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Seasonal Variations in the Growth and Chemical Composition of Kentucky Bluegrass

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COLUMBIA, MISSOURI

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ABSTRACT

1. Since efficient grazing management must be based on a knowledge of the growth habits and composition of pasture grasses as well as on an understanding of the grazing habits, and nutritive requirements of grazing animals, this investigation, covering a 4-year period, was undertaken to determine seasonal variations in the development and chemical composition of Kentucky bluegrass (*Poa pratensis* L.).

2. Important climatic factors—air and soil temperature, rainfall, and soil moisture content—were measured.

3. Kentucky bluegrass swards one or more years old made very little top growth until the average soil temperature at the ½-inch depth rose above 50° F. The rate of herbage production increased rapidly in April and usually reached a maximum during the first half of May at an average soil temperature of 60° to 64° F. The period of maximum herbage yield was also the period when reproductive shoots elongated and inflorescences emerged.

Herbage production by bluegrass that was mowed semi-monthly began to decrease in late May and reached a minimum in July at an average soil temperature of 80° to 82° F. Irrigation reduced but did not prevent this midsummer decline in herbage production by Kentucky bluegrass. With adequate supplies of soil moisture and available nitrogen, herbage production increased to a second but smaller peak during late August at an average soil temperature of 74° F.

Top growth declined during September and remained quite small during October, although the mean temperature during the latter month was almost the same as that during the first half of May when herbage production was at a maximum.

4. Seasonal variations in herbage production were influenced by temperature, soil moisture, length of day, age of the grass sward, applications of sodium nitrate, semi-monthly mowing, and the quantity of roots and rhizomes in the sod.

5. Rather large seasonal variations in the crude protein, crude fiber, lignin, calcium and phosphorus content of the herbage occurred even when the bluegrass was mowed semi-monthly at the 1-inch level.

Kentucky bluegrass hay cut at full bloom and again near the end of the growing season was lower in crude protein and higher in crude fiber and lignin than clippings cut on comparable dates from frequently mowed bluegrass.

6. Spring, when semi-monthly average soil temperatures ranged from 40° to 75° F., and fall, when they ranged downward from 70° to 50°, were the more favorable periods of the year for root and rhizome development by dense swards of Kentucky bluegrass after the first year. Root development was larger during early spring (March 6 to May 20) when semi-monthly average soil temperatures were 40° to 60° than during late spring and early summer (May 20 to June 30) when average temperatures ranged between 65° to 75°.

Rhizomes increased more in weight from May 20 to June 30 than earlier, probably because of the longer photoperiod rather than because of the higher temperature. Both roots and rhizomes either made little gain in weight or actually lost weight during July and August when average soil temperatures were usually above 80°F.

7. Late autumn (mid-October to late November) was the period during which sugar and starch accumulated most rapidly in bluegrass rhizomes, although carbohydrate storage also occurred during September and early October. The total quantity of carbohydrates in roots increased during the spring, but this increase was due to an increase in dry matter, since the percentage content of carbohydrates remained unchanged or decreased. Both the concentration and total quantity of carbohydrates (sugars and starch) decreased in the roots during late spring and summer.

Hemicellulose is probably not a carbohydrate reserve in Kentucky bluegrass.

8. Larger yields of herbage resulted from cutting Kentucky bluegrass once or twice annually at hay stages than from semi-monthly mowing at either the 1-inch or 2½-inch level. Smallest yields were obtained from plots mowed semi-monthly with the cutter bar set 2½ inches above the ground.

Clipping bluegrass semi-monthly to a height of 1 inch had little or no effect on the quantity of roots in the upper 6 inches of sod, but repeated close mowing did reduce materially the quantity of rhizomes by retarding their development during the spring and by increasing the rate of their depletion during summer. During the autumn, rhizome development in the 1-inch cut plots was practically equal to that in the 2½-inch and hay-cut plots.

The sugar and starch content of bluegrass rhizomes was influenced less by clipping treatment than their dry weight.

9. Only 2 weeks without rain were required to reduce the soil moisture content of Kentucky bluegrass sod from a surplus to a deficit at summer temperatures. Summer irrigation accelerated the decomposition of old, dead bluegrass roots, more completely exhausted carbohydrate reserves in the rhizomes and hastened their death, and facilitated the ingress of summer annual weeds and weed grasses.

10. Kentucky bluegrass was much more productive during the first spring following a September seeding than during any of the next 3 years. Sodium nitrate applied at the rate of 600 to 800 pounds per acre increased but did not fully restore the growth vigor that characterized the young grass.

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INTRODUCTION

Widely divergent opinions are held as to the time of year when grazing should begin and end, and the intensity with which permanent pastures should be grazed. Graber and his co-workers (23, 24, 25),[1] for example, found that close and frequent clipping or grazing of Kentucky bluegrass and some other perennial grasses retards root and rhizome growth, reduces the density, and eventually the productivity of the sward, favors the ingress of weeds, and weakens the resistance of the grass to unfavorable weather conditions. Carrier (14), on the other hand, expressed the opinion that in the northeastern part of the United States more pastures have been harmed by undergrazing than by overgrazing, and that the nearer a first-class lawn can be imitated in pastures the better the animals will thrive. Johnstone-Wallace (29) observed that cattle show a preference for pasturage consisting of short leafy herbage and that, although they can graze such herbage to within half an inch of the ground, maximum consumption is obtained from a dense sward with a height of about 4 inches.

Sprague (44), having found that fully one-half of the root system of Kentucky bluegrass is generated each spring concluded that root development by this grass is more likely to be affected by cultural treatments applied in the spring than at any other season. Gardner (21) and Waters (52) believed, on the other hand, that conservative grazing to avoid depletion of the reserves in the roots and crowns is of greater importance during the fall than during the spring.

Brown (11) reports that over twice as much beef was produced per acre when grazing started May 5 as when it began June 10. Tyson (50) states that the bulk of the forage, consisting largely of Kentucky and Canada bluegrass, in native Michigan pastures is produced in May, June, and September, and that unless it is used as it grows it dries up and becomes unpalatable. In New York, Johnstone-Wallace (29) found that delayed grazing in the spring allows much of the herbage to reach a highly fibrous stage before

[1]Numerals refer to "Literature cited." Page 54.

the stock can graze. This, in turn, frequently results in a part of a pasture being overgrazed while most of it is undergrazed or not grazed at all.

Both Brown and Johnstone-Wallace found that early grazing increased the white clover content of pasture herbage, and Johnstone-Wallace expressed the opinion that bluegrass will benefit more from a vigorous growth of white clover that results from close early grazing than it will suffer from the direct effect of close early defoliation. Ellet and Carrier (19) observed that Kentucky bluegrass, redtop, and white clover predominated in frequently clipped plots, while these grasses gave way to tall growing weeds on plots cut but once a year.

These different opinions as to when and how intensively permanent pastures should be grazed result partly from differences in climatic and soil conditions under which this problem has been investigated. Differences in seasonal temperatures, distribution of rainfall, and the frequency and extent of the occurrence of white clover in pastures would certainly influence the response of both grass and livestock to a given type of grazing management. They are also due, in part, to an incompleteness of available knowledge of the growth habits of the separate species which constitute the vegetation of permanent pastures. The management of grazing, if it is to yield maximum production without lasting injury to the pasture sward, must take into account not only the nutritive needs and grazing habits of livestock, but also the seasonal development of pasture grasses and the influence of grazing on this development.

Kentucky bluegrass (*Poa pratensis* L.) is an important pasture grass, not only in Missouri, but in the entire northeastern quarter of the United States. This study of its seasonal growth habits and seasonal variations in chemical composition was undertaken because it was believed that a better understanding of the seasonal variations in its development would clarify some problems of permanent pasture management.

PLAN OF THE EXPERIMENT

Location, Climate, and Soil

This study of seasonal growth and changes in the composition of Kentucky bluegrass was made at Columbia, Missouri, the approximate latitude and longitude of which is 39°N. and 92°W. The altitude is 740 feet. A climatic summary for Columbia is given in Table 1.

The soil on which the experimental plots were located is a modified phase of Putnam Silt Loam, with an A-horizon varying from 8 to 12 inches in depth and a B-horizon of plastic clay that is neither quite so compact nor so thick as that normally found in more level and more typical phases of this soil type. The composition and some physical properties of this soil are shown in Table 2.

TABLE 1. AVERAGE TEMPERATURE AND PRECIPITATION AT COLUMBIA, MISSOURI, FOR A 51-YEAR PERIOD AND AVERAGE RELATIVE HUMIDITY FOR A 24-YEAR PERIOD

Month	Temperature °F.			Precipitation in inches	Relative humidity at noon in per cent
	Ave. daily Maximum	Ave. daily Minimum	Average		
January	39.5	20.0	30.9	1.98	65
February	41.7	23.0	32.4	1.77	62
March	53.9	33.1	42.9	2.95	54
April	65.2	44.2	54.8	3.73	51
May	74.9	53.7	65.0	4.64	54
June	83.8	63.0	73.4	4.74	55
July	88.9	66.5	77.3	3.16	49
August	87.7	65.2	76.3	3.86	53
September	80.4	58.0	69.4	4.38	53
October	69.0	46.1	56.9	2.65	52
November	54.2	33.8	44.1	2.38	58
December	42.4	25.0	34.0	1.83	65
Year	65.1	44.4	54.8	38.07	56

Average date of last killing frost in spring, April 13.
Average date of first killing frost in autumn, October 18.
Average length of frost-free period, 188 days.

TABLE 2. SOME PROPERTIES OF THE SOIL ON WHICH THE EXPERIMENTAL PLOTS OF BLUEGRASS WERE LOCATED

Soil property	Depth of sample	
	0-6 inches	6-12 inches
Moisture equivalent (%)	32.0	30.6
p H (determined with glass electrode)	6.2	4.9
Total exchangeable bases (M. E. /100 gms. soil)	16.1	14.4
Readily decomposable organic matter (%)	2.0	1.5
Available phosphorus (lbs. per acre)*	60.0	31.0

*Determined by procedure given on page 6, Missouri Agricultural Experiment Station Bulletin 404.

The fertility of this soil, which was not naturally high, had been fairly well maintained over a 20-year period, during which the land had grown wheat, oats, and corn, by the use of both green and barnyard manure, and liberal applications of phosphate fertilizer. Two years before bluegrass was sown, the soil was limed and seeded to sweet clover which was plowed back into the soil.

Two field plots, comparable in fertility and soil type and separated by not more than 100 feet, were used. For convenience they will be referred to as blocks A and B.

Establishing the Grass

Block A was fertilized with 4-16-4 fertilizer applied at the rate of 500 pounds per acre and seeded to Kentucky bluegrass at the rate of 25 pounds of seed per acre September 10, 1935. The stand of grass, estimated at 71 per cent in the spring of 1936, was materially reduced by the severe drought and high temperatures of that year. Although the bluegrass in this block was quite sparse at the beginning of the 1937 growing season, it had thickened to almost a complete vegetative cover by mid-summer.

Block B was seeded at the rate of 36 pounds of seed per acre September 3, 1936. This block had been plowed in the fall of 1935, and a seeding that failed completely because of severe drought had been made in the spring of 1936. The 4-16-4 fertilizer was applied at the rate of 400 pounds per acre with both the spring and fall seeding, a total of 800 pounds of this material.

Irrigation

In this region, high summer temperatures are usually accompanied by a soil moisure deficiency. In order to separate the effects of summer drought and summer temperatures on the growth and composition of bluegrass, block A was watered whenever soil sampling indicated a need for additional soil moisture, but block B was not irrigated during summer periods. According to original plans, block B was not to be irrigated at any time, but when a severe fall drought occurred in 1939 for the third consecutive year, watering this block was started September 22 and continued through October. In the following year, 1940, irrigation of block B began on September 1, and was repeated as needed throughout September and the first week of October. Irrigation of block A usually began in late June or early July and was continued at approximately weekly intervals until October.

Application of Nitrate

The addition of nitrogenous fertilizer after the grass had been established was not included in original plans, but the herbage yields obtained from all plots during 1938 were so small that sodium nitrate was applied at the rate of 300 pounds per acre to 5 plots in block A on September 3, 1938, and to the same plots at the rate of 100 pounds per acre at monthly intervals from March 15 to October 15, 1939. The very large increase in growth that resulted from the application of nitrate showed that a deficiency of available nitrogen was seriously limiting the growth of untreated grass. In 1940, sodium nitrate was applied at the rate of 100 pounds per acre to all plots in block A on March 15, and semi-monthly thereafter at the rate of 50 pounds per acre until September 30, when the final application was made. All plots in block B received during 1940 the same nitrate treatments given plots in block A except that the nitrate was not applied July 1, 15, or 31.

Measurement of Environmental Factors

Air temperature and relative humidity were measured by a Julien P. Friez hygrothermograph located in a Weather Bureau type of instrument shelter, the floor of which was 6 inches above bluegrass sod.

Soil temperatures were automatically recorded every hour by means of a Leeds and Northrup temperature recorder to which electrical resistance thermometers were connected by leaded cables.

Rainfall was measured by a Julian P. Friez Fergusson type rain gauge that used weekly charts.

Samples of soil, taken weekly or more often, depending on the distribution of rainfall, were dried at 110° C. to determine their moisture content.

Measurements of day length were obtained from records of the Weather Bureau.

Evaporation from a free water surface was measured daily during 1937, 1938, and 1939.

Clipping Treatments

Block A was divided into 10 plots, each of which was 6 feet wide and 50 feet long. Alternate plots were mowed semi-monthly with the bottom knife of the mower set 1 inch above the ground (1-inch cut). The other 5 plots were cut semi-monthly with the bottom knife set at the 2½-inch level (2½-inch cut).

Block B was divided into 24 plots, each of which was 6 feet wide and 50 feet long. Eight of these plots were mowed semi-monthly at the 1-inch level, 8 were mowed semi-monthly at the 2½-inch level, and the remaining 8 plots were cut at the 2½-inch level when the grass was in full bloom and again at the end of the growing season.

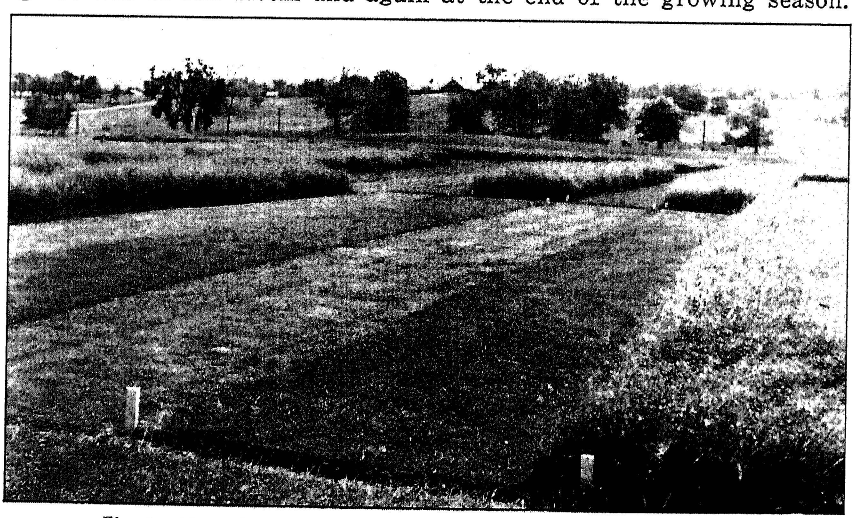

Fig. 1.—Kentucky bluegrass plots, block B, photographed May 28, 1937.

The latter plots will hereafter be referred to as hay-cut plots. Thus there were in block B, 8 replicates for each clipping treatment arranged in 8 randomized blocks. All clippings were removed from the plots.

