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Some Effects Of Temperature On The Growth And Chemical Composition Of Certain Pasture Grasses

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INTRODUCTION

The geographical region to which each pasture grass is adapted is limited by various climatic factors of which temperature is of major importance. Furthermore, even within the region to which each of the grasses is well adapted, seasonal variations in growth and chemical composition occur which are conditioned to a considerable extent by temperature. This seasonal variability in growth and chemical composition constitutes one of the major problems in the management and utilization of pasture grasses. Therefore, an advanced knowledge of the temperature relations of grasses used for pasturage should contribute to the solution of some of the problems of pasture management and afford a better understanding of the climatic adaptation of the species investigated.

The species of pasture grass included in investigations herein reported are Kentucky bluegrass (*Poa pratensis*), Canada bluegrass (*Poa compressa*), orchard grass (*Dactylis glomerata*), and Bermuda grass (*Cynodon dactylon*).

SOME PREVIOUSLY REPORTED EFFECTS OF TEMPERATURE ON PLANTS

Effect of Temperature on Plant Distribution

Merriam (20)[1] states that, "Apart from obvious mechanical barriers, such as oceans, temperature is the most important single factor in fixing the limits beyond which particular species of animals and plants can not go."

Vinall and Hein (26) show that the southern limit of the region to which Kentucky and Canada bluegrass and orchard grass are adapted corresponds rather closely with the 60° F. isotherm. The

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[1]Numerals refer to "Literature Cited", page 60.

northern limit for orchard grass corresponds roughly with the 45° isotherm but the two bluegrasses are successfully grown much farther north.

Piper (24) states that Kentucky bluegrass is resistant to cold but shows little vigor during the hot weather of July and August. Canada bluegrass is adapted to about the same range of climatic conditions as Kentucky bluegrass, although somewhat more resistant to summer heat. Orchard grass, on the other hand, withstands a longer season of heat than the two bluegrasses but is more easily injured by winter cold. Bermuda grass (24, 26) is best adapted in the United States to the same general area as cotton.

Effect of Temperature on Plant Growth

Leitch (18) found the lowest temperature at which growth took place in root tips of *Pisum sativum* to be 28.4° F. However she agrees with Lehenbauer (17) that at higher temperatures—above 87.8° in corn and 84.2° in peas—the initial growth rate is not maintained, there being a marked falling off in the growth rate during prolonged periods of exposure. Their results support the opinion expressed by Lundegardh (19) that the van't Hoff rule has only a limited application to the temperature-growth curve for plants.

Kincaