turf and 1 very poor. Factors considered in the rating values were: uniformity of cover, golf ball supporting ability, freedom from weeds and clover, and general appearance of the turf. Nonirrigated fescue turf as shown in Plate 16, when cut at one-inch height was given a rating of 4 in October while that cut at one and one-half inches was rated as 6. The nonirrigated fescue turf cut at one-inch height had many small bare spots between the crowns of the fescue. These spots are undesirable for the lie of golf balls. The irrigated turf, shown in Plate 17, was given a rating of 10 because it gave good



one and one-half inch cut one inch cut
 Plate 16. Nonirrigated fescue after fall growth began. White sand placed in bare spots show bunched growth.

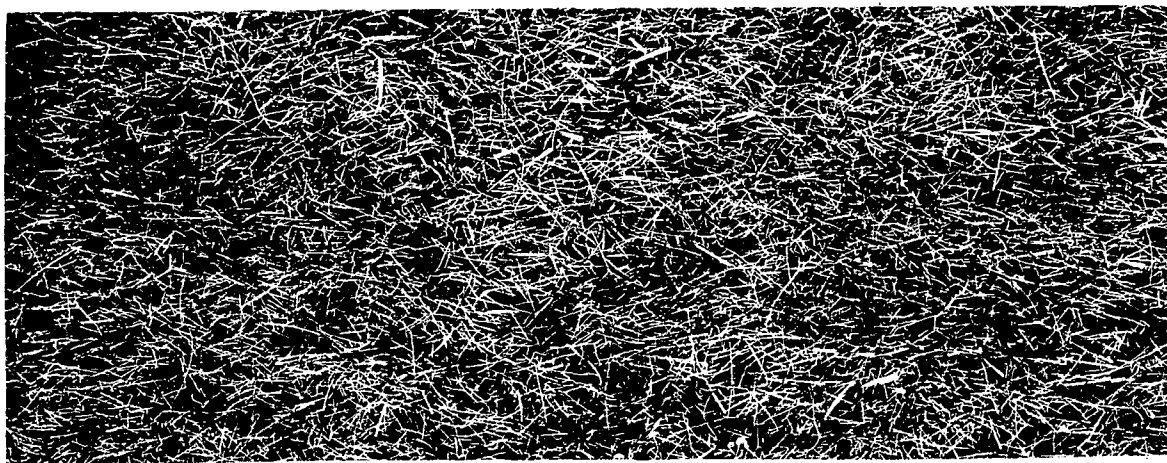


Plate 17. One and a half inch cut fescue in irrigated plots. Note dense ground cover.

ground cover, was free of weeds, and supported golf balls at a uniform height above the ground.

Table 14 summarizes the turf ratings of the plots as affected by five soil moisture ranges. As the soil moisture increased the turf ratings increased. In August the various soil moisture conditions caused little variation in the turf ratings as only one dry period had occurred. During September the ratings of the nonirrigated turf decreased to about

Table 15. Average of turf plot ratings as affected by the three heights of cut in 1949.*

Height of cut inches	Dates of ratings			Averages
	Aug.15	Sept.17	Oct.2	
Creeping Red Fescue				
one-half	4.8	2.0	2.8	3.2
one	6.4	5.6	6.6	6.2
one and one-half	8.6	8.1	8.5	8.4
average for dates	6.6	5.2	6.0	6.0
Kentucky bluegrass				
one-half	5.9	3.2	5.6	4.9
one	7.3	6.4	7.9	7.2
one and one-half	8.5	7.2	8.2	8.0
average for dates	7.2	5.6	7.2	6.7

* Individual plot ratings given in Table 3 Appendix.

one-half that of the August ratings. The turf ratings decreased only 20 per cent on plots with low soil moisture. The September turf rating on the three plots averaging above 50 per cent available soil moisture was only 10 per cent less than in August.

By October the fall rains and the additional fertilization had caused new growth in the nonirrigated plots as indicated by the higher ratings. Fall growth of the bluegrass turf showed more improvement than fescue turf for all moisture ranges in October.

Within the different soil moisture ranges various heights of cut caused large variations in ratings. In Table 15 the low-cut fescue ratings averaged only 2.8 in October while the low-cut bluegrass averaged 5.6, or twice that of the fescue. The bluegrass turf, cut at a one-inch height, rated better than the fescue of the same height. The high-cut fescue was superior to bluegrass cut at the same height. Within the high-cut fescue turf there was little difference

in the ratings of turf on plots maintained in the high, and very high soil moisture range as shown in Figure 14. From these ratings the turf of the medium-cut bluegrass and the high-cut fescue appear outstanding.

Composition of the turf

Considerable use of the per cent composition method for measuring turf has been made by Welton (26) and Musser (20) in following changes in turf conditions after fertilization. The effects on turf of varying soil moisture and cutting heights was measured in this study by estimating the per cent of bare ground, clover, weeds, and grass. A square foot grid, divided by fine wire into 100 divisions, was placed at several positions on the turf of different plots and the percentages estimated by observing the area under the grid. Individual turf plot percentages are given in Tables 4 and 5 of the Appendix and are summarized in Tables 16 and 17.