Figure 1 shows the arrangement of plots and the condition of the grass sward in block B on May 28, 1937.

Measuring Herbage Yields

Herbage yields of all mowed plots were determined by harvesting 2 strips 22 inches wide and 50 feet long from each plot by means of a 22-inch-cut Ideal Majestic power mower equipped with a basket to catch the clipped grass. The harvested herbage from each plot was weighed green and its dry weight determined by drying a sample in an oven at 170°F. Immediately after the plots were mowed for the determination of herbage yields, the portions of each plot not included in the 2 harvested strips were mowed to the same level.

Herbage production in the hay-cut plots was measured during 1937 by harvesting one yard-square sample from each of the 8 plots at monthly intervals. The grass in the sampled area was cut to the 1-inch level. Each successive sample was taken from an area not previously sampled and the growth increment was calculated by deducting the dry weight of the sample harvested at the beginning of each monthly period from that harvested at the end of the same period. All hay-cut plots were cut with a horse drawn hay mower on June 12, 1937, and the cut grass was raked from the plots.

In each of the years after 1937, the hay-cut plots were mowed to the 2½-inch level at full bloom stage and at the end of the growing season.

Measuring Root and Rhizome Development

In order to measure seasonal changes in the dry weight and composition of bluegrass roots and rhizomes, 2 cylindrical cores of sod 6 inches in diameter and 6 inches deep were taken from every plot on each date of sampling. The nature and operation of the tool that was designed and constructed for this special purpose[2] is illustrated in Figure 2. After the spot to be sampled had been scraped clean with a hoe, (A) the steel cylinder, was driven into the sod to a depth of about 8 inches, (B) the driver was removed and the cylinder was pulled from the ground with its contained core of sod, (C) the sod core was pushed from the cylinder, and (D) this sod core was placed in the cutting mold and reduced to a 6-inch length.

After being dug, each sample of sod was soaked in water until nearly saturated and the soil was washed away by a stream of water from a hose nozzle. Sods were washed over screens of 3/16-inch mesh hardware cloth to prevent the loss of all except the smallest fragments of roots and rhizomes broken loose by the force of the water. All foreign material that could not be removed by washing

[2]Designed and constructed by Gustaf Tornsjo, Chief Technician, University of Missouri.

Fig. 2.—Method of sampling Kentucky bluegrass roots and rhizomes.

was picked out with forceps. After rhizomes had been separated from roots, both were dried at 170°F. and the dry weight of each was determined.

Stuckey (47) who worked with Kentucky bluegrass and other grasses states that, "To date, no satisfactory test has been devised to determine whether mature grass roots are living or dead unless the roots are disintegrating." Even if living and dead roots could be distinguished, they could not be separated. After the first year, therefore, all sod samples included an unknown fraction of roots that had developed in previous years. Losses in dry weight and changes in composition of older, dead or non-functioning roots would tend to obscure changes in weight and composition that were occurring in younger, functioning roots, if the measurement of these changes had to be based on the dry weight and chemical analysis of the entire root mass.

In order to avoid this difficulty, a somewhat modified method of sampling seasonal changes in the development of roots and rhizomes was used during 1940 in addition to the original method of sampling.

During early December, 1939, 10 holes 6 inches in diameter and approximately 8 inches deep were dug in each plot with the root sampler previously described. The holes thus made with as little disturbance as possible to the contiguous grass sod were filled immediately with an alluvial soil that was high in fertility and darker in color than the soil on which the grass plots were located. This difference in soil color made it possible, to locate during 1940 the exact boundary between the "soil plug" and the old sod. By using the same cylinder with which the holes had been dug, soil plugs with the roots and rhizomes that had grown into them from the surrounding sod could be taken up during the 1940 growing season. These samples will be referred to hereafter as "soil plugs" in order to distinguish them from "sods," the samples taken from previously undisturbed sod.

Chemical Analysis

Composite samples of oven-dried herbage, oven-dried roots, and oven-dried rhizomes, when the quantity of the latter was sufficiently large, were stored in fruit jars until they could be analyzed.

All chemical analyses were made by the Department of Agricultural Chemistry, University of Missouri. The procedure used for the determination of the starch and sugar content of roots and rhizomes was the modified Shaffer-Somogyi method described by Heinz and Murneek (28). For the determination of lignin, the analytical procedure developed by E. W. Crampton was followed with slight modifications. All other chemical determinations were made by methods described in Chapter 27 of the Methods of Analysis of the Association of Official Agricultural Chemists, Fourth Edition.

Statistical Analysis

The significance of measured differences in the dry weight of roots and rhizomes that resulted from either date of sampling or clipping treatment was tested by Fisher's analysis of variance as described by Snedecor (43). Joe D. Baldridge planned and supervised the statistical analyses.

AIR AND SOIL TEMPERATURES

Experimental Results

Air and soil temperatures were measured primarily to determine their relation to seasonal variations in the growth and composition of Kentucky bluegrass. The relation of soil temperature to concomitant air temperature, the temperature of soil at different depths, and the influence of vegetative cover and soil moisture on soil temperature may also be of interest because: (a) air temperature is less difficult to measure than soil temperature and records of air temperature are more generally available; yet (b) the temperature of the soil near its surface seems (13) to exert a greater influence on the growth of Kentucky bluegrass than air temperature or soil temperature at deeper levels; and (c) soil temperature has been reported to be influenced by the amount of grass cover (9, 10), its moisture content (31), and depth (31, 40, 41, 42).

Soil temperatures were measured ½ inch deep[3] in bare soil; ½ inch, 2 inches, and 6 inches deep in bluegrass sod where the grass was maintained at a height of 2 to 3 inches by mowing; ½ inch deep in bluegrass that was mowed and also watered whenever rainfall was insufficient to keep the soil moist; and ½ inch deep in bluegrass that was not cut during the growing season.

TABLE 3. FOUR-YEAR AVERAGES OF DAILY MEAN, DAILY MAXIMUM, AND DAILY MINIMUM TEMPERATURES OF THE AIR, AND 1/2 INCH DEEP UNDER MOWED BLUEGRASS AND UNDER BARE SOIL, FROM 1937 TO 1940

	Average temperature °F.								
	Mean			Maximum			Minimum		
Period	Air	Mowed bluegrass	Bare soil	Air	Mowed bluegrass	Bare soil	Air	Mowed bluegrass	Bare soil
March 1-15	41	41	42	50	44	52	33	38	35
March 16-31	48	46	46	57	52	58	39	43	40
April 1-15	48	48	48	57	53	59	41	43	39
April 16-30	57	56	56	66	63	69	48	51	47
May 1-15	60	62	62	70	70	76	51	57	52
May 16-31	67	70	70	77	78	84	59	64	60
June 1-15	70	74	73	79	82	87	62	68	64
June 16-30	76	78	78	84	88	93	66	72	68
July 1-15	79	81	83	90	92	102	68	74	70
July 16-31	78	81	81	90	91	100	68	74	69
Aug. 1-15	80	82	82	92	93	102	69	75	70
Aug. 16-31	75	78	78	87	88	96	66	72	67
Sept. 1-15	76	76	77	88	85	96	64	70	65
Sept. 16-30	65	68	66	80	77	85	53	62	55
Oct. 1-15	62	64	63	77	72	79	52	60	53
Oct. 16-31	56	57	56	69	63	70	46	52	47

Four-year averages of daily mean, daily maximum, and daily minimum air temperatures are given in Table 3 and illustrated

[3]The depth in each case refers to the depth of the upper side of the thermometer bulb, a cylindrical tube ½ inch in diameter and 6 inches long, lying in a horizontal position.

graphically in Fig. 3. For comparison, averages of daily mean, daily maximum and daily minimum soil temperatures measured ½ inch

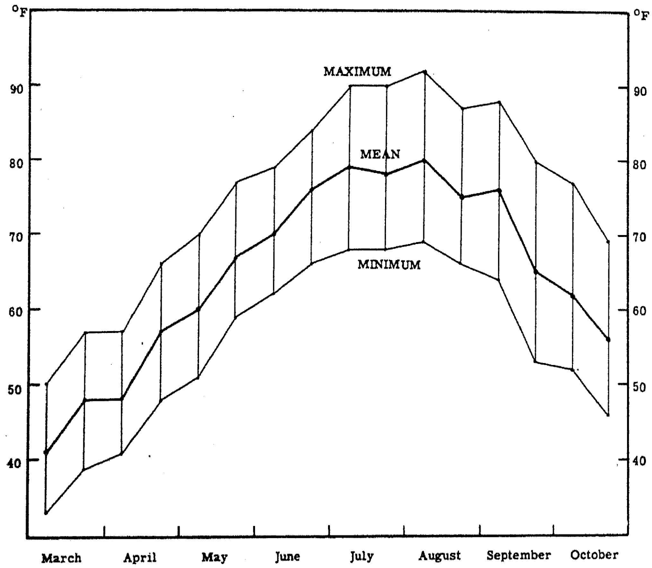

Fig. 3.—Four-year averages of daily mean, daily maximum, and daily minimum air temperatures, from 1937 to 1940.

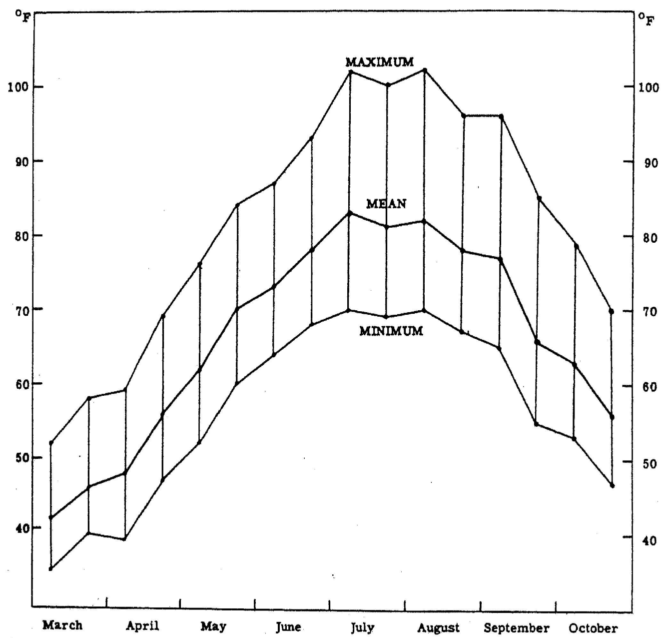

Fig. 4.—Four-year averages of daily mean, daily maximum, and daily minimum temperatures of bare soil at a depth of ½ inch, from 1937 to 1940.

below the surface of a mowed bluegrass sod and at the same depth in bare soil are also included in Table 3. Curves in Figs. 4 and 5 show seasonal trends and the average diurnal spread between daily minima and daily maxima of these soil temperatures.

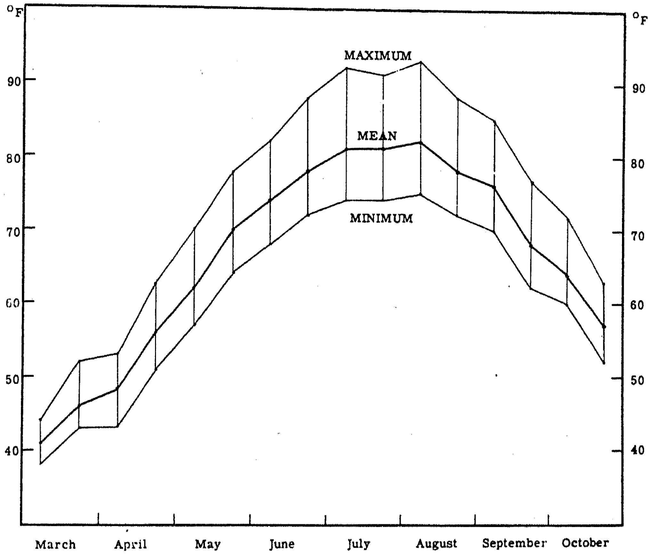

Fig. 5.—Four-year averages of the daily mean, daily maximum, and daily minimum temperatures of a mowed bluegrass sod at a depth of ½ inch, from 1937 to 1940.

TABLE 4. FOUR-YEAR AVERAGES OF THE DAILY MEAN, DAILY MAXIMUM, AND DAILY MINIMUM SOIL TEMPERATURES AT DEPTHS OF 1/2, 2, AND 6 INCHES IN MOWED BLUEGRASS SOD, 1937 TO 1940

	Soil temperature °F.								
	Mean			Average maximum			Average minimum		
Period	1/2 in. deep	2 in. deep	6 in. deep	1/2 in. deep	2 in. deep	6 in. deep	1/2 in. deep	2 in. deep	6 in. deep
March 1-15	41	41	41	44	43	41	38	39	40
March 16-31	46	47	46	52	50	48	43	44	44
April 1-15	48	48	48	53	52	50	43	44	46
April 16-30	56	56	56	63	61	58	51	52	54
May 1-15	62	62	62	70	68	65	57	58	60
May 16-31	70	69	68	78	75	71	64	65	66
June 1-15	74	73	73	82	79	76	68	68	70
June 16-30	78	78	77	88	85	81	72	73	75
July 1-15	81	81	80	92	88	84	74	74	76
July 16-31	81	80	80	91	88	84	74	74	77
Aug. 1-15	82	82	82	93	90	84	75	76	78
Aug. 16-31	78	78	78	88	85	81	72	73	76
Sept. 1-15	76	76	76	85	83	80	70	71	74
Sept. 16-30	68	68	70	77	75	72	62	64	67
Oct. 1-15	64	64	66	72	70	68	60	61	64
Oct. 16-31	57	58	59	63	62	61	52	54	57

Differences in average soil temperatures found to occur at different depths below the surface of a mowed bluegrass sod are shown by the data in Table 4 and the curves in Figs. 5, 6, and 7.

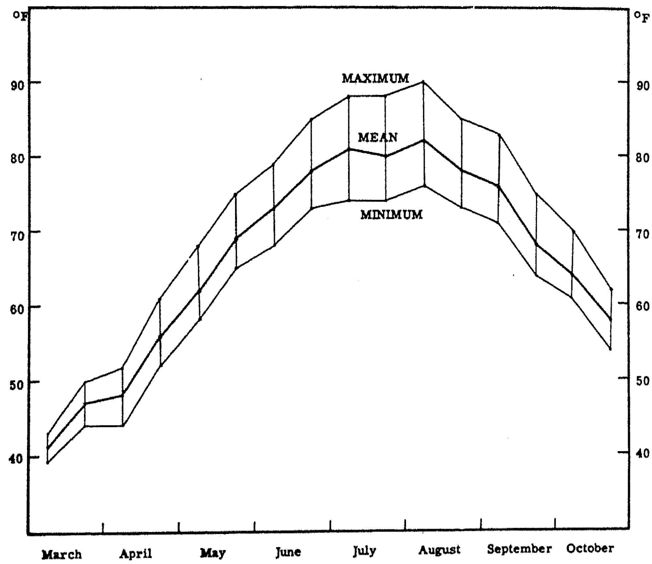

Fig. 6.—Four-year averages of daily mean, daily maximum, and daily minimum soil temperatures 2 inches deep in mowed bluegrass sod, from 1937 to 1940.

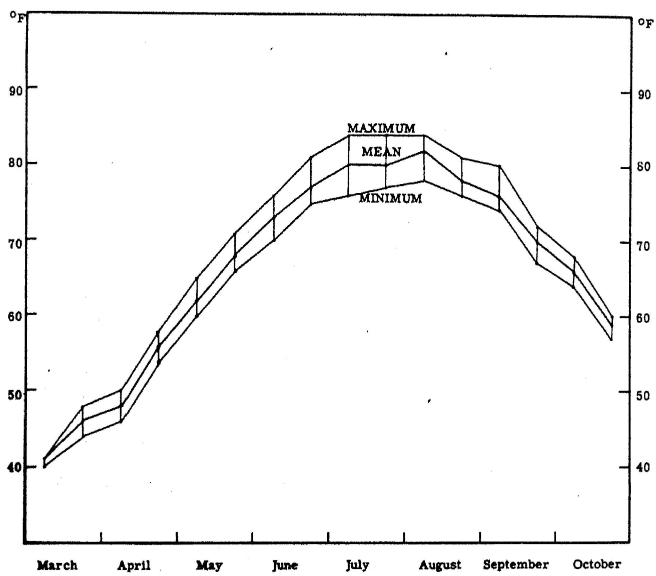

Fig. 7.—Four-year averages of daily mean, daily maximum, and daily minimum soil temperatures 6 inches deep in mowed bluegrass sod, from 1937 to 1940.

Data in Table 5, and curves in Fig. 8, show the influence of summer irrigation on average mean, maximum and minimum soil temperatures under mowed bluegrass.

TABLE 5. FOUR-YEAR AVERAGES OF THE DAILY MEAN, DAILY MAXIMUM, AND DAILY MINIMUM SOIL TEMPERATURES 1/2 INCH DEEP IN WATERED AND NOT WATERED BLUEGRASS SOD, FROM 1937 TO 1940

	Soil temperature °F.					
	Mean		Average maximum		Average minimum	
Period	Not watered	Watered	Not watered	Watered	Not watered	watered
March 1-15	41	40	44	43	38	38
March 16-31	46	46	52	50	43	42
April 1-15	48	47	53	52	43	43
April 16-30	56	56	63	62	51	51
May 1-15	62	62	70	69	57	57
May 16-31	70	69	78	76	64	64
June 1-15	74	72	82	80	68	67
June 16-30	78	77	88	85	72	71
July 1-15	81	79	92	88	74	73
July 16-31	81	80	91	88	74	73
Aug. 1-15	82	80	93	88	75	74
Aug. 16-31	78	77	88	84	72	72
Sept. 1-15	76	74	85	82	70	70
Sept. 16-30	68	68	77	75	62	63
Oct. 1-15	64	64	72	70	60	60
Oct. 16-31	57	57	63	62	52	53

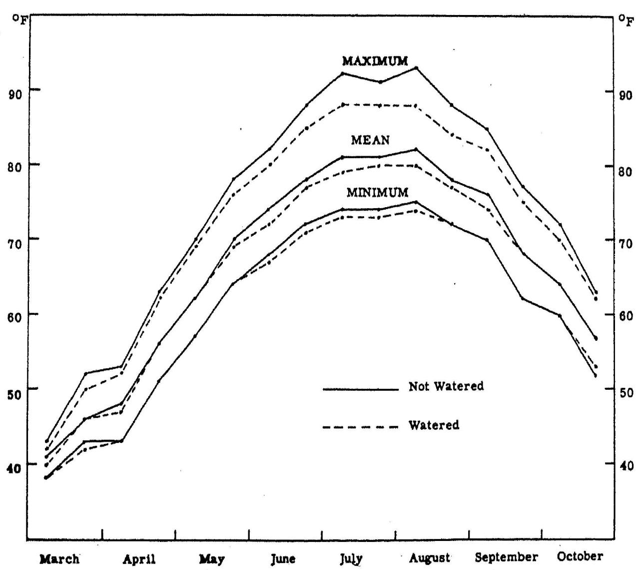

Fig. 8.—Four-year averages of the mean, daily maximum, and daily minimum soil temperatures ½ inch deep in watered and not-watered bluegrass sod, 1937 to 1940.

The extent to which a tall, dense growth of uncut bluegrass insulated the soil against heat absorption and heat loss during summer is indicated by data in Table 6 and curves in Figs. 9, 10 and 11.

TABLE 6. SEMI-MONTHLY AVERAGES OF SOIL TEMPERATURES 1/2 INCH DEEP IN MOWED BLUEGRASS SOD AND IN BLUEGRASS THAT WAS NOT MOWED, DURING 1940

	Soil temperature 1/2 inch deep					
	Mean		Average maximum		Average minimum	
Period	Uncut grass	Mowed grass	Uncut grass	Mowed grass	Uncut grass	Mowed grass
March 1-15	36	37	38	37	36	36
March 16-31	45	44	51	50	41	41
April 1-15	50	50	55	56	46	46
April 16-30	52	52	56	58	48	48
May 1-15	59	60	64	67	54	55
May 16-31	62	64	65	70	59	60
June 1-15	69	75	72	82	67	70
June 16-30	70	76	73	84	68	71
July 1-15	70	76	73	87	66	69
July 16-31	75	82	79	91	72	75
Aug. 1-15	74	80	77	90	71	74
Aug. 16-31	69	74	72	83	67	69
Sept. 1-15	66	72	69	81	64	65
Sept. 16-30	64	69	68	78	61	62
Oct. 1-15	62	64	65	72	59	59
Oct. 16-31	58	60	62	67	56	55

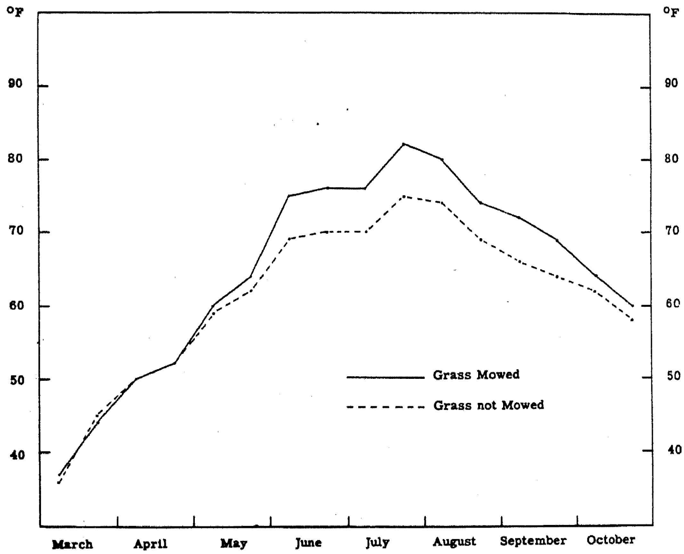

Fig. 9.—Semi-monthly averages of mean soil temperatures ½ inch deep in mowed and uncut bluegrass during 1940.

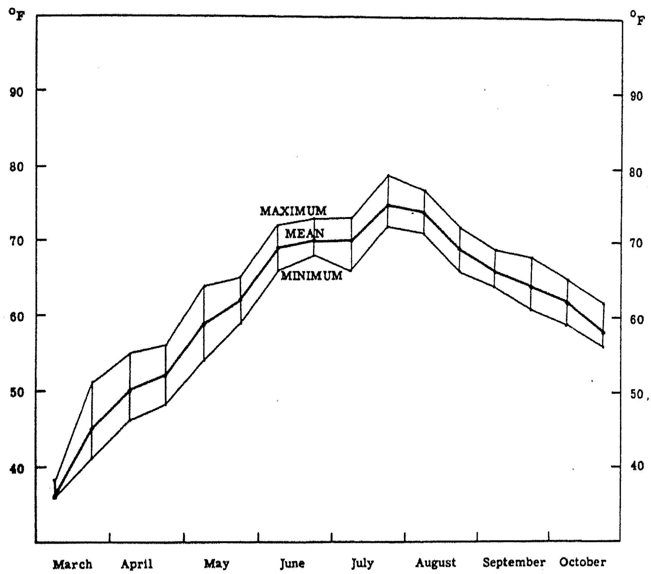

Fig. 10.—Semi-monthly averages of the mean, daily maximum, and daily minimum soil temperatures ½ inch deep under bluegrass that was not cut during 1940.

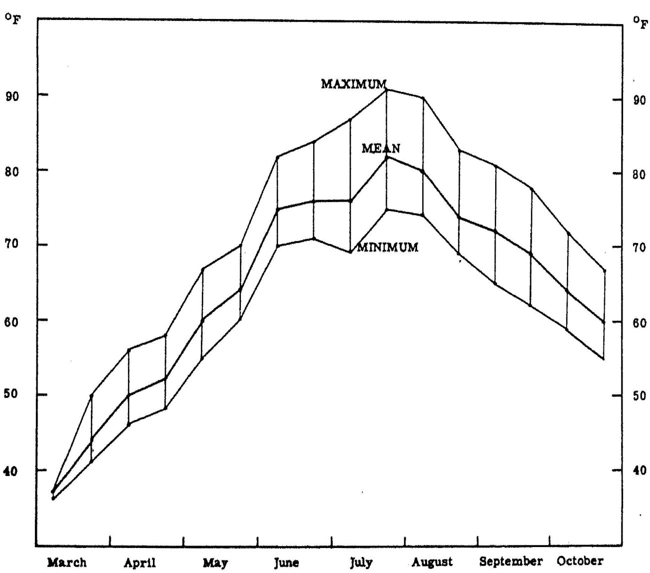

Fig. 11.—Semi-monthly averages of mean, daily maximum, and daily minimum soil temperatures ½ inch deep under mowed bluegrass, 1940.

Discussion

Air and soil temperature measurements reported here indicate that in determining the relation of seasonal variations in the growth and composition of grass to average mean temperatures, air temperatures would be as useful as soil temperatures. If, however, the object should be to determine the specific temperature that acted as the conditioning factor in growth or chemical change, soil temperature should be measured because maximum and minimum soil temperatures differed materially from corresponding air temperatures and even mean soil temperatures differed slightly from those of the air during some periods of the growing season.

Mean soil temperatures did not differ much at different depths within the ½- to 6-inch zone during any semi-monthly period from March 1 to October 31. The average maximum temperature was lower and the average minimum temperature higher as the depth increased from ½- to 6 inches below the surface of the soil.

A moderate vegetative cover, such as mowed bluegrass, insulated the soil against heat absorption and heat loss so that, as compared with bare soil, the diurnal range was reduced, although the mean temperature was nearly the same. When the soil was covered by a heavy growth of grass, heat absorption was retarded sufficiently to lower the mean as well as the maximum soil temperature during the summer period.

Watering the sod lowered maximum, mean, and minimum soil temperatures during the summer. The effect of irrigation on soil temperature at the ½-inch depth probably would have been greater if water had been applied more often than at weekly intervals since the surface soil dried rapidly between waterings.

RAINFALL, EVAPORATION, AND SOIL MOISTURE

Rainfall from March 1 to October 31, for the years 1937 to 1940, is shown in Table 7. Although rainfall was below normal during some of the months from March 1 to June 30, each year (Table 7), the growth of the grass was not noticeably limited by a deficiency of soil moisure prior to July 1. Very little rain fell during the first half of July in any of the 4 years and the rain that fell during the latter half of July was usually torrential in character, so that much of the water was lost as runoff.

TABLE 7. PRECIPITATION FROM MARCH 1 TO NOVEMBER 30

Period	Precipitation in inches				
	1937	1938	1939	1940	51 year ave.*
March 1-15	1.29	3.68	1.44	1.60	2.95
March 16-31	0.78	1.91	1.05	0.27	
April 1-15	1.08	3.08	3.61	0.70	3.73
April 16-30	2.69	1.16	0.94	2.06	
May 1-15	2.78	3.07	2.94	0.20	4.64
May 16-31	1.94	3.51	1.73	3.59	
June 1-15	3.98	4.94	1.13	2.82	4.74
June 16-30	0.02	3.85	1.73	3.30	
July 1-15	0.21	0.04	0.00	0.00	3.16
July 16-31	2.33	2.14	2.04	1.47	
Aug. 1-15	0.52	0.16	5.47	3.54	3.86
Aug. 16-31	1.00	1.53	2.80	2.37	
Sept. 1-15	0.30	1.16	0.12	0.00	4.38
Sept. 16-30	1.33	0.20	0.38	0.19	
Oct. 1-15	0.91	0.12	0.80	2.08	2.65
Oct. 16-31	0.77	0.50	0.63	0.55	
Nov. 1-15	1.57	4.57	0.85	0.24	2.38
Nov. 16-30	0.70	0.00	3.15	2.16	
Total	24.20	35.62	30.81	27.14	32.49

* Weather Bureau, Columbia, Missouri.

During 1937 and 1938, droughts that started in July continued without a break until the end of October. In 1939 and 1940, August rainfall was above normal, but in each of these years this temporary interruption of summer drought was followed by severe fall drought that continued through September and October in 1939 and through September in 1940. Irrigation of block B was begun in September of 1939, when it became apparent that normal rainfall during the autumn months might not occur in any year during the investigation, as proved to be what actually happened.

During each of the years that evaporation from a free water surface was measured, 1937 to 1939, a high rate of evaporation occurred during the period of lowest rainfall, July 1 to 15 (Table 8).

TABLE 8. EVAPORATION OF WATER FROM A FREE WATER SURFACE

Period	Evaporation in inches per day.		
	1937	1938	1939
April 1-15	.094	.123	.109
April 16-30	.139	.179	.126
May 1-15	.104	.136	.167
May 16-31	.167	.111	.136
June 1-15	.099	.153	.157
June 16-30	.198	.162	.164
July 1-15	.213	.225	.240
July 16-31	.190	.174	.196
Aug. 1-15	.197	.245	.180
Aug. 16-31	.183	.185	.133
Sept. 1-15	.178	.139	.227
Sept. 16-30	.158	.135	.175

Under the combined influence of low rainfall and high evaporation that occurred during mid-summer, a moisture deficiency developed quickly in bluegrass sod (Table 9). Since a rain-free period of two

TABLE 9. SOIL MOISTURE CONTENT OF BARE SOIL AND MOWED KENTUCKY BLUEGRASS SOD DURING PERIODS OF HIGH TEMPERATURE AND DEFICIENT RAINFALL

Date sampled	Soil moisture content in per cent					
	Bare soil			Mowed bluegrass		
	0-6 in.	6-12 in.	12-24 in.	0-6 in.	6-12 in.	12-24 in.
1937						
June 19	19.4	23.1		21.4	21.9	
June 26	18.3	23.5		12.1	17.1	
July 3	16.0	23.7		9.0	12.4	
July 10	13.6	22.4		7.9	11.3	
July 15	14.4	22.1	22.1	6.7	9.4	14.1
1938						
June 29	19.3	23.7		21.3	25.5	
July 5	17.4	22.9		13.8	19.5	
July 12	15.2	22.2		9.7	15.0	
July 16	14.5	21.6		9.2	14.0	

weeks was sufficient to reduce the water supply of the soil under bluegrass from near the optimum for plant growth to a deficiency level, Kentucky bluegrass can seldom escape the effects of summer drought in mid-western states.

During a year of severe drought, 1936, Kentucky bluegrass used a large part of the available moisture to a depth of 24 inches, but was able to use only a small part of the moisture in the 24 to 36 inch layer of soil (Table 10). In soils that do not have as large a clay fraction in the 12 to 36-inch layer as this soil, moisure might be absorbed by bluegrass more readily at greater depths and summer droughts might not so quickly affect grass yields. These results agree, however, with those of Karraker and Bortner (30) who found at Lexington, Kentucky in the dry years of 1930 and 1936, that Kentucky bluegrass was able to absorb a much smaller fraction of the water from the 2 to 3-foot layer than from the upper 24 inches of soil.