Each increase in available soil moisture gave a reduction in the bare ground percentages as shown in Table 16. The turf on plots of the very low soil moisture range had an average of 30 per cent bare ground on September 17. Turf on plots in the very high soil moisture range averaged only 7 per cent bare ground. The turf on plots of the low soil moisture range did not become dormant. However, the percentage of bare ground was uniformly more in these plots than on the plots receiving greater amounts of water. By October 2, the thickening of the turf and late season

Table 16. Percentage of bare ground in turf plots as affected by five soil moisture ranges during 1949.*

Available soil moisture range	Dates of ratings			
	Sept.17	Oct.2	Sept.17	Oct.2
	Creeping Red Fescue		Kentucky bluegrass	
very low	35	14	26	11
low	20	14	15	7
medium	15	12	8	6
high	14	10	7	7
very high	9	8	5	4.5

* Each figure is the average of six plots. Individual percentages are given in Table 4, Appendix.

Table 17. Percentage of bare ground in turf plots as affected by three heights of cut during 1949.*

Height of cut inches	Dates of ratings			
	Sept.17	Oct.2	Sept.17	Oct.2
	Creeping Red fescue		Kentucky bluegrass	
one-half	31.7	20.6	23.1	11.6
one	16.6	9.7	7.6	5.2
one & one-half	7.3	4.7	5.8	4.2
average for dates	18.7	11.7	12.2	7.0

* Each figure is average of ten plots.

growth of clover, materially reduced the percentages of bare ground as illustrated in Plate 18.

In both September and October the fescue plots had greater percentages of bare ground area than the bluegrass. This difference is clearly shown in Table 17 which gives the effect of three cutting heights on the percentages of bare ground. With both grasses the greatest percentage of bare ground was in the low-cut areas. The percentage of bare ground in the high-cut grasses on plots receiving medium, high and very high soil moisture averaged only 2.5 per cent for both September and October. The medium-cut fescue turf was more pitted with bare spots and had less clover. The fescue plots consistently contained a larger

amount of bare ground than the corresponding bluegrass plots.

The 1949 season was favorable for white clover. A high June rainfall followed by irrigation in the dry periods resulted in favorable soil moisture conditions for clover germination and growth. Also this was the first year of the turf seeding and the turf was thin.

Table 18. Percentage of clover in turf plots as affected by the varying soil moistures during 1949.*

Available soil moisture range	Dates of ratings			
	Sept.17	Oct.2	Sept.17	Oct.2
	Creeping Red Fescue		Kentucky bluegrass	
very low	3.0	7.7	5.3	9.3
low	5.0	8.7	9.1	11.5
medium	4.1	7.0	9.8	15.3
high	6.8	9.1	7.5	16.5
very high	6.5	8.3	7.7	19.0

* Each figure is an average of six plots. Individual plot ratings given in Table 5 of the Appendix.

Turf on the plots was practically free of clover until after mid-summer. By August 15 it was present in only about one-half the plots but by September small clover plants were present in all the plots. As shown in Table 18, the infestation of the fescue turf with clover appears to have little relationship to available soil moisture in either September or October although a slight increase occurred by October.

On plots maintained in the very low soil moisture range, the bluegrass turf remained more clover free than on the irrigated plots which had higher available soil moisture during the time of early clover growth. Clover was considerably denser in the bluegrass than in the fescue turf during both September and October. In October the percentages

Table 19. Percentage of clover in turf plots as affected by three heights of cutting during 1949.*

Height of cut inches	Dates of ratings			
	Sept.17	Oct.2	Sept.17	Oct.2
	Creeping Red Fescue		Kentucky Bluegrass	
one-half	7.9	13.6	8.6	16.5
one	4.7	7.3	7.7	12.5
one and one-half	2.7	3.6	7.4	14.0
average for each date	5.1	8.2	7.9	14.3

* Each figure is the average of 10 plots.

of clover increased with increasing moisture. Turf on the plots receiving very high soil moisture had almost twice as much clover as that on plots receiving a very low amount of soil moisture.

Since white clover grows more closely to the ground than the grasses studies, the height of cutting thus became a factor mainly in the amount of resistance that the remaining turf could give to the clover infestation. Table 19 shows that the clover percentages increased with each decrease in the height of cutting on the fescue turf for both months. Between the September and October ratings, the percentages of clover in the high-cut fescue turf increased very little compared to that in the low-cut. The relative freedom of the high-cut fescue from clover (Plate 20) was attributed to the competition of the thick turf.

The bluegrass turf contained uniformly high percentages of clover at all heights of cut. The values were about equal to those of the low-cut fescue turf. It appeared that the turf on these plots was not thick enough to afford effective competition to the clover. The high-cut bluegrass