TABLE 10. SOIL MOISTURE CONTENT AT DIFFERENT DEPTHS UNDER BARE SOIL AND KENTUCKY BLUEGRASS SOD JULY 9, 1936

	Soil moisture content in per cent			
	0-6 in.	6-12 in.	12-24 in.	24-36 in.
Bare soil	10.5	20.2	19.8	20.8
Ky. bluegrass sod	5.0	8.3	9.5	14.8

HERBAGE YIELDS

Experimental Results

Data in Table 11 show: (1) the effect of clipping treatment on annual herbage yields of bluegrass that was watered during each summer (block A) and that was exposed to drought each summer without irrigation (block B); (2) the relation of annual herbage yields to the age of the bluegrass sward; and (3) the effect of applications of sodium nitrate on herbage yields.

Nitrogen deficiency was suspected as the cause of the greatly reduced productivity of bluegrass during 1938 so that sodium nitrate

TABLE 11. ANNUAL YIELDS OF HERBAGE OBTAINED FROM KENTUCKY BLUEGRASS BY 3 DIFFERENT MOWING TREATMENTS

	Pounds dry herbage per acre			Minimum difference required for significance between clipping treatments.	
	1-inch cut	2 1/2-in. cut	Hay-cut	1% level	5% level
Block A					
1937	1623	1112		383	263
1938	516	208		215	148
1939	2143*	1580*		440	290
1940	2171*	2046*		221	146
Block B					
1937	2833	2254	5857	620	447
1938	508	310	1280	214	154
1939	382	141	501	76	55
1940	1286**	900**	1601**	195	140

* Sodium nitrate applied monthly during 1939 at the rate of 100 pounds per acre from March 15 to October 15 and semi-monthly during 1940 at the rate of 100 pounds per acre on March 15, and at the rate of 50 pounds per acre from April 1 to September 30.

** Sodium nitrate applied at the rate of 100 pounds per acre March 15 and semi-monthly at the rate of 50 pounds per acre from April 1 to June 15 and from August 15 to September 30.

was applied at the rate of 300 pounds per acre to 5 plots of block A in September. The response of the grass to added nitrogen was so striking that nitrate was applied to the same plots during 1939, and to all plots of blocks A and B during 1940, with the results shown in Table 11.

Yields of herbage harvested at semi-monthly intervals from 2½-inch cut plots followed the same seasonal trend as semi-monthly yields obtained from 1-inch cut plots. Since yields obtained from 1-inch cut plots were larger, these are presented in Tables 12 to 15,

TABLE 12. YIELDS OF HERBAGE HARVESTED FROM KENTUCKY BLUEGRASS PLOTS MOWED SEMI-MONTHLY TO THE 1-INCH LEVEL, AND SOME ENVIRONMENTAL FACTORS THAT INFLUENCE SEASONAL PRODUCTION

1937

	Block A			Block B			
Period	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Average day length hrs.
March 16-31	40			40			12.3
April 1-15	45		23.6	44	444	22.4	13.0
April 16-30	54	261	21.7	54	879	22.0	13.5
May 1-15	62	264	21.7	62	801	21.3	14.0
May 16-31	71	221	17.3	70	468	18.3	14.5
June 1-15	70	247	20.6	70		23.7	14.8
June 16-30	80	214	20.4	80	126	20.7	14.9
July 1-15	82	150	15.9	82	55	7.9	14.8
July 16-31	80	59	16.4	81	45	9.0	14.4
Aug. 1-15	80	59	14.3	83	8	6.4	14.0
Aug. 16-31	80	64	17.4	82	7	9.1	13.4
Sept. 1-15	74	50	16.7	76		6.9	12.7
Sept. 16-30	66	22	19.2	66		12.0	12.1
Oct. 1-15	62	12	18.7	62		14.3	11.5
Oct. 16-31	52		19.4	52		14.6	11.0
Total		1623			2833		

Block A. Grass seeded in fall of 1935, watered as needed during 1937.
Block B. Grass seeded in fall of 1936, not watered during 1937.

TABLE 13. YIELDS OF HERBAGE HARVESTED FROM KENTUCKY BLUEGRASS PLOTS MOWED SEMI-MONTHLY TO THE 1-INCH LEVEL, AND SOME ENVIRONMENTAL FACTORS THAT INFLUENCE SEASONAL PRODUCTION

1938

	Block A			Block B			
Period	Ave. soil temp. 1/2 in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Average day length hrs.
March 16-31	53	34		54	74		12.3
April 1-15	47	7	26.5	48	20	27.7	13.0
April 16-30	64	27	23.3	64	65	23.0	13.5
May 1-15	64	35	24.0	64	63	24.8	14.0
May 16-31	70	67	24.7	70	91	24.5	14.5
June 1-15	74	56	24.0	75	73	24.3	14.8
June 16-30	78	40	19.7	78	45	20.8	14.9
July 1-15	82	42	17.5	84	18	13.5	14.8
July 16-31	80	51	20.6	81	23	14.3	14.4
Aug. 1-15	84	35	20.1	88	6	8.5	14.0
Aug. 16-31	80	29	21.4	82	12	11.3	13.4
Sept. 1-15	78	51	22.4	79	12	10.1	12.7
Sept. 16-30	69	28	23.3	68	6	9.9	12.1
Oct. 1-15	68	10	22.5	69		7.0	11.5
Oct. 16-31	58	4	20.3	58		7.3	11.0
Total		516			508		

Block A-watered as needed.
Block B-not watered.

along with soil temperature, soil moisure, and day length, to show seasonal variations in herbage production in relation to variations in these environmental factors.

TABLE 14. YIELDS OF HERBAGE HARVESTED FROM KENTUCKY BLUEGRASS PLOTS MOWED SEMI-MONTHLY TO THE 1-INCH LEVEL, AND SOME ENVIRONMENTAL FACTORS THAT INFLUENCE SEASONAL PRODUCTION

1939

Period	Block A			Block B			
	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Average day length hrs.
March 16-31	48	14	24.2	48	9	26.2	12.3
April 1-15	48	39	24.5	48	9	28.0	13.0
April 16-30	56	112	22.8	56	34	26.8	13.5
May 1-15	64	261	23.7	64	81	22.0	14.0
May 16-31	72	369	24.7	74	55	21.0	14.5
June 1-15	74	225	24.0	76	45	18.6	14.8
June 16-30	77	255	22.2	80	64	18.2	14.9
July 1-15	80	80	20.9	82	4	10.5	14.8
July 16-31	78	177	22.7	81	12	10.9	14.4
Aug. 1-15	76	138	22.5	78	10	14.4	14.0
Aug. 16-31	74	253	20.8	76	29	22.1	13.4
Sept. 1-15	76	57	18.5	78	9	11.9	12.7
Sept. 16-30	67	103	23.1	69	12	12.3	12.1
Oct. 1-15	62	31	22.3	63	5	21.5	11.5
Oct. 16-31	58	29	21.4	58	4	23.1	11.0
Total		2143			382		

Block A. Watered as needed. Sodium nitrate was applied at the rate of 300 pounds per acre September 1938, and at the rate of 100 pounds per acre per month from March to October, 1939.

Block B. Watered only after September 22. No nitrate added.

TABLE 15. YIELDS OF HERBAGE HARVESTED FROM KENTUCKY BLUEGRASS PLOTS MOWED SEMI-MONTHLY TO THE 1-INCH LEVEL, AND SOME ENVIRONMENTAL FACTORS THAT INFLUENCE SEASONAL PRODUCTION

1940

Period	Block A			Block B			
	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Ave. soil temp. 1/2-in. °F.	Yield dry herbage per acre lbs.	Ave. soil moisture 0-6 in. %	Average day length hrs.
March 16-31	44	14		44	5		12.3
April 1-15	50	45	18.4	50	17	20.7	13.0
April 16-30	52	166	18.8	52	64	20.9	13.5
May 1-15	60	330	17.2	60	188	20.3	14.0
May 16-31	64	271	19.6	64	164	22.8	14.5
June 1-15	75	204	21.8	75	190	23.6	14.8
June 16-30	76	176	20.7	76	192	20.7	14.9
July 1-15	76	140	20.0	76	33	11.2	14.8
July 16-31	82	131	22.9	82	14	10.4	14.4
Aug. 1-15	80	159	22.9	80	33	6.8	14.0
Aug. 16-31	74	185	23.6	74	135	22.5	13.4
Sept. 1-15	72	112	18.9	72	109	20.2	12.7
Sept. 16-30	69	112	19.5	69	71	20.8	12.1
Oct. 1-15	64	93	21.9	64	52	23.2	11.5
Oct. 16-31	60	33	18.1	60	19	20.0	11.0
Total		2171			1286		

Block A. Plots watered as needed. Sodium nitrate applied at the rate of 100 pounds per acre March 15, and semi-monthly at the rate of 50 pounds per acre from March 31 to September 30.

Block B. Plots watered only after September 1. Sodium nitrate applied at the rate of 100 pounds per acre March 15, and semi-monthly at the rate of 50 pounds per acre from March 31, to June 15, and August 15 to September 30.

Discussion

The large yield of herbage produced by fall sown Kentucky bluegrass during its first full season of growth was never approached during any subsequent year, even when the sod was irrigated and fertilized with sodium nitrate. This agrees with results reported by Albert (2) who found that Kentucky bluegrass seeded in the late summer of 1923 and clipped only twice annually thereafter, yielded 8,800 pounds of air dry herbage in 1924, the first harvest year, but only 1,368 pounds in the second year, 1925. Sprague, Farris, and Cathcart (45) located some plots in an old bluegrass pasture and mowed them every 14 days during the growing seasons of 1929, 1930, and 1931. They found that yields obtained during 1931 were much smaller than those obtained during 1929, although rainfall was both more abundant and better distributed during 1931. Graber and coworkers (25) found that 2 years of frequent cutting reduced the productivity of a well established bluegrass sod to less than that of adjacent bluegrass cut but once annually at maturity. Although young bluegrass appeared in this study to be more productive than older bluegrass, repeated mowing and the removal of the clippings probably also had a cumulative adverse effect on herbage production.

The reduced productivity of legume-free grass swards, the so-called "sod-bound" condition, is now generally accepted as being due largely to a deficiency in available nitrogen. That nitrogen deficiency retarded the growth of Kentucky bluegrass in all untreated plots of blocks A and B during 1938 and 1939 is clearly demonstrated by the increased yields that resulted from applications of sodium nitrate. The failure of the nitrate treatments plus irrigation to restore to the grass its first-year productivity indicates, however, that some factor or factors other than nitrogen deficiency retarded growth after the first year. Benedict (5) has presented data which indicate that an accumulation of growth inhibiting substances derived from dead roots may be at least partly responsible for the thinning out and the reduced productivity of bromegrass. Sprague (44) found that when roots accumulated in the upper soil because their decomposition was retarded by high soil acidity, top growth by Kentucky bluegrass was hampered. This may account for the greater response to added nitrogen shown during 1940 by the bluegrass in block A, for, as will be shown later, the quantity of roots and rhizomes in block A was considerably less than in block B.

The lower yields that were obtained from semi-monthly mowings, as compared with yields that resulted when the grass was cut only once or twice annually, agree with the findings of Albert (2), Biswell and Weaver (7), Brown and Munsell (12), Ellet and Carrier (19) and Sprague and Graber (46). Yields from plots mowed at semi-monthly intervals were larger when cut at the 1-inch level than when cut at the 2½-inch level. This result agrees with those reported by Mortimer and Ahlgren (35) and by Graber (24).

Large seasonal variations in the productivity of pastures consisting partly or largely of Kentucky bluegrass have been reported by many workers. Brown and Munsell (12) found that 61 to 75 per cent of the total pasture production occurred before July 16 in Connecticut. The usual zenith period of growth was May 16 to June 15. Peak periods of herbage production for other regions have been reported as being: June 5 to 11 and August 7 to 13 in Vermont (18); May, June and September in Michigan (50); May 23 to June 5, and August 12 to 26 in New York (29); May and September in New Jersey (45); and, May in Maryland (51). Only in Vermont did herbage production during late summer or fall equal or exceed that of the spring zenith period of growth.

An increase in the supply of available nitrogen either by the associated growth of white clover (29) or by spring applications of nitrogenous fertilizers (12, 51) accentuated the May-June peak of herbage production. Frequent cutting (12), on the other hand, leveled seasonal variations but also reduced the total yield.

After the first year, Kentucky bluegrass "greened up" during late March and early April, but made relatively little top growth at average soil temperatures below 50° F. In the first year after seeding, herbage production was large at an average soil temperature of only 44° (Table 12). When the average soil temperature rose above 50° during the latter half of April, herbage production increased and usually reached a maximum level during the first half of May at an average soil temperature of 60° to 64°. In 1938, an unseasonable cold spell during the first half of April, after early growth had been stimulated by unusual warmth in March, gave the grass a setback from which it was slow to recover. This probably accounts for herbage production reaching its maximum during that year in the latter half of May at an average soil temperature of 70° (Table 13).

Brown and Munsell (12) have pointed out that the period of maximum herbage production can be postponed by late, heavy applications of nitrogenous fertilizer. Applications of sodium nitrate to plots 7 and 9 of block A at the rate of 100 pounds per acre on May 15 and June 15, 1939, explain the relatively large yields of herbage obtained at the end of each of those months (Table 14). The increased yields of herbage obtained June 15 and 30, 1940, from block B (Table 15), after the spring peak had apparently been passed during the first half of May was also probably due to the cumulative effect of semi-monthly applied nitrate to sod that was deficient in available nitrogen.

These results and the observed fact that, in this latitude, reproductive shoots of Kentucky bluegrass begin to elongate in late April and the inflorescences begin to emerge from the enveloping leaves about the first of May, indicate that maximum top growth is associated with reproduction. Average soil temperatures of 60°

to 64°, at which maximum top growth was usually made, are not necessarily optimum temperatures for herbage production. In fact, the relatively large growth of herbage produced by plots 7 and 9 of block A during the latter half of June, 1939, at an average soil temperature of 77° F. (Table 14), and that produced by block B throughout June of 1940 (Table 15), at average soil temperatures of 75° and 76°, indicate that the optimum temperature for top growth by bluegrass may be well above 60°. In thermo-regulated growth chambers, Kentucky bluegrass has been found to make its largest top growth at some temperature between 80° and 90°, when cut at monthly intervals (13).

Except where production was stimulated during late May and June by applications of sodium nitrate to nitrogen deficient sod (block A, Table 14 and block B, Table 15) a decline in herbage production began in late May or early June, and continued until a minimum level was reached in July, at average soil temperatures of 80° F. or above. Sprague and his co-workers (45) concluded that the good growth made by grass during May was due largely to an accumulation in the soil of an adequate moisture supply, and that the reduced yield of herbage in July and August was due to a chronic soil moisture shortage during those months. It is true that soil moisture deficiency checked the growth of unwatered bluegrass in July and the first half of August during each of 4 successive years, but an abundant supply of moisture failed to prevent a summer decline in herbage production by irrigated bluegrass, although much more herbage was produced during July in watered than in unwatered plots. Results presented here indicate, therefore, that the reduction in productivity of Kentucky bluegrass that occurs during summer is, at least in the southern part of the region in which it grows, partly due to super-optimal summer temperatures, and would occur even if summer rainfall were fully adequate.

Under the conditions of this experiment, 50° F. appeared to be the critical mean temperature below which top growth was very slow in bluegrass sods more than one year old. No definite optimum or maximum temperature for herbage production was established, but at average soil temperatures above 75° F., the combined factors of high temperature and repeated defoliation had a depressing influence on herbage production that was cumulative.

If supplies of soil moisture and available nitrogen were adequate, as in block A during 1939, and in both blocks during 1940, herbage production rose to a second but smaller peak during the latter half of August, when the average soil temperature was 74°. During September, herbage production declined regardless of the nitrogen and water supply, and the amount of top growth made during October was always quite small.