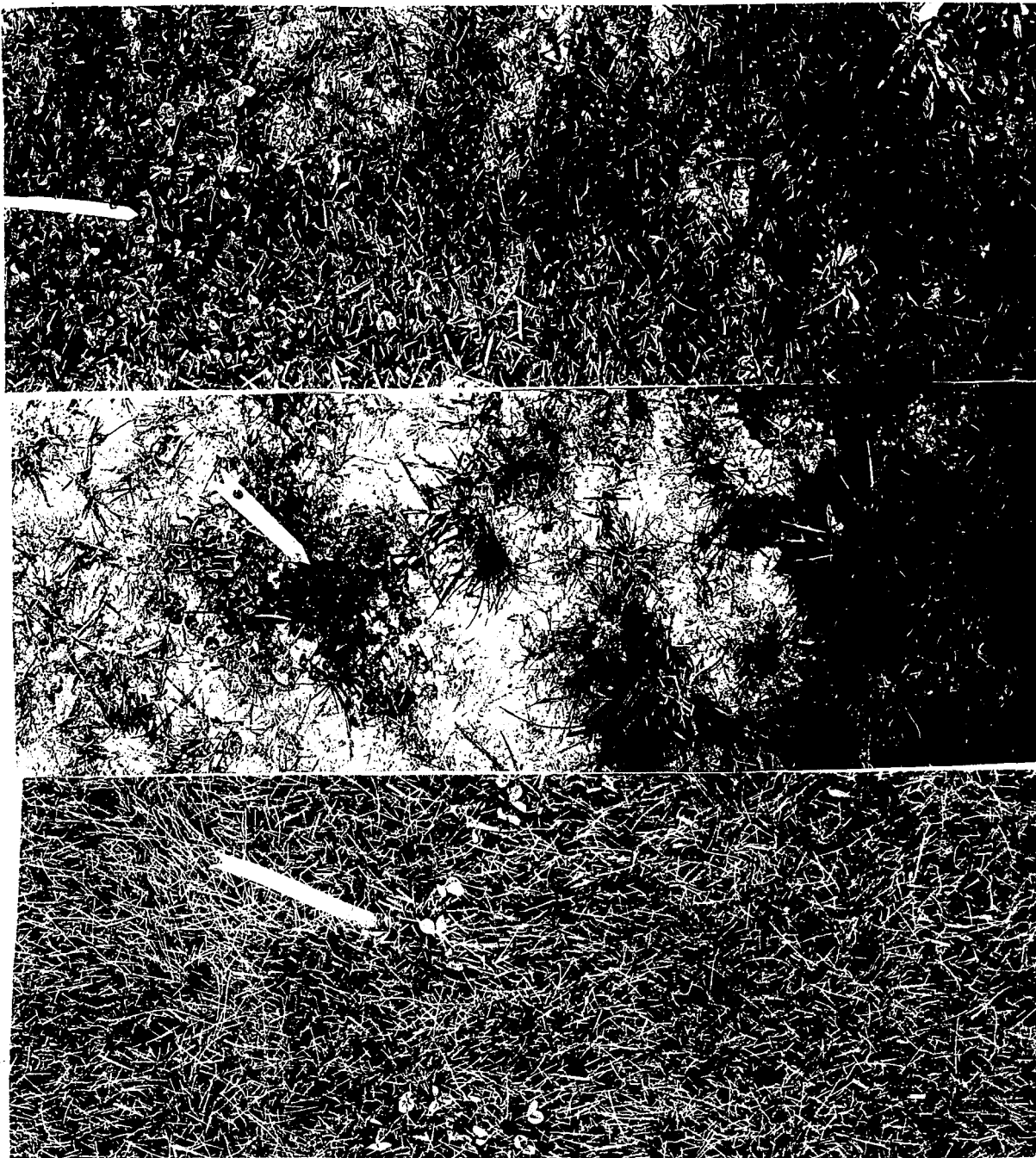


Plate 18. Top. One-half inch cut, nonirrigated bluegrass late in the season. Composition included 25% clover and 12% bare ground.

Plate 19. Middle. One-half inch cut, unirrigated fescue late in season. Weeds germinated during late spring; percentages include clover 10%, bare ground 40%, and crabgrass 5%.

Plate 20. Bottom. One and one-half inch cut irrigated fescue. Composition was 95% grasses.

plots contained an exceptionally high percentage of clover. The greater height of mowing on these plots cut off little of the low growing clover in the rather open bluegrass turf. The bluegrass plots had less bare ground area than the fescue plots but the situation was reversed for the amount of clover present. The total area of bare ground plus the area covered by clover was nearly the same for each grass.

In May an application of 2,4-D, as an ester in oil, at the rate of 1.5 pounds per acre, gave a good weed kill except on sorrel which was prevalent in the area. Several weeds such as narrow leaf plantain, dandelion, purslane, and crabgrass, invaded the plots during the summer. This was particularly true on the irrigated and closely cut plots. The sorrel remained in the turf plots in slight amounts all season. The other weeds increased to as much as 5 per cent in the low-cut fescue turf which was irrigated. Plates 18, 19 and 20 give some of the contrast in bare ground, clover, and weeds in the turf at different cutting heights and moisture levels.

After estimating the percentage of bare ground, clover and weeds in the turf the remainder was considered as turf grasses. Percentages of grass varied from a low of 43 to a high of 95. The high-cut fescue turf that was irrigated averaged 91 per cent turf grasses. Since the turf plots were planted on an area of established bluegrass, old rhizomes and seed of bluegrass were in the soil and initiated some new bluegrass growth in the plots. In the bluegrass

this was not noticeable. In the seeded fescue turf, however, the appearance of the bluegrass was easily correlated with the height of cut. The percentages of fescue and bluegrass in samples of clippings taken from the fescue plots were determined. In the high-cut fescue clippings, 95 per cent was fescue, in the medium-cut 80 per cent and in the low-cut only 37 per cent.