Sprague and his co-workers (45) and Brown and Munsell (12) concluded that the poor growth made by grass in October was due principally to unfavorably cool weather. In these studies, average soil temperatures during October were nearly the same as those at which maximum top growth was made during May. Average day length, on the other hand, was 2.5 hours shorter during the first half of October and 3 hours shorter during the second half of October than during the first half of May. These results, therefore, support the conclusions of Evans and Watkins (20) that the characteristic differences between late spring and fall growth of Kentucky bluegrass are partly due to the difference in the length of day of these two periods. Tincker (49) also found that *Dactylis glomerata* and *Phleum pratense* produced less dry weight of top growth at a day length of 10 hours than at a longer photoperiod. Orchard grass plants grown by Stuckey (48) under a 16-hour photo-period developed leaves that were longer and more erect than those developed by plants exposed to a day length of 8 hours.

Summary

Kentucky bluegrass seeded in September not only was more productive during its first year but the young grass also began growth earlier in the spring at a lower soil temperature than during any subsequent year.

Top growth, after the first year, was very slow during March or early April at mean temperatures below 50° F., but increased rapidly during April and reached a maximum during the first half of May at mean temperatures of 60° to 64°. This spring peak of herbage production was associated with reproductive processes. Herbage production declined at summer temperatures near or above 80°, even if the grass was irrigated. If the supply of moisture was adequate, a second but much smaller peak of herbage production occurred in the latter half of August at a mean temperature of 74° F. Herbage yields declined during September and were quite small during October although mean soil temperatures during October were nearly the same as during the first half of May.

COMPOSITION OF THE HERBAGE

Experimental Results

The crude protein, crude fiber, ether extract, nitrogen-free extract, calcium, and phosphorus contents of Kentucky bluegrass herbage harvested from 1-inch cut plots of block A during 1938 and 1939 are shown by data in Table 16. Seasonal trends in the calcium and phosphorus content of herbage from these plots are also shown by the curves in Fig. 12. The bluegrass in block A was irrigated as often as necessary to maintain an adequate supply of moisture in the soil, during the summer and autumn.

The crude protein, crude fiber, ether extract, nitrogen-free extract, calcium, and phosphorus contents of herbage harvested from 1-inch cut plots of block B during 1937, 1938, and 1939 are shown

TABLE 16. COMPOSITION OF KENTUCKY BLUEGRASS HERBAGE HARVESTED FROM THE 1-INCH CUT PLOTS OF BLOCK A, 1938 AND 1939

Date Sampled		Percentage of the dry matter Crude protein	Crude fiber	Ether extract	N-free extract	Ca	P
1938							
March	31	16.2	17.2	2.6	46.8	.524	.329
April	29	16.6	18.6	3.2	49.4	.453	.403
May	30	15.9	22.4	2.2	48.1	.482	.422
June	29	16.2	23.1	4.2	45.8	.574	.562
July	30	18.1	22.5	4.5	45.6	.686	.576
August	30	19.6	21.5	4.8	45.3	.583	.558
September	29	20.0	19.4	3.5	44.6	.610	.611
October	31	18.4	17.6	5.0	45.4	.755	.456
1939							
April	15	17.1	18.4	4.1	48.8	.434	.362
April	30	16.9	18.8	3.8	48.8	.459	.391
May	15	14.6	23.2	3.1	49.9	.325	.385
May	30	13.8	23.4	3.0	50.9	.473	.372
June	15	14.2	25.5	3.2	48.0	.582	.427
June	30	16.0	25.2	3.0	47.4	.523	.443
July	31	17.7	24.6	3.1	46.4	.665	.503
August	30	20.3	22.1	3.2	45.1	.499	.602
September	30	21.5	21.7	3.0	43.6	.749	.536
October	31	18.5	16.7	3.4	47.6	.581	.443

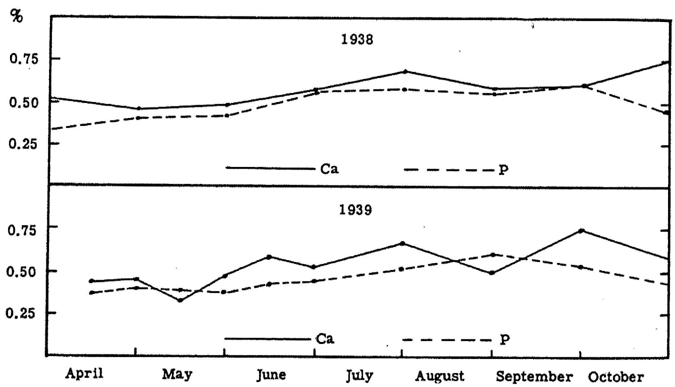

Fig. 12.—Seasonal variations in the calcium and phosphorus content of the herbage harvested from the 1-inch cut plots of block A.

by data in Table 17. Since these plots were not watered during the summer, the influence of drought on the composition of the herbage is indicated. A comparison of the composition of herbage harvested during 1937 with that of herbage harvested from the same plots during subsequent years also demonstrates that the first-year grass contained higher percentages of crude protein and lower percentages of crude fiber than older grass.

Seasonal variations in the composition of Kentucky bluegrass herbage that might be expected to occur under grazing conditions are perhaps better represented by the analyses of samples obtained from block B during 1940 (Table 18, Figure 13). This grass re-

TABLE 17. COMPOSITION OF KENTUCKY BLUEGRASS HERBAGE HARVESTED FROM THE 1-INCH CUT PLOTS OF BLOCK B, 1937 TO 1939

Date Sampled		Percentage of dry matter					
		Crude protein	Crude fiber	Ether extract	N-free extract	Ca	P
1937							
April	15	29.8	14.1	4.4	43.1	.510	.476
April	30	27.7	19.0	3.0	40.6	.395	.456
May	27	24.4	20.5	3.4	41.5	.412	.373
June	28	22.9	22.2	3.2	39.2	.563	.288
July	29	21.2	24.0	3.3	42.3	.552	.286
August	30	19.4	26.8	2.6	43.2	.570	.245
1938							
March	31	21.8	17.7	2.8	45.5	.391	.385
April	29	17.6	20.3	3.0	46.5	.377	.391
May	30	15.8	22.6	2.4	46.5	.409	.365
June	29	16.3	23.0	4.2	44.8	539	.453
July	30	17.4	21.1	3.2	47.8	.695	.512
August	30	17.7	23.3	4.8	45.4	.871	.432
September	29	19.5	18.8	4.4	48.2	.708	.444
1939							
April	15	19.1	17.5	3.3	49.3	.364	.360
April	30	18.2	19.8	3.5	46.2	.435	.380
May	15	13.3	24.5	2.8	49.7	.264	.364
May	30	14.6	24.7	3.1	46.6	.414	.350
June	15	14.8	25.4	3.1	46.4	.487	.394
June	30	13.3	26.5	3.3	46.2	.638	.360
July	31	15.8	25.5	4.1	45.1	.753	.536
August	30	19.5	21.5	3.1	44.7	.603	.665
October	15	18.9	18.4	2.6	48.1	.619	.511

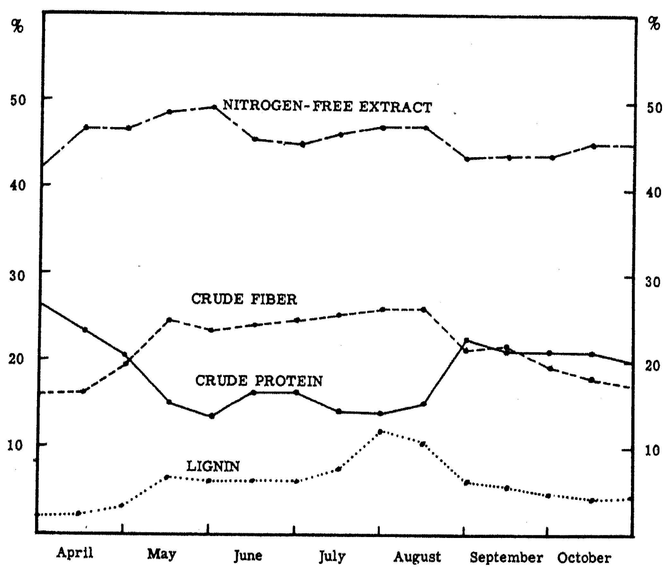

Fig. 13.—Seasonal variations in the composition of Kentucky bluegrass herbage harvested from the mowed plots of block B during 1940.

ceived sodium nitrate (100 pounds per acre March 15 and 50 pounds per acre thereafter) applied 2 weeks before the harvesting of each

TABLE 18. COMPOSITION OF KENTUCKY BLUEGRASS HERBAGE HARVESTED FROM THE MOWED PLOTS OF BLOCK B DURING 1940

Date Sampled		Percentage of dry matter					
		Crude protein	Crude fiber	Lignin	N-free extract	Ca	P
April	1	26.4	15.9	2.13	42.1	.413	.364
April	15	23.4	16.2	2.38	46.8	.444	.376
May	1	20.4	19.4	3.29	46.6	.376	.332
May	15	15.0	24.6	6.85	48.6	.306	.352
May	31	13.6	23.6	6.35	49.2	.302	.275
June	15	16.4	24.2	6.41	45.6	.378	.335
July	1	16.4	24.7	6.31	45.0	.452	.374
July	15	14.2	25.5	7.77	46.4	.506	.313
July	31	13.9	26.1	12.11	47.1	.628	.357
August	15	15.2	26.2	10.79	47.1	.489	.434
August	30	22.6	21.5	6.20	43.6	.462	.544
September	14	21.3	21.8	5.78	43.9	.523	.537
October	1	21.3	19.6	4.94	44.0	.506	.472
October	15	21.2	18.1	4.20	45.3	.430	.440
October	31	20.1	17.3	4.56	45.2	.541	.373

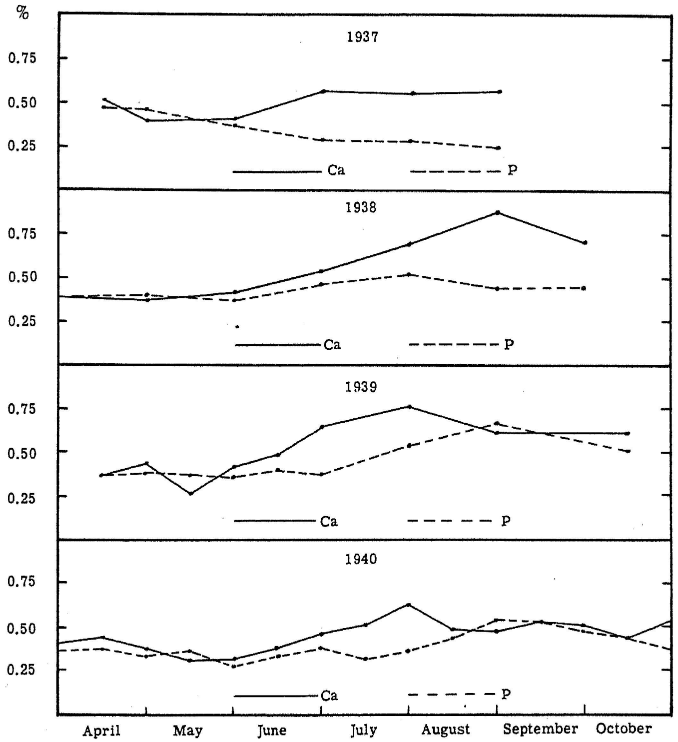

Fig. 14.—Seasonal variations in the calcium and phosphorus content of Kentucky bluegrass herbage harvested from mowed plots, 1937 to 1940.

herbage sample, except those taken July 15 and 31, and August 15. The supply of soil moisture, maintained by irrigation after September 1, was fully adequate during all of the growing season except the normally dry period from July 1 to August 10. Composite samples of herbage were taken during 1940 from both 1-inch and 2½-inch cut plots, so that all mowed plots were represented.

Seasonal trends in the calcium and phosphorus content of bluegrass herbage harvested semi-monthly from block B are illustrated in Fig. 14 for each of the 4 years, 1937 to 1940.

The calcium and phosphorus content of herbage harvested from block B was influenced by severe drought from early July until the final samples were taken during 1937 and 1938. In 1939 and 1940, the drought that began in July was broken by rains during August, and the grass was irrigated as needed during September and October.

TABLE 19. COMPOSITION OF KENTUCKY BLUEGRASS HERBAGE HARVESTED FROM MOWED PLOTS COMPARED WITH THAT OF HERBAGE HARVESTED FROM HAY-CUT PLOTS, BLOCK B, 1937 TO 1940

Plots Sampled	Date Sampled	Percentage of dry matter					
		Crude protein	Crude fiber	Lignin	N-free extract	Ca	P
	1937						
1-inch cut	May 27	24.4	20.5		41.5	.412	.373
Hay-cut	May 27	13.8	33.2		42.2	.260	.315
	1938						
1-inch cut	May 30	15.8	22.6		46.5	.409	.365
Hay-cut	May 18	9.1	29.2		50.4	.244	.257
	1939						
1-inch cut	May 30	14.6	24.7		46.6	.414	.350
Hay-cut	May 20	9.4	30.8		48.3	.247	.288
1-inch cut	Oct. 15	18.9	18.4		48.1	.619	.511
Hay-cut	Dec. 5	7.1	28.7		48.5	.366	.180
	1940						
Mowed	May 31	13.6	23.6	6.35	49.2	.302	.275
Hay-cut	May 24	10.8	29.1	7.17	49.2	.230	.286
Mowed	Oct. 31	20.1	17.3	4.56	45.2	.541	.373
Hay-cut	Nov. 18	10.8	24.6	7.52	49.8	.425	.244

Data in Table 19 show the composition of bluegrass herbage harvested when in full bloom as contrasted with the composition of clippings taken on comparable dates from plots mowed semi-monthly. The composition of grass harvested from the hay-cut plots December 5, 1939, and November 18, 1940, is also compared with that of clippings saved from the final cutting of the semi-monthly mowed plots in each of those years.

Discussion

Limitations of the standard feed analysis when applied to forage crops are generally recognized, but as yet methods by which the nutritive value of forages can be more accurately determined chemically have not been devised. Thus Brown (11) recommends that feed analyses of pasture herbage should be made according to methods approved by the American Association of Official Agricultural Chemists. He adds that animals seem able to make about the same response to feeds varying considerably in their chemical composition so that exact interpretations of many chemical analyses into terms of animal production will have to await further advances in the field of animal nutrition. Maynard (33) states that the separation of the higher carbohydrates by the feed chemist into crude fiber and nitrogen-free extract has a variable significance as regards digestibility since the relative amounts of starch, lignin, and hemicellulose in the nitrogen-free extract and of lignin in the crude fiber may vary considerably. Norman (37) observes that carefully conducted digestibility trials not infrequently show the coefficient of digestibility of crude fiber to equal that of nitrogen-free extract, and he expresses the opinion that, "It would be an important advance if the determination of the crude fiber fraction and its use in expressing composition were abandoned as inadequate, unreliable, and misleading."

Both Norman (37) and Crampton and Forshaw (15) considered lignin to be the most important single fraction determining the digestibility of a forage. Norman showed that the fructosan content of at least one grass varied enough to influence materially its nutritive value. A very small increase in the lignin content (6, 15, 33, 37) apparently results in a markedly lower digestibility.

Ellenberger, Newlander, and Jones (18) report that samples of herbage taken at monthly intervals from closely grazed Vermont pastures showed a comparatively uniform seasonal composition. This might have been due to the presence in the sward of several different species so that changes in composition of one might have obscured opposing changes in the composition of another.

Data presented here show that relatively close and frequent defoliation did not prevent seasonal changes in the fractions of crude protein, crude fiber, lignin, calcium, and phosphorus in the herbage of Kentucky bluegrass grown in pure stand. Repeated cutting back of the tops did reduce materially the extent of changes in percentages of these constituents from the start of growth to full bloom, and from late May to the end of the growing season. Growth and digestion studies made by Crampton and Forshaw (15) with rabbits indicated that marked seasonal changes in nutritive value occurred in the herbage of a mixture of Kentucky bluegrass, redtop, and wild white clover even when the sward was mowed closely about once every 10 days. This progressive falling off in nutritive value during summer months apparently was associated with an increase in the lignin content of the forage (6, 15, 33) which occurred most rapidly as the rate of growth declined, either at maturity or as the result of some unfavorable weather condition.

Norman (37) found the fructosan content of ryegrass to increase until May 26, about the time of full emergence of the heads, after which it decreased. Both the cellulose and lignin fractions increased steadily from May 12 to September 21, but the cellulose-lignin ratio narrowed gradually from 7.3:1 at the beginning to 3:1 at the end of this period.

Results presented here agree with those of Bennett (6) and Mortimer and Ahlgren (35) in that the nitrogen content of Kentucky bluegrass declined as the plant approached maturity, and this change occurred, although to a smaller degree, even when the grass was mowed often enough to retard flowering and to prevent seed production. The increase in percentage of crude protein that occurred in late August appears to have been associated with the increased production and growth of new shoots.

The high nitrogen content of herbage produced by bluegrass during the first spring after its establishment (1937) was never equaled by herbage harvested from the same plots during subsequent years when the stand was older, even when sodium nitrate was applied. Thus the crude protein content of herbage harvested April 15, 1937, from a first-year stand of Kentucky bluegrass was 29.8 per cent as compared with 23.4 per cent in herbage harvested April 15, 1940, from the same plots when the grass was 3 years older. The difference at the end of May was even greater, 24.4 per cent of crude protein in the herbage of first-year grass as compared with only 13.6 per cent in the herbage of 4-year old grass. The yields of crude protein harvested in the herbage were 132 and 114 pounds per acre in mid-April and late May from young grass, 4 and 22 pounds per acre from the 4-year-old grass.

The increase in crude fiber content of herbage that occurred during April and May was probably related to rising temperature for the crude fiber content of the herbage of Kentucky bluegrass grown in thermo-regulated growth chambers was found to increase materially as the temperature rose from 40° to 70° F. (13), and to increase slightly with a further rise to a characteristic summer level of 80°. In spite of the probable relation of the crude fiber content to temperature, its relation to advancing maturity can not be completely discounted.

Whatever significance the residue referred to as nitrogen-free extract might have had with respect either to the nutritive value of the herbage or to the development of the grass, its seasonal variations were relatively small and appeared to be more closely associated with concurrent variations in the crude fiber and crude protein fractions than with any measured environmental factors.

Tyson (50) reports that the calcium content of the herbage of a Kentucky and Canada bluegrass mixture increased from spring to August and decreased in the fall, while the phosphorus content was highest in the spring and lowest during the mid-season, when the growth of the grass usually was inhibited by hot, dry weather. Mortimer and Ahlgren (35) found that when moisture was not a limiting factor, the phosphorus content of regularly cut bluegrass increased from spring to a maximum during July and August and then dropped slightly in the fall, but that the calcium content increased steadily from spring to fall.

Results reported here show that the calcium and phosphorus content of herbage from regularly mowed plots of Kentucky bluegrass either remained nearly constant or decreased slightly from mid-April to late May. During this period the calcium phosphorus ratio remained close to unity. The calcium content of the herbage increased from late May to the end of July, and decreased during August, unless that month was very dry, as it was during 1937 and 1938. Changes in calcium content of the herbage during September and October were relatively small, except in 1938, when the supply of moisture in the soil was quite low.

Percentages of phosphorus also showed a general tendency to rise with rising temperature from the end of May to the end of August, and this upward trend was not checked by a moderate moisture deficiency, but it was reversed by conditions of severe drought, such as occurred during August in 1937 and 1938. The widest spread in the ratio of calcium to phosphorus usually occurred at the end of July, except when conditions of severe moisture deficiency resulted in a still wider spread in late August.

Black, Knapp, and Douglas (8) state that the requirements of beef cattle for calcium ranges from 0.2 per cent for fattening cattle to 0.4 per cent for growing calves or cows in late pregnancy, that the approximate phosphorus requirement ranges from 0.2 to 0.3 per cent of the dry matter, and that a satisfactory ratio of calcium to phosphorus seems to be between 2:1 and 1:2. Meigs (34) reports that dairy cows giving liberal quantities of milk should receive rations containing not less than 0.25 per cent of calcium and from 0.25 to 0.30 per cent of phosphorus. The only sample of herbage found to fall substantially below the minimum standards for either calcium or phosphorus was that taken December 5, 1939, from hay-cut plots (Table 19). Pure stands of Kentucky bluegrass can, therefore, be expected to satisfy the requirements of cattle for both calcium and phosphorus throughout the growing season, if the grass is kept eaten down and if supplies of these minerals in the soil are not deficient, but the accumulated summer and fall growth of bluegrass saved for winter grazing may be deficient in phosphorus. It is true that by the end of August, 1937 the phosphorus content of the herbage was only 0.24 per cent and the calcium phosphorus ratio was 2.32:1, but the drought which continued unbroken through both July and August was so severe that only 15 pounds of dry herbage per acre was harvested from 1-inch cut plots during all of August. Under such conditions, little grass would have been left to supply any of the feed requirements of grazing animals by the time the phosphorus content of the herbage became a limiting factor.

Kentucky bluegrass herbage harvested at full bloom, had a much lower protein content and contained higher percentages of crude fiber and lignin than herbage harvested at comparable dates from plots kept short by repeated mowing. The calcium and phosphorus content of bluegrass hay was also lower than that of regularly mowed grass. These results agree with those reported by Ellet and Carrier (19) in showing that the increase in dry weight of mature grass over frequently clipped grass consists largely of fiber and other nitrogen-free substances, and do not encourage the practice of deferring grazing late in the spring in order to encourage a greater production of dry matter.

Samples of herbage taken from hay-cut plots December 5, 1939 and November 18, 1940, consisted of herbage that had accumulated after the plots had been cut in the latter part of May. They may be considered to represent bluegrass that had been protected from grazing during the summer and fall in order to save it for winter pasture. The analyses show that this "winter" grass contained no more protein and even less phosphorus than bluegrass hay. It contained less crude fiber, but slightly more lignin than bluegrass hay cut in late May at the full-bloom stage of development.

Summary

The following seasonal changes occurred in the chemical composition of the herbage of Kentucky bluegrass that was adequately supplied with moisture and fertilized semi-monthly with sodium nitrate from the first of April to June 15 and from mid-August to late October and that was mowed semi-monthly:

1. The protein content declined from 26.4 per cent April 1, to 15.0 per cent May 15, and fluctuated moderately above and below this level until August 15. It rose to 22.6 per cent in late August and remained near this relatively high level through September and October.

2. Crude fiber varied from 15.9 per cent on April 1 to 26.2 per cent on August 15, its seasonal variations being directly opposite to those of crude protein.

3. The lignin content was relatively low during April (2.1 to 3.3 per cent), increased to a medium level May 15 (6.8 per cent) and remained almost constant until July 1 (6.3 per cent). It rose to high levels during the summer drought (7.8 per cent July 15, 12.1 per cent July 31, 10.8 per cent August 15), then fell sharply with the resumption of growth following August rains (6.2 per cent August 30) and continued to decline gradually until October 15.

4. Variations in the nitrogen-free extract content were relatively small and without definite seasonal trends.

5. Percentages of both calcium and phosphorus were relatively low during April and May after which the percentage of both minerals increased. Calcium reached its highest level at the end of July and phosphorus at the end of August. Both the phosphorus and calcium content of bluegrass herbage remained relatively high, with little spread, from mid-August to mid-October. Minimum percentages of both occurred May 31, when the percentage of calcium was 0.302 and that of phorphorus was 0.275.

Kentucky bluegrass hay cut at the full bloom stage and the aftermath cut in November or December contained lower percentages of crude protein and higher percentages of crude fiber and lignin than herbage harvested on comparable dates from plots mowed semi-monthly. Bluegrass hay also contained less calcium and phosphorus than the clippings from plots moved semi-monthly.

Herbage harvested during the first spring from fall-sown bluegrass contained a higher percentage of crude protein than herbage harvested from the same plots on comparable dates during any subsequent year.

Severe droughts greatly depressed the phosphorus but not the calcium content of blue grass herbage.

ROOT AND RHIZOME DEVELOPMENT

Experimental Results

Average dry weights of roots and rhizomes measured in the plots of block A for each sampling date during the 4-year period 1937 to 1940 are recorded in Table 20. No samples were taken in 1937 before June 3, because of the sparsity of the stand of bluegrass which had been injured severely by heat and drought during 1936.

TABLE 20: DRY WEIGHT OF ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS, BLOCK A, SAMPLED TO A DEPTH OF 6 INCHES DURING THE GROWING SEASONS OF 1937 TO 1940

Date Sampled	Pounds per acre in upper 6 inches of sod			
	Roots		Rhizomes	
	1-inch cut	2 1/2-inch cut	1-inch cut	2 1/2-inch cut
1937				
June 3	1237	1183	153	155
July 2	1169	1110	454	548
Aug. 2	1134	1306	479	695
Sept. 2	1203	1281	572	768
Sept. 30	1247	1418	709	954
Oct. 28	1369	1535	719	1120
1938				
March 29	1487	1621	646	887
June 1	1707	1929	754	1279
July 11	1613	1942	819	1090
Aug. 28	1353	1605	646	850
Sept. 29	1327	1485	611	771
Oct. 31	1591	1835	627	977
1939				
March 4	1770	1809	655	918
May 2	1995	2249	625	1001
June 19	1673	1970	722	795
Aug. 1	1465	1543	534	827
Sept. 20	1294	1361	433	576
Oct. 19	1099	1254	198	319
Nov. 27	1211	1240	250	346
1940				
March 11	1428	1433	303	382
June 25	1565	1570	347	362
Sept. 2	1027	1095	255	367
Oct. 8	1056	978	244	328
Nov. 19	1330	1090	377	352

Although it was not possible to distinguish between dead and living roots, dead rhizomes could be identified by their black or gray color and their flaccid texture. A few dead rhizomes were detected in samples taken from block A as early as April, 1938, but the number of such rhizomes was relatively small until the summer of 1939. Dead rhizomes were not separated and discarded until October 19, 1939, when the quantity was so large that it was evident that they should no longer be included in samples to be weighed and saved for chemical analysis. Dead rhizomes were removed from all samples obtained on and after October 19, 1939, and were discarded before dry weights were determined. A part, therefore, of the decrease in rhizome weight that occurred between September 20 and October 19, 1939, (Table 20) resulted from the fact that no dead rhizomes were included in weighed samples after September 20. Dead rhizomes weighed so little when dry that their removal affected the total weight less than might be expected.

In these studies of the development under field conditions of Kentucky blue grass roots and rhizomes, we are primarily interested in seasonal changes in their dry weight and chemical composition. Statistical analysis of the experimental results showed that the interaction between clipping treatment and date of sampling was not significant. It was possible, therefore, to determine seasonal changes in the weight of roots and rhizomes by averaging all samples obtained on any given date from all plots, regardless of mowing

TABLE 21. SEASONAL CHANGES IN THE DRY WEIGHT OF THE ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS, BLOCK A, SAMPLED TO A DEPTH OF 6 INCHES, 1937 TO 1940

Year	Growth Period		Pounds per acre	
	Dates	Days	Roots	Rhizomes
		Sod Samples		
1937	June 3-July 2	29	- 70	347**
	July 3-Sept. 2	62	102	169*
	Sept. 3-Oct. 28	56	210**	250**
1938	March 29-June 1	63	264**	250**
	June 2-Sept. 29	121	-412**	-325**
	Sept. 30-Oct. 31	32	307**	111
1939	March 4-May 2	59	332**	27
	May 3-Aug. 1	91	-618**	-133*
	Aug. 2-Sept. 20	50	-176*	-176*
	Sept. 21-Oct. 19	29	-151	-246**
	Oct. 20-Nov. 27	39	49	40
1940	March 11-June 25	106	138*	12
	June 26-Sept. 2	69	-507**	- 43
	Sept. 3-Oct. 8	36	- 44	- 25
	Oct. 9-Nov. 19	42	193**	78
		Soil Plug Samples		
1940	March 6-June 25	111	856**	112**
	June 26-Sept. 2	69	- 61**	59
	Sept. 3-Oct. 8	36	76**	41
	Oct. 9-Nov. 19	42	334**	171**

* Changes in weight that exceed the minimum difference required for significance at the 5% level.

**Changes in weight that exceed the minimum difference required for significance at the 1% level.

TABLE 22. DRY WEIGHT OF ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS, BLOCK B, SAMPLED PERIODICALLY DURING THE GROWING SEASONS OF 1937 TO 1940, TO A DEPTH OF 6 INCHES

	Pounds per acre in upper 6-inches of sod					
	Roots			Rhizomes		
Date Sampled	1-in. cut	2 1/2-in. cut	Hay-cut	1-in. cut	2 1/2-in. cut	Hay-cut
1937						
April 1	1751	1751	1751			
May 1	1770	1863	1922			
June 1	1897	1966	1741	29	29	15
June 30	1980	1873	1853	78	54	54
Aug. 2	1902	2039	1917	137	98	132
Aug. 31	1927	2049	1922	122	122	108
1938						
April 1	1932	1888	2059	168	187	224
June 9	1971	2122	2152	396	424	437
July 12	2127	2147	2269	437	474	442
Aug. 30	2024	2264	2396	406	489	514
Oct. 18	1897	2137	2210	372	478	505
1939						
March 7	1936	2269	2484	363	494	498
May 10	2293	2435	2704	419	459	493
June 21	2181	2308	2479	438	484	498
Aug. 8	2171	2293	2435	465	549	509
Sept. 24	2097	2347	2347	424	488	438
Oct. 25	1922	1917	2122	358	394	425
Nov. 30	1897	2289	2281	398	519	507
1940						
March 6	1868	2029	2186	362	474	475
May 20	2249	2504	2518	405	504	631
June 30	2156	2528	2504	509	714	899
Sept. 5	1721	1995	2147	460	670	831
Oct. 14	2000	2254	2117	597	753	968
Nov. 21	1946	2088	2455	660	817	1071

treatment. By doubling (block A) or tripling (block B) in this way the number of samples on which each average weight was based, minimum seasonal differences in the weight of either roots or rhizomes that were statistically significant were reduced. Seasonal changes in the dry weight of roots and rhizomes presented in Table 21 are based, therefore, on the average weights of samples obtained from all 10 plots of block A on any given date.

Kentucky bluegrass sown September 3, 1936, in block B, had already made a large root development by April 1, of the following spring (Table 22). Seasonal variations in root weight occurred during the next 4 years, but there was no further large increase in the total weight of roots in the upper 6 inches of sod.

Rhizomes were not found in measurable quantities in sod samples of block B before June 1, 1937, after which, the total quantity of rhizomes increased each year. Although dead rhizomes were found occasionally in samples from block B, and these were discarded without being weighed after September 1939, the number of dead rhizomes was much smaller in bluegrass that was not irrigated during mid-summer than in the plots of block A which were watered liberally every summer.

Seasonal changes in the weight of roots and rhizomes, based on averages of samples obtained on any given date from all 24 plots of block B are shown by the data in Table 23.