Ability of Turf to Support Golf Balls

In an attempt to find measurements of turf characteristics other than yields, per cent composition, and visual ratings, the height at which golf balls were held above the soil surface was measured. A meter stick was used having a sliding wire that turned outward at the base so that it could touch the top of the ball lying on the turf as illustrated in Plate 21. Since regulation golf balls are the same diameter it was possible to measure the top of the ball and deduct the ball diameter to find the distance in millimeters between the ball and the ground. Ten golf balls were rolled onto the turf of each plot to secure the range in the height of ball support. Table 20 gives the averages of twenty ball heights for each cutting-moisture condition on September 15.

The ability of turf to support golf balls at a uniform height and the extent of the variation in the readings was found to be a good indication of the pockets and thin spots in the turf in which all the distances between the ball and

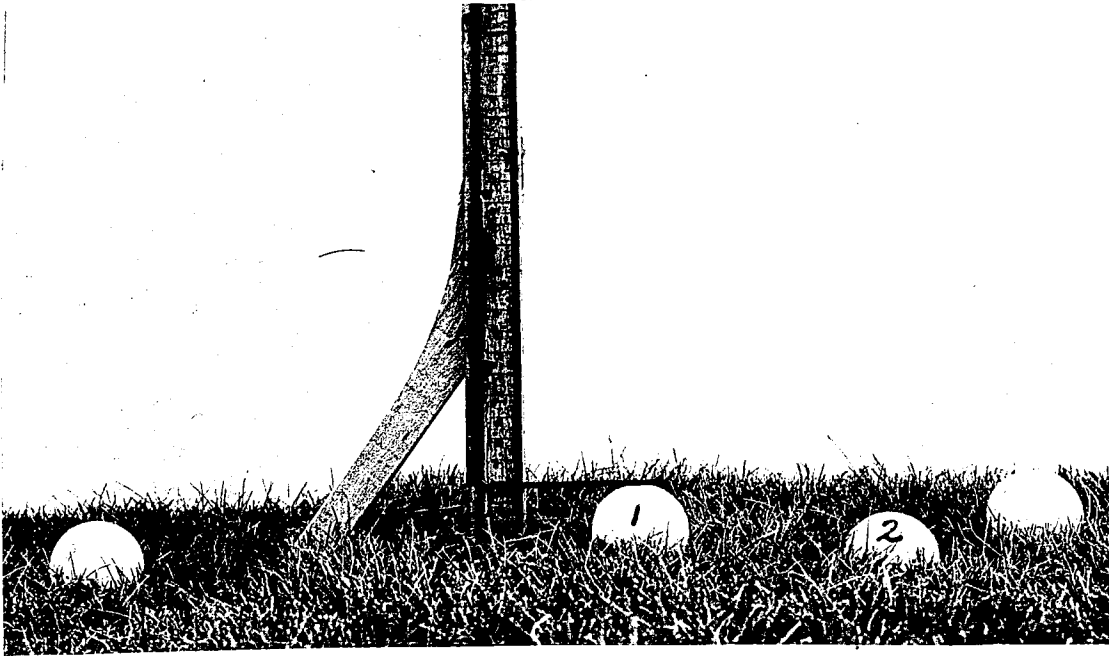


Plate 21. Illustration of the sliding wire attached to a meter stick to measure the height of the ball above the ground by subtracting the ball diameter.

the soil were near the same. In only six of the sixty plots was this uniformity of distances obtained. In contrast the range of ball support heights on many of the plots was quite wide and the averages fail to show these extremes. In Table 20 the averages show that ball support of the medium-cut bluegrass is much better than the same height of fescue turf. The low-cut fescue turf had several negative readings when the ball rolled into low pockets between the crowns and was below the general ground level. The irrigated and high cut fescue turf was again outstanding by its uniformity of ball support. The 14 mm. distance between the ball and the ground was in effect an excessive "automatic tee". However, this did indicate that the turf

Table 20. Effect of three heights of cut and five soil moisture ranges on the height, in millimeters, of golf balls above ground. *

Available soil moisture range	Creeping Red fescue			Kentucky bluegrass			Ave.
	Height of cutting, inches						
	0.5	1.0	1.5	0.5	1.0	1.5	
very low	0	0	4	2	5	5	2.8
low	0	7	9	1	8	10	6.0
medium	1.5	7	10	3	12	10	7.2
high	2	7	14	3	9	13	8.0
very high	1	8	14	3	9	12	7.8

* Each figure is average of twenty measurements.

was thick and uniform on these plots. The ball support height of the turf for a given cutting level averaged about the same on the plots with medium, high, and very high soil moisture.

SUMMARY AND CONCLUSIONS

This investigation was undertaken to study by means of greenhouse cultures and field plots, the relationship between available soil moisture, fertilizers, and height of clipping on the yield and value of bent, bluegrass and fescue turfs.

Fifteen cultures each of Astoria bent, Creeping Red fescue and Kentucky bluegrass were grown on Hillsdale sandy loam surface soil and fifteen cultures of bluegrass were grown on Brookston clay loam surface soil in the greenhouse. Three cultures of each group were left as unfertilized checks; within the twelve fertilized cultures four soil moisture ranges, excess, high, medium and low were maintained by soil moisture block control. Three periods of growth were harvested by cutting at one and one-fourth inches above the soil surface. The dry weight, height of growth, water applied, and progressive available soil moisture for each period were measured.