TABLE 23. SEASONAL CHANGES IN THE DRY WEIGHT OF ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS, BLOCK B, SAMPLED TO A DEPTH OF 6 INCHES 1937 TO 1940

Year	Growth periods: Dates	Growth periods: Days	Pounds per acre: Roots	Pounds per acre: Rhizomes
	Sod Samples			
1937	April 1-May 1	30	101	
	May 2-June 1	31	16	24*
	June 2-June 30	29	34	38**
	July 1-Aug. 2	33	51	60**
	Aug. 3-Aug. 31	29	13	- 5
1938	April 1-June 9	70	122*	226**
	June 10-Aug. 30	82	146**	51*
	Aug. 31-Oct. 18	49	-147*	- 8
1939	March 7-May 10	64	247**	5
	May 11-Aug. 8	90	-177**	51*
	Aug. 9-Sept. 24	47	- 36	- 58*
	Sept. 25-Oct. 25	31	-277**	- 58*
	Oct. 26-Nov. 30	36	169*	83**
1940	March 6-May 20	75	396**	76*
	May 21-June 30	41	- 28	194**
	July 1-Sept. 5	67	-442**	- 53
	Sept. 6-Oct. 14	39	170*	119**
	Oct. 15-Nov. 21	38	39	76*
	Soil plug samples			
1940	March 6-May 20	75	707**	72**
	May 21-June 30	41	267**	271**
	July 1-Sept. 5	67	-148**	- 39
	Sept. 6-Oct. 14	39	202**	115**
	Oct. 15-Nov. 21	38	69*	93**

* Changes in weight that exceed the minimum difference required for significance at the 5% level.

**Changes in weight that exceed the minimum difference required for significance at the 1% level.

Total dry weights of Kentucky bluegrass roots and rhizomes (6 inches deep) at the time the last samples were taken in each of the years 1937 to 1940 are presented in table 24 to show the influence of: (a) summer irrigation, and (b) mowing treatment.

In soil plug samples, (Table 24) where the measurement of new growth was not complicated by the presence of preexisting old roots and rhizomes, the quantity of roots developed during 1940 in block A was slightly larger than in block B. This indicated that the smaller quantity of roots found in the old sods of block A might have resulted from a more rapid decomposition of dead roots in grass that was irrigated during summer and fall rather than from a slower growth of new roots.

Data in Table 25 show the relative effect of the 3 clipping treatments on root and rhizome development. The changes in weight tabulated here occurred during 1940 in soil plugs in block B.

TABLE 24. TOTAL DRY WEIGHTS OF KENTUCKY BLUEGRASS ROOTS AND RHIZOMES IN THE UPPER 6 INCHES OF SOD WHEN THE FINAL SAMPLES WERE TAKEN IN EACH OF THE YEARS, 1937 TO 1940

			Pounds of dry matter per acre					
			Roots			Rhizomes		
Year	Block	Sample	1-in. cut	2 1/2-in. cut	Hay-cut	1-in. cut	2 1/2-in. cut	Hay-cut
1937	A	sod	1369	1535		719	1120	
	B	sod	1927	2049	1922	122	122	108
1938	A	sod	1591	1835		627	977	
	B	sod	1897	2137	2210	372	478	505
1939	A	sod	1211	1240		250	346	
	B	sod	1879	2289	2281	398	519	507
1940	A	sod	1330	1090		377	352	
	B	sod	1946	2088	2455	660	817	1071
1940	A	soil-plug	1222	1188		337	430	
	B		1105	1188	998	440	533	562

MINIMUM DIFFERENCES REQUIRED FOR SIGNIFICANCE BETWEEN MOWING TREATMENTS

			Roots		Rhizomes	
Year	Block	Sample	1% level	5% level	1% level	5% level
1937	A	sod	272	201	258	192
	B	sod	273	203	53	39
1938	A	sod	278	203	380	278
	B	sod	259	192	116	86
1939	A	sod	375	270	320	230
	B	sod	311	230	121	89
1940	A	sod	294	212	194	139
	B	sod	364	271	149	111
1940	A	soil-plug	207	149	140	101
	B		145	108	118	88

TABLE 25. SEASONAL CHANGES IN THE DRY WEIGHT OF ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS (BLOCK B) THAT OCCURED UNDER 3 DIFFERENT CLIPPING TREATMENTS DURING 1940 (DETERMINED FROM THE SOIL-PLUG SAMPLES)

Period	Changes in pounds per acre		
	1-in. cut	2 1/2-in. cut	Hay-cut
		Roots	
March 6 - June 30	944**	1144**	836**
July 1 - September 5	-157**	- 269**	- 19
September 6 - November 21	318**	313**	181**
Total increment	1105	1188	998
		Rhizomes	
March 6 - June 30	289**	401**	342**
July 1 - September 5	-128**	- 68	79
September 6 - November 21	284**	200**	141**
Total increment	440	533	562

* Changes in weight that exceed the minimum difference required for significance at the 5% level.

**Changes in weight that exceed the minimum difference required for significance at the 1% level.

Discussion

It is unlikely that there were any rhizomes below the 6-inch depth to which the bluegrass sod was sampled, but data relating to root development might be justly criticized because only that fraction of roots located in the upper 6 inches of sod was sampled. It was not practical, however, to take deeper samples in the quantity that would have been required to overcome plot variability and establish significant differences between periods and treatments. Furthermore, the major portion of Kentucky bluegrass roots are in the surface 6 inches of soil, even though some of them extend much deeper. Karraker and Bortner (30) observed that most of the roots in a Kentucky bluegrass-white clover sod were in the surface 4 inches, that they were numerous to a depth of 10 inches, but that below the 10-inch depth they decreased rapidly to almost none at all below 24 inches. Sprague (44) found that the dry weight of Kentucky bluegrass roots in the 6 to 9-inch layer of soil was only 4.5 per cent of that in the 0 to 3-inch layer. Partridge (38) measured the roots of Kentucky bluegrass at successive depths in the soil and found the following distribution: 0 to 6 inches, 75.5 per cent; 6 to 12 inches, 12.1 per cent; 12 to 18 inches, 7.0 per cent; 18 to 24 inches, 2.5 per cent; and, 24 to 48 inches, 2.6 per cent.

In 1936, the quantity of roots in the 0 to 6-inch and in the 6 to 12-inch layers were measured in bluegrass that had been sown the previous September and in bluegrass that had been sown in the spring of 1934. In 1-year-old sod, 81.2 per cent of the roots in the upper foot of soil were located in the surface 6 inches; and in 2-year-old sod, 87.6 per cent of the roots found to a depth of 1 foot were located in the top 6 inches of sod. It is reasonable to assume, therefore, that major changes in root growth could be detected by sampling the sod to a 6-inch depth.

Kentucky bluegrass made a much more rapid root growth from the time seedlings first appeared in mid-September to the end of the following March than during any subsequent period (Table 22.) This agrees with the findings of Stuckey (47) who reports that Kentucky bluegrass seeded in September produced roots actively during October, and that root growth continued slowly throughout the winter, increased rapidly after the soil had thawed in March, and reached a maximum in April. After mid-June, few new roots were formed, and there was no appreciable growth of existing roots until October. Only a small percentage of the old roots disintegrated during the second year and only a few new roots developed after the first spring.

No rhizomes, on the other hand, developed during the first autumn and winter after the September seeding, and rhizome production throughout the first spring and summer was relatively small (Table 22). Rhizome production by the young grass was restricted by drought during midsummer and fall, but it was not retarded by moisture deficiency before July.

The ability of Kentucky bluegrass to thicken a sparse stand by vegetative reproduction, when soil and moisture conditions are favorable, is shown by the very rapid development of rhizomes that occurred during the summer and fall of 1937 in the second-year bluegrass sward in which rhizome production had been largely inhibited and many plants killed by the severe drought and heat of 1936 (Tables 20 and 21). Rhizome production then proceeded at a much slower pace during the next 3 years, 1938 to 1940, after the bluegrass sward had thickened. This influence of density of stand on rhizome production is not, however, peculiar to Kentucky bluegrass, for Dexter (17) found that quack grass formed relatively few rhizomes in dense sods and Watkins (53) discovered that this also applies to bromegrass.

Spring and fall were the more favorable seasons for increases in weight of roots and rhizomes in dense swards of bluegrass, after the first year (Tables 21 and 23). Early spring, March 6 to May 20, when semi-monthly average soil temperatures ranged from 40° to 60° F., was the most favorable period for root development. Stuckey (47) states that if cell division can be accepted as a criterion of growth, root tips of Kentucky bluegrass grow at temperatures very close to 32° F., although root growth reached a maximum during April. Sprague (44) found that the roots of Kentucky bluegrass in the upper 9 inches of soil increased in dry weight from April 6 to May 11, then decreased in weight until May 25, after which they again gained weight until June 22, when the last samples were taken.

Late spring and early summer (May 21 to June 30), on the other hand, is more favorable for rhizome development than early spring (Tables 21 and 23). The longer photoperiod rather than the higher temperature probably accounts for the increased rhizome production occurring during this period (13, 53).

In well established bluegrass swards that had existed for 2 or more years, the roots and rhizomes either made no gain or actually lost weight during the summer, when the temperature of the grass-covered soil just below the surface usually averaged near or slightly above 80° F. (Tables 21 and 23). Brown (13), Darrow (16) and Harrison (26) have shown that temperatures of 80° F. or above are unfavorable for root and rhizome development by Kentucky bluegrass.

The amount of herbage produced by Kentucky bluegrass under field conditions at 80° F. or above is probably influenced more by the adverse effect of super-optimal temperatures on root growth than by the direct influence of such temperatures on top growth. A temperature of 80° did not retard top growth of Kentucky bluegrass grown for 8 weeks in thermo-regulated growth chambers (13) but it did almost completely check root growth. Because of highly favorable conditions of soil and moisture in pot cultures, little root extension was required to maintain good top growth. Under field conditions, where a crowded population of bluegrass plants competes for a limited supply of plant nutrients, a reduction in root development was soon followed by a decrease in top growth.

The watering of bluegrass during mid-summer did not influence root growth very much, but it did appear to accelerate the rate of decomposition of the older roots (Table 24). This more rapid disintegration of dead roots might have had a beneficial effect on top growth, for bluegrass that was irrigated during mid-summer produced more herbage than grass that was subjected to summer drought. This was true even during the spring and autumn when both blocks were equally well supplied with water (Table 15). Reference has already been made to the findings of Sprague (44) and Benedict (5) that top growth is retarded by an accumulation of old roots, or their decomposition products, in the soil.

Keeping bluegrass vegetative by irrigation during midsummer plus semi-monthly mowings hastened the death and decay of older rhizomes. By 1940, bluegrass that had been exposed to 4 summer and 2 autumn droughts during its 4 growing seasons had a larger quantity of rhizomes than bluegrass that had never experienced a moisture deficiency during the same 4 year period (Table 24). Since herbage yields in the final year, 1940, were larger in the irrigated grass (Table 15) the importance of the greater survival of rhizomes might be questioned. Much more hand weeding was required to keep weeds and white clover out of summer-irrigated plots than was required to keep weeds and clover out of grass that was not watered during mid-summer. Weeds, especially summer annuals, were undoubtedly encouraged by the directly beneficial effects of the higher soil moisture content during summer, but the exhausting effect of summer watering and mowing, evidenced by the death of a larger fraction of rhizomes, probably reduced the competitive efficiency of the grass. Therefore, it may be a fortunate circumstance, as far as the survival of Kentucky bluegrass and its resistance to the ingress of weeds is concerned, that, in the southern part of the region to which it is adapted, summer heat is usually accompanied by moisture deficiency. This influence of summer irrigation on the longevity of rhizomes also is of practical significance in the watering of bluegrass lawns, which are usually mowed even more intensively than the grass in the 1-inch cut plots of this experiment.

Although summer drought, if not too severe or too long extended, probably protected the grass to some degree from excessive depletion of food reserves during the summer, fall droughts were altogether harmful because they retarded or inhibited root and rhizome growth and food storage during periods that were otherwise favorable for their development.

Much has been written about the influence of defoliation on the underground development of grasses. Biswell (7), Darrow (16), Dexter (17), Gernert (22), Graber, Nelson, and Luekel (25), Harrison and Hodgson (27), and Roberts and Hunt (39) found that the roots of perennial grasses, and also the rhizomes of those species having rhizomes, were reduced by clipping the tops. In general, the extent of reduction was in proportion to the intensity of defoliation. Continuous close clipping was less injurious, however, to Kentucky bluegrass than to quack grass, smooth bromegrass, timothy, or orchard grass (27) and root growth by Kentucky bluegrass was reduced less by clipping than that of several tall-growing prairie grasses (7).

Results obtained here (Table 25) indicate that semi-monthly mowings, even to the 1-inch level, affected root development in the 0 to 6-inch layer of soil little if any. Repeated defoliation affected materially the quantity of rhizomes, by retarding their development during the spring and by increasing the rate at which they lost weight during the summer. In autumn, however, the largest increase in rhizome weight occurred in plots mowed semi-monthly to the 1-inch level, provided the moisture supply was adequate for growth during this period.

TABLE 26. SEASONAL VARIATIONS IN HERBAGE PRODUCTION, AND ROOT AND RHIZOME DEVELOPMENT BY KENTUCKY BLUEGRASS DURING 1940

	Pounds of dry matter per acre				
	Herbage (1)	Changes in weight (2)			
	Yields	Roots		Rhizomes	
Period	1-in. cut	1-in. cut	Hay-cut	1-in. cut	Hay-cut
March 1 - June 30	820	944	836	289	342
July 1 - August 31	215	-157	- 19	-128	79
Sept. 1 - Nov. 20	251	318	181	284	141

(1) Plots of block B mowed semi-monthly at the 1-inch level.
(2) Soil plug samples taken from block B.

These results might be considered to justify "deferred" grazing, that is sometimes recommended for bluegrass as well as for other pastures. Data in Table 26 show, however, that a large fraction of the total herbage was produced during the spring. If this herbage is not consumed as produced, it deteriorates in quality. It would seem advisable, therefore, to utilize bluegrass fully during the spring, if food reserves can be restored by resting the grass during some other season of the year when less herbage is produced. Autumn appears to satisfy these requirements.

The "soil-plug" method of sampling roots and rhizomes in old grass sods has the advantage of separating changes in weight that occur in living, functional roots from those that result from the decomposition of dead roots. A comparison of changes in root weight measured by sod samples with those measured by the soil-plug samples (Tables 21 and 23) indicates that either the development of new roots was obscured by the decay and consequent loss in weight of old roots, or the development of new roots was retarded by the presence in the soil of a mass of old roots. Both may have been true.

Summary

Root growth by Kentucky bluegrass was more rapid during the first autumn and winter following a September seeding than during any subsequent period. No rhizomes developed before spring, and their development was slow during the first spring and summer. Rhizome production was most rapid during the second summer in a sparse stand of irrigated bluegrass.

In older, dense bluegrass sods, spring and fall were the more favorable seasons for root and rhizome growth. Root growth was most active during early spring at mean temperatures below 60° F., but rhizomes developed most rapidly in late spring and early summer. Both roots and rhizomes usually lost weight during the summer at mean temperatures near or above 80° F. The depressing influence of super-optimal summer temperature on root growth probably was responsible for the summer decline in herbage production.

Summer irrigation accelerated the decomposition of older bluegrass roots, which was probably beneficial, and hastened the death of older rhizomes, which was probably harmful to the grass.

Autumn droughts retarded or inhibited root and rhizome growth during a period that was otherwise favorable for their growth.