In the field investigations parallel strips of bluegrass and fescue were divided on July 1, 1949 and cut at three different heights under five soil moisture ranges. Nylon soil moisture blocks were placed at four-inch and ten-inch depths in the plots to record the available soil moisture and determine when to apply supplemental water. The yield, rating, composition, and fairway characteristics of the turf were determined during the growing season.

The soil moisture blocks, both nylon and plaster of

paris, proved adequate for determining the available soil moisture. In the calibration of the blocks under turf, the roots, gravel and fertilizer present lowered the resistance readings to less than that of the laboratory calibration from a screened soil sample. Soil moisture blocks located at the top and bottom of a thirteen inch soil column showed that one block placed midway was adequate after the roots were established, for determining when to apply water and for following the soil moisture trend.

Grasses growing under greenhouse conditions of high, 150 to 50 per cent, available soil moisture produced the highest growth, greatest yield, and required the least water (778 units) to produce one unit of dry grass. In contrast, cultures in the medium, 120 to 20 per cent, available soil moisture range produced only 66 per cent as much yield, required 72 per cent as much water and 840 units of water per unit of dry matter. Allowing the grass to wilt between water applications gave only 10 per cent less water use and yield than that secured under non-wilting conditions. Excess water applications in the greenhouse resulted in severe reduction in growth that was partially corrected by an addition of soluble nitrogen.

In a seedling experiment, roots of fescue extended 24 cm. in nineteen days after germination while the tops grew only 13 cm. At the end of forty days growth the roots and crowns were the same weight as the tops. Similarly, the weight of roots produced under different soil moisture ranges varied directly with the top growth. However, the proportion

of roots to tops was generally greater in the low moisture and low fertility ranges. Under excess moisture conditions a mass of surface roots was produced, meanwhile roots were pruned to less than two inches depth in the soil. Under medium and high soil moisture range conditions, the bluegrass had large white rhizomes, while those under low soil moisture range conditions were small, brown and much less active.

The unfertilized cultures in the greenhouse produced less than half that of those fertilized, yet required 85 per cent as much water to maintain the same soil moisture conditions. In both fertility conditions bentgrass had the highest yields and fescue had the least. Cultures on unfertilized Brookston soil gave more dry weight yield than on unfertilized Hillsdale soil.

It was not possible to maintain excess soil moisture conditions in the open sandy soil of the turf plots but by frequent additions of small irrigations the very high soil moisture range averaged 106 per cent available soil moisture. During August there were two dry periods that allowed five soil moisture ranges to be maintained and the comparison of the yield, rating and available soil moisture was made. The progressively greater yield for each increase in moisture for all plots illustrates that the excess irrigation was not sufficient to reduce yields. Yet, for economy of maintenance, the yield of the turf on the medium soil moisture range plots appeared as satisfactory as that of the higher soil moisture range plots.

Figure 12. Summary charts showing the soil moisture ranges, number and amount of irrigations, per cent available soil moisture and relation to yield and ratings of turf.

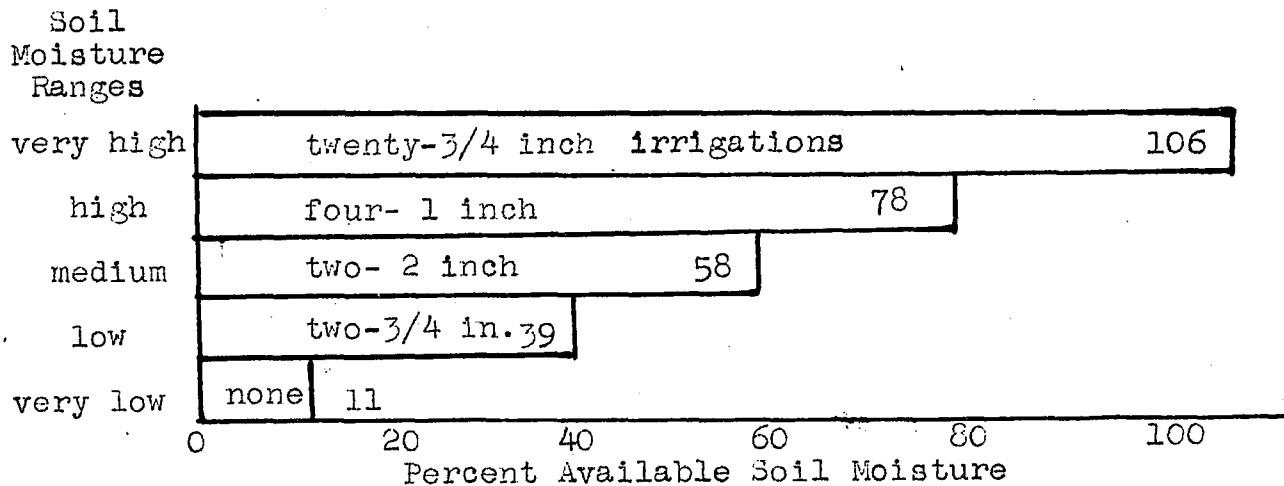


Figure 13. Comparison of the yield from high cut fescue plots with soil moisture ranges produced by irrigation.