Mowing bluegrass semi-monthly to the 1-inch level had little or no effect on root growth in the upper 6 inches of sod, but it did retard rhizome development in the spring and increased rhizome exhaustion during the summer. The exhausting effect of close mowing on rhizomes during spring and summer was partly counterbalanced by a larger gain in weight by rhizomes in the 1-inch cut plots during autumn, if the supply of soil moisture was adequate for growth at that time.

CARBOHYDRATE CONTENT OF THE ROOTS AND RHIZOMES

Experimental Results

Analyses of the roots and rhizomes were made to determine the amount of carbohydrate reserves stored in them at different times of the year under different mowing treatments. The particular carbohydrate or carbohydrates that are stored as reserves in Kentucky bluegrass are not definitely known, but it was assumed that they would be included in the sugar, starch, and hemicellulose fractions. Therefore, total sugar, starch, and hemicellulose contents of root and rhizome samples obtained during 1940 from blocks A and B were determined. Seasonal changes in these 3 carbohydrate fractions were determined by averaging the results obtained from differently mowed plots on any particular date (Tables 27 and 28).

Data in Tables 27 and 28 indicate that hemicellulose does not constitute an important part of carbohydrate reserves stored in the roots and rhizomes of Kentucky bluegrass. Therefore, in order to show the

TABLE 27. THE CARBOHYDRATE CONTENT OF THE ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS IN BLOCK A DURING 1940

		Per cent of dry matter					
		Sod samples			Soil plug samples		
		Total sugars	Starch	Hemi-cellulose	Total sugars	Starch	Hemi-cellulose
				Roots			
March	11	2.48	2.25	21.19			
June	24	1.09	1.12	22.18	1.34	1.20	21.62
September	2	.49	.48	20.44	1.00	.83	22.56
October	7	.66	1.25	22.68	1.00	1.09	22.13
November	19	1.30	1.78	21.95	1.96	1.31	20.40
				Rhizomes			
March	11	3.73	5.69	19.82			
June	24	2.06	3.60	20.75	2.54	2.74	21.21
September	2	1.54	3.28	21.50			
October	7	1.29	3.10	19.82			
November	19	2.30	3.70	18.44	2.60	4.40	18.22

TABLE 28. THE CARBOHYDRATE CONTENT OF THE ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS IN BLOCK B DURING 1940

		Per cent of dry matter					
		Sod samples			Soil plug samples		
		Total Sugars	Starch	Hemi-cellulose	Total Sugars	Starch	Hemi-cellulose
				Roots			
March	6	2.03	1.48	20.69			
May	20	1.06	2.27	20.72	1.40	2.69	23.38
June	30	.70	1.66	21.77	2.01	1.40	21.98
September	5	.76	1.28	21.46	1.12	1.24	22.66
October	14	.78	1.63	23.02	1.08	1.25	22.51
November	21	1.15	1.37	22.80	2.14	1.64	21.92
				Rhizomes			
March	6	4.36	3.52	18.66			
May	20	1.89	4.45	19.98			
June	30	1.59	3.79	19.32	2.63	4.13	18.43
September	5	1.55	4.46	19.44	1.92	3.90	18.90
October	14	1.75	4.00	18.55	1.79	4.04	18.42
November	21	2.31	5.27	17.76	3.48	5.09	17.05

influence of seasonal factors and mowing treatments on the storage and exhaustion of carbohydrate reserves in bluegrass, only the sugar and starch contents, expressed both in percentage and pounds of "starch equivalent" per acre, are given for the different mowing treatments in Tables 29 to 32. Starch equivalent was computed in each case by adding 0.9 of the determined percentage of total sugars to the determined percentage of total starch.

A comparison of the data in Tables 29 and 31 shows that much less sugar and starch was stored in the roots and rhizomes of the grass in block A on September 2 than in block B. A further comparison of the data in Tables 29, 30, 31, and 32 shows that by late November, the roots in block A contained approximately the same amount of sugar and starch as those in block B but that the rhizomes in block A contained much less sugar and starch than those in block B.

TABLE 29. THE TOTAL SUGAR AND STARCH CONTENT, EXPRESSED AS STARCH EQUIVALENT, OF THE ROOTS AND RHIZOMES IN KENTUCKY BLUEGRASS SOD (BLOCK A) DURING 1940

		Total sugar and starch as starch equivalent			
		1-inch cut		2 1/2-inch cut	
		%	lbs. per acre	%	lbs. per acre
		Roots			
March	11	4.48	64.9	4.48	63.9
June	24	2.21	35.4	2.00	30.8
September	2	.93	9.7	.91	9.8
October	7	1.86	20.5	1.83	17.8
November	19	3.29	43.7	2.62	28.2
		Rhizomes			
March	11	9.05	27.4	9.05	28.0
June	24	5.85	18.5	5.04	19.9
September	2	4.44	9.9	4.91	18.5
October	7	5.36	11.7	3.17	10.4
November	19	6.30	19.7	5.24	17.3

TABLE 30. THE TOTAL SUGAR AND STARCH CONTENT, EXPRESSED AS STARCH EQUIVALENT, OF THE ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS (BLOCK A) DEVELOPED DURING 1940 IN THE SOIL PLUGS

		Total sugar and starch as starch equivalent			
		1-inch cut		2 1/2-inch cut	
		%	lbs. per acre	%	lbs. per acre
		Roots			
June	26	2.35	20.3	2.46	20.7
September	3	1.80	14.3	1.66	12.9
October	10	1.90	16.1	2.09	19.1
November	19	3.02	38.4	3.13	37.9
		Rhizomes			
June	26	5.03	5.0	5.03	5.9
September	3				
October	10				
November	19	6.76	22.8	6.73	26.7

TABLE 31. THE TOTAL SUGAR AND STARCH CONTENT, EXPRESSED AS STARCH EQUIVALENT OF THE ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS SOD (BLOCK B) SAMPLED PERIODICALLY DURING 1940

		Total sugar and starch as starch equivalent					
		1-inch cut		2 1/2-inch cut		hay cut	
		%	lbs. per acre	%	lbs. per acre	%	lbs. per acre
		Roots					
March	6	3.33	62.2	3.39	68.8	3.21	70.2
May	20	3.40	76.5	3.22	80.6	3.06	77.1
June	30	2.21	47.6	2.37	59.9	2.30	57.6
September	5	1.91	32.9	2.06	41.1	1.92	41.2
October	14	2.26	45.2	2.54	57.3	2.18	46.2
November	21	2.09	40.7	2.33	48.7	2.81	69.0
		Rhizomes					
March	6	8.37	30.3	7.13	33.8	6.81	32.3
May	20	6.89	27.9	6.06	30.5	5.49	34.6
June	30	4.71	24.0	4.71	33.6	6.26	56.3
September	5	5.70	26.2	5.99	40.1	5.88	48.9
October	14	5.32	31.8	5.71	43.0	5.70	55.2
November	21	7.39	48.8	7.75	63.3	6.90	73.9

TABLE 32. THE TOTAL SUGAR AND STARCH CONTENT, EXPRESSED AS STARCH EQUIVALENT, OF THE ROOTS AND RHIZOMES OF KENTUCKY BLUEGRASS (BLOCK B) DEVELOPED DURING 1940 IN THE SOIL PLUGS

		Total sugar and starch as starch equivalent					
		1-inch cut		2 1/2-inch cut		Hay-cut	
		%	lbs. per acre	%	lbs. per acre	%	lbs. per acre
				Roots			
May	20	3.88	28.5	3.80	29.9	4.20	25.2
July	2	3.28	31.0	2.96	33.9	3.40	28.4
September	4	2.04	16.1	2.24	19.6	2.47	20.2
October	16	2.15	22.2	2.11	23.0	3.07	29.6
November	22	3.56	39.3	3.30	39.2	3.83	38.2
				Rhizomes			
July	2	6.18	17.6	6.41	25.7	6.91	23.6
September	4			5.39	17.9	5.89	24.8
October	16	4.85	14.5	5.46	23.5	6.63	35.0
November	22	8.93	39.3	7.36	39.2	8.39	47.2

Discussion

Aldous (3) states that the storage of organic food reserves in forage plants is essential to their normal functioning and that the extent of storage of these reserves throughout the growing season appears to provide one of the principal indexes to plant growth requirements. Graber (23) points out that the productive capacity of grasses is dependent on adequate food reserves as well as on favorable external environmental factors. Earlier Graber, Nelson, Leukel, and Albert (25) had observed that "—— in many cases, permanent pastures are unproductive, not because the fertility of the soil has necessarily been exhausted, but because those limiting factors of plant growth—the manufacture of organic food and its translocation to and storage in the rhizomes and roots of the pasture grasses—have been seriously reduced by a lack of maturity in the top growth."

Graber (23) states that food reserves may be regarded as those organic compounds which are synthesized and maintained in forms capable of being subsequently utilized by the plant in the performance of its various functions. McCarty (36) expressed the opinion that, in mountain brome, the sugars and starches are the more potent of the stored carbohydrate foods and that the behavior of hemicellulose suggests that it is employed largely as a structural material. Results obtained by Albert (2), Aldous (3), Barr (4), and Graber, Nelson, Luekel, and Albert (25), as well as those reported here, support McCarty's viewpoint.

The relatively high percentage of total sugar found in roots and rhizomes of bluegrass both in early spring and in late autumn also agree with results reported by Albert (2) and McCarty (36) who found that the ratio of sugar to starch in plants increases during cold seasons. McCarty concluded from this that a relatively high concentration of sugars in the basal organs and in newly developed shoots is associated with resistance to low temperatures and is essential to the winter survival of plants.

Norman (37) found the chief place of storage of fructosan in Western Wolths ryegrass to be the culm, particularly the first node above ground level. Roberts and Hunt (39) concluded from their studies that the roots of perennial ryegrass serve as storage organs, but that no reserve food is stored in the roots of timothy. Results reported by Watkins (53) indicate that the rhizomes of bromegrass serve as the source of organic reserves required to support a rapid production of top growth. Darrow (16) and Harrison (26) concluded from their own investigations and those reported by others that carbohydrate reserves are stored in the rhizomes of Kentucky bluegrass.

In studies reported here, rhizomes always contained larger percentages of sugar and starch than roots, but because of the larger total dry weight of roots, they sometimes contained larger total quantities of these carbohydrates than the rhizomes. Changes that occurred in the sugar and starch content indicate that carbohydrates were stored in roots as well as in rhizomes, but whether or not carbohydrates stored in the roots were subsequently translocated to and used by some other part of the plant was not demonstrated.

Aldous (3) explains that the food reserves, sugar and starch, decreased from May 7 to May 21 in the roots of little bluestem because of the rapid growth that occurred while the leaf material was as yet insufficient to elaborate food as rapidly as it was used. Bluegrass is apparently able to synthesize carbohydrates as rapidly as they are used during the relatively cool period of early spring, March 6 to May 20. The increase in the total quantity of sugar and starch that occurred in roots during this period exceeded the slight reduction in rhizomes even in mowed plots. This increase in the quantity of sugar and starch in bluegrass roots during early spring resulted from root growth rather than from carbohydrate storage, because the total percentage of sugar and starch did not change appreciably.

Both the percentage and the total quantity of sugar and starch in the roots of bluegrass decreased from May 20 to June 30, a period of moderate temperatures and relatively large herbage production. This decline in carbohydrate content continued in the roots throughout the summer. Aldous (3) found, too, that the starch and sugar content in the roots of little bluestem decreased from June 25 to July 16 when the grass was in a vigorous growing condition. To him this seemed to be contrary to physiological principles since from May 21 to June 25, photosynthesis had not only taken care of current food requirements for growth, but had also partly restored the supply of carbohydrates depleted by early growth. The rate of carbohydrate use by plants is influenced, however, not only by rate of growth but also by temperature, since the temperature at which respiration reaches a maximum is much higher than the temperature at which photosynthesis is most rapid. This is especially true of a "cool weather" plant such as Kentucky bluegrass (13, 16, 26).

That a portion of the carbohydrates previously stored in the rhizomes was utilized for growth during the spring is indicated by the decrease in the percentage content of sugar and starch in rhizomes of mowed bluegrass from early March to June 30.

Summer drought appears to have protected the bluegrass against the exhausting effect of high temperatures on carbohydrate reserves. The decrease in the sugar and starch content of both roots and rhizomes was much greater in sod that was watered during mid-summer drought than in sod that was not watered.

Carbohydrate storage in bluegrass roots developed during the current season apparently occurred during the autumn between September 5 and November 21. The most favorable period for carbohydrate storage in rhizomes was late fall, from mid-October to late November. These results agree with the observations of Waters (52) that the autumn is a more favorable period for the storage of carbohydrate reserves in the "underground stocks" of bluegrass than summer or spring. Whether or not carbohydrate storage by bluegrass is inhibited at other times by vegetative growth, as was stated by McCarty (36) to be the case in mountain brome, the greatest accumulation of sugar and starch in the rhizomes occurred after top growth had almost stopped.

Mowing treatment did not have much effect on the quantity of sugar and starch stored in the roots developed during the current growing season. Cutting the grass only twice, May 24 and November 18, or elevating the blade of the mower to the 2½-inch level increased the accumulation of sugar and starch in the rhizomes. The smaller carbohydrate content of rhizomes in the 1-inch cut plots resulted largely from the greater net loss that occurred during spring and summer, for storage of sugar and starch proceeded almost as rapidly during the autumn in the rhizomes of closely mowed grass as in those of grass that was not cut at all from May 24 to November 18.

The data presented here indicate that deferring grazing until May 20 would have increased the storage of carbohydrates in rhizomes, but not without a very considerable reduction in the nutritive quality of the grass. The results also show, that carbohydrate storage in rhizomes of closely mowed bluegrass is relatively rapid from early September to late November, even when mowing continued until late October. What might have occurred if mowing the 1-inch cut plots had been suspended from the end of the summer drought to the end of the growing season is not shown by the results of this investigation, but it is reasonable to assume that synthesis and storage of carbohydrates would have increased. It is possible, therefore, that full use could be made of Kentucky bluegrass herbage by grazing it intensively during spring and early summer without substantial reduction in the carbohydrate reserves finally stored in the plant, if the grass were protected from defoliation during autumn.

Summary

The storage of organic food reserves in perennial forage plants is essential to their normal functioning.

Sugars and starches are the more potent of the stored carbohydrates. Hemicellulose is used largely as a structural material rather than as a reserve food.

Sugar and starch appeared to be stored in both the roots and the rhizomes of Kentucky bluegrass.

Kentucky bluegrass synthesized carbohydrates more rapidly than they were used during the cool period of early spring, even when the grass was mowed semi-monthly. The surplus went into the rapidly growing roots. During late spring and early summer, there was a net loss of carbohydrates from the roots. This loss was counterbalanced by an equally large storage in the rhizomes of bluegrass cut as hay, but not in those of bluegrass that was mowed semi-monthly. A further net reduction in the carbohydrate content of bluegrass roots occurred during the summer period. A loss of carbohydrates from the rhizomes of watered bluegrass also occurred during the summer, but drought protected the rhizomes of unwatered bluegrass from exhaustion of their stored carbohydrates at high summer temperatures.

The period most favorable for carbohydrate storage by both roots and rhizomes of Kentucky bluegrass was autumn. Carbohydrate storage in the rhizomes was most rapid after mid-October when top growth had practically ceased.

Storage of carbohydrate reserves during the fall was almost as rapid in the rhizomes of bluegrass mowed semi-monthly at the 1-inch level as in those of bluegrass mowed semi-monthly at the 2½-inch level or cut only twice annually as hay. During the spring when top growth was most rapid, the closer defoliation resulted in a greater loss of carbohydrates from the rhizomes.

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