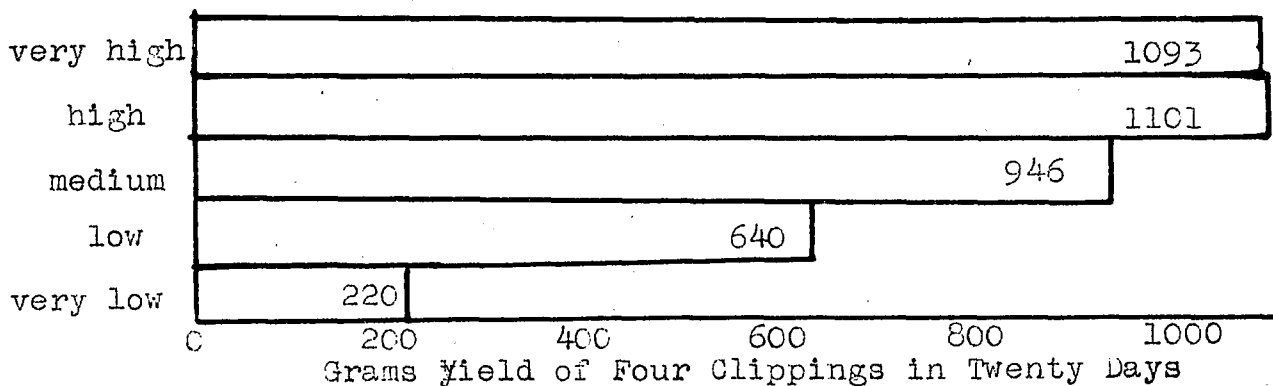
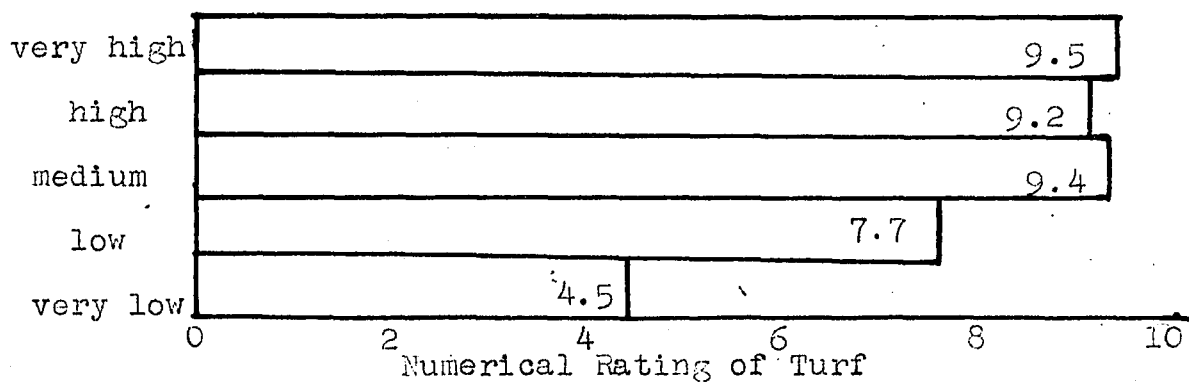


Figure 14. Rating of the turf; average of two replications for three months on the high cut fescue. (10-very good, 1-very poor)



Two small irrigations, applied at critical times, prevented the turf from going dormant and provided a better turf throughout the season, as is illustrated in the ratings of the turf in plots which were maintained in the low soil moisture range. By use of the soil moisture blocks to determine when the soil is low in available moisture, relatively large applications can be applied and held in the root zone for use by the turf. Thus those plots receiving only two heavy irrigations, gave a good rating throughout the season.

Rating of the turf, from 1, low, to 10, high, were made three times during the growing season as a visual measurement of the turf. Within a given height of cut the medium, high and very high soil moisture ranges had little effect on the rating of the turf produced. In September, nonirrigated turf was dormant and had many open areas.

The low-cut turf had the lowest ratings due to its inadequate ground cover and poor ball support. On the high-cut plots the fescue rated superior to the bluegrass as it was more dense, gave more uniform ball support, and was more nearly free from weeds and clover. In the medium and low-cut plots the bluegrass was superior to the fescue as the bluegrass had smaller openings and better distribution of turf.

Percentage composition estimates were made for three months to determine the bare ground, clover, weeds, and grasses. The bluegrass turf contained uniformly high clover percentages in October, but contained less bare ground than the fescue turf. In the low-cut fescue, native bluegrass

constituted one-half of the clippings, while in the high-cut fescue the clippings were 95 per cent fescue.

Fairway characteristics as determined by the support and position of golf balls rolled onto the turf were measured by use of a sliding wire on a meter stick. Excessive ball support was obtained on the high-cut fescue, but this indicates the uniformity of the turf when the soil was kept within a desirable moisture range. On low-cut turf the average ball support was reduced by the low pitted turf. On thin turf, as in unirrigated bluegrass, the use of a higher cut to obtain better ball support was of slight value as it gave "bedded lies"; in thick turf higher cutting gave uniform although high ball support.

From this experiment it was found that the best growth of fescue was obtained where the height of cut was above one inch, and where sufficient moisture was applied to prevent the grass from going dormant and developing bare spots. The most practical method of applying water was to permit the soil to dry to about 20 per cent available moisture and then apply a rather large amount of water to replenish the supply in the entire root zone for the extended use of the turf.

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APPENDIX



Table 1. Yield of Clippings on 30 Kentucky bluegrass plots on River Farm, 1949. Yield is dry weight in grams from 6 by 18 foot plots.

S. Moist. R.	Ht. of cut					
Plot No.	inches	16	22	26	31	Total
<u>Very low</u>						
1	0.5	90	35	25	57	207
	1.0	50	18	10	36	114
	1.5	36	22	10	30	98
6	0.5	12	91	43	95	241
	1.0	75	68	27	61	231
	1.5	64	107	31	76	278
		327	341	146	255	1169
<u>Low</u>						
5	0.5	153	113	95	132	493
	1.0	155	147	100	162	564
	1.5	134	195	123	174	626
10	0.5	155	79	96	125	455
	1.0	98	109	53	101	361
	1.5	88	107	48	90	333
		783	750	515	784	2832
<u>Medium</u>						
4	0.5	155	144	148	168	615
	1.0	119	143	133	187	582
	1.5	106	143	106	174	529
9	0.5	213	108	168	208	697
	1.0	116	149	150	210	615
	1.5	77	98	79	120	374
		786	785	784	1067	3412
<u>High</u>						
2	0.5	206	203	157	180	746
	1.0	179	248	151	200	778
	1.5	155	224	124	230	733
7	0.5	155	166	146	153	620
	1.0	144	192	123	181	640
	1.5	131	232	105	184	652
		970	1265	806	1128	4169
<u>Very High</u>						
3	0.5	240	208	179	190	817
	1.0	235	228	171	208	842
	1.5	176	261	125	201	763
8	0.5	250	225	182	200	857
	1.0	179	196	168	191	734
	1.5	139	233	112	165	649
		1219	1351	937	1155	4662
Totals by dates		4085	4492	3188	4489	16,244
Totals by height		0.5--5748	1.0--5461	1.5--5035		

Table 2. Yield of Clippings on 30 Creeping Red fescue plots on River Farm in 1949. Yield is dry weight in grams from 6 by 18 foot plots.

S. Moist. R.	Ht. of cut					
Plot No.	inches	16	22	26	31	Total
<u>Very low</u>						
6	0.5	91	69	56	89	305
	1.0	36	40	19	40	135
	1.5	41	45	13	38	137
1	0.5	76	69	53	69	267
	1.0	27	26	11	25	89
	1.5	27	24	8	24	83
		298	273	160	285	1016
<u>Low</u>						
5	0.5	82	68	67	110	327
	1.0	62	91	81	126	360
	1.5	53	105	81	113	352
10	0.5	60	54	34	65	213
	1.0	55	86	71	108	320
	1.5	50	96	57	85	288
		362	500	391	607	1860
<u>Medium</u>						
4	0.5	106	91	87	144	428
	1.0	75	113	142	166	496
	1.5	66	160	124	171	521
9	0.5	68	58	51	85	262
	1.0	67	112	100	144	423
	1.5	55	124	97	149	425
		437	658	601	859	2555
<u>High</u>						
2	0.5	106	110	82	128	426
	1.0	87	139	96	147	469
	1.5	84	182	113	164	543
7	0.5	120	122	88	151	481
	1.0	98	152	119	173	542
	1.5	71	200	114	173	558
		566	905	612	936	3019
<u>Very High</u>						
3	0.5	127	127	94	169	517
	1.0	130	164	124	185	603
	1.5	78	221	123	157	579
8	0.5	107	110	85	132	434
	1.0	108	188	120	169	585
	1.5	78	172	100	164	514
		628	982	646	976	3232
Totals by dates		2291	3318	2410	3663	11,682
Totals by heights		0.5--3660	1.0--4022	1.5--4000		

Table 3. Comparative ratings of individual turf plots for three months as affected by varying soil moisture and height of cutting.

Soil Moist. Ranges		Creeping Red fescue				Kentucky bluegrass			
plot nos.	month of rating	0.5	1.0	1.5	total	1.5	1.0	0.5	total
<u>Very low</u>									
1	Aug.	5	5	7	17	8	7	6	19
	Sept.	1	2	3	6	4	3	1	8
	Oct.	2	4	6	12	7	6	4	17
					35	44			
6	Aug.	5	6	9	20	9	8	5	22
	Sept.	1	3	6	10	7	5	2	14
	Oct.	3	7	7	17	8	8	4	20
					47	56			
					882	100			
<u>Low</u>									
5	Aug.	4	6	8	18	9	7	5	21
	Sept.	3	7	9	19	8	7	3	18
	Oct.	2	5	8	15	9	9	5	23
					52	62			
10	Aug.	4	7	9	20	8	7	6	21
	Sept.	1	5	6	12	6	6	2	14
	Oct.	2	5	6	13	7	8	5	20
					45	55			
					97	117			
<u>Medium</u>									
4	Aug.	5	7	9	21	8	7	5	20
	Sept.	3	7	10	20	8	7	3	18
	Oct.	3	7	10	20	8	8	5	21
					61	59			
9	Aug.	4	6	9	19	8	7	6	21
	Sept.	1	4	9	14	7	7	4	18
	Oct.	3	7	9	19	8	8	7	23
					52	62			
					113	121			
<u>High</u>									
2	Aug.	6	7	8	21	9	8	6	23
	Sept.	2	6	9	17	8	6	3	17
	Oct.	3	8	9	20	9	8	7	24
					58	64			
7	Aug.	5	7	9	21	9	8	7	24
	Sept.	2	8	10	20	8	8	3	19
	Oct.	3	8	10	21	9	8	5	22
					62	65			
					120	129			
<u>Very high</u>									
3	Aug.	5	6	9	20	8	6	6	20
	Sept.	3	8	10	21	8	7	5	20
	Oct.	4	8	10	22	7	7	6	20
					63	60			
8	Aug.	5	7	9	21	9	8	7	24
	Sept.	3	6	9	18	8	8	6	22
	Oct.	3	7	10	20	9	9	8	26
					59	72			
					122	132			
Total									
Aug.		48	64	86		85	73	59	
Sept.		20	56	81		72	64	32	
Oct.		28	66	85		82	79	56	
		96	186	252	534	239	216	147	599

Table 4. Percentage of bare ground in individual turf plots as affected by varying soil moisture and height of cutting.

as affected by varying soil moisture and height of cutting								
S. Moist. R.	Creeping Red fescue				Kentucky bluegrass			
	Height of cutting, inches							
Plot No.	0.5	1.0	1.5	totals	1.5	1.0	0.5	totals
<u>September 17</u>								
<u>Very low</u>								
1	50	40	30	120	25	30	45	100
6	35	40	15	90	8	10	40	58
				<u>210</u>				<u>158</u>
<u>Low</u>								
5	30	10	8	48	5	5	27	37
10	45	15	9	69	4	7	40	51
				<u>117</u>				<u>88</u>
<u>Medium</u>								
4	20	8	1	29	2	5	22	29
9	45	16	3	64	4	3	15	22
				<u>93</u>				<u>51</u>
<u>High</u>								
2	32	15	5	52	4	6	13	23
7	25	9	1	35	1	3	13	17
				<u>87</u>				<u>40</u>
<u>Very High</u>								
3	14	5	0	19	3	4	8	15
8	25	8	1	34	2	3	8	13
				<u>53</u>				<u>28</u>
	<u>317</u>	<u>166</u>	<u>73</u>	<u>560</u>	<u>58</u>	<u>76</u>	<u>231</u>	<u>365</u>
<u>October 2</u>								
<u>Very low</u>								
1	30	18	7	55	6	9	12	27
6	12	10	8	30	7	5	25	37
				<u>85</u>				<u>64</u>
<u>Low</u>								
5	12	10	6	28	2	4	12	18
10	30	14	12	56	6	8	14	28
				<u>84</u>				<u>46</u>
<u>Medium</u>								
4	15	5	2	22	4	4	12	20
9	28	14	6	48	2	5	6	13
				<u>70</u>				<u>33</u>
<u>High</u>								
2	25	5	2	32	4	4	10	18
7	20	8	1	29	3	4	15	22
				<u>61</u>				<u>40</u>
<u>Very high</u>								
3	14	5	2	21	5	5	5	15
8	20	8	1	29	3	4	5	12
				<u>50</u>				<u>27</u>
	<u>206</u>	<u>97</u>	<u>47</u>	<u>350</u>	<u>42</u>	<u>52</u>	<u>116</u>	<u>210</u>

Table 5. Percentage of clover in turf plots as affected by five soil moisture ranges and three heights of cutting during 1949.

during 1949.		Creeping Red fescue				Kentucky bluegrass		
S.Moist.R.		Height of cutting, inches						
Plot No.	0.5	1.0	1.5	totals	1.5	1.0	0.5	totals
September 17								
<u>Very low</u>								
1	2	3	0	5	0	1	5	6
6	10	3	0	13	10	7	9	26
				<u>18</u>				<u>32</u>
<u>Low</u>								
5	10	5	2	17	8	10	7	25
10	10	2	1	13	12	10	8	30
				<u>30</u>				<u>55</u>
<u>Medium</u>								
4	9	7	2	18	10	12	12	34
9	5	1	1	7	8	9	8	25
				<u>25</u>				<u>59</u>
<u>High</u>								
2	5	5	3	13	7	12	5	24
7	10	10	8	28	12	4	5	21
				<u>41</u>				<u>45</u>
<u>Very High</u>								
3	8	5	5	18	9	6	9	24
8	10	6	5	21	10	7	5	22
				<u>39</u>				<u>46</u>
	<u>79</u>	<u>47</u>	<u>27</u>	<u>153</u>	<u>86</u>	<u>77</u>	<u>74</u>	<u>237</u>
October 2								
<u>Very low</u>								
1	4	6	0	10	2	2	8	12
6	30	5	1	37	16*	13	15	44
				<u>46</u>				<u>56</u>
<u>Low</u>								
5	25	9	3	37	14	11	12	37
10	9	4	2	15	12	14	6	32
				<u>52</u>				<u>69</u>
<u>Medium</u>								
4	15	16	6	37	25	14	25	64
9	2	2	1	5	10	9	9	28
				<u>42</u>				<u>92</u>
<u>High</u>								
2	4	4	1	9	15	20	15	50
7	25	13	8	46	25	12	12	49
				<u>55</u>				<u>99</u>
<u>Very high</u>								
3	12	7	7	26	20	18	30	68
8	10	7	7	24	26	12	8	46
				<u>50</u>				<u>114</u>
	<u>136</u>	<u>73</u>	<u>36</u>	<u>245</u>	<u>165</u>	<u>125</u>	<u>140</u>	<u>430</u>

* Plot was lower and received some run off from other plots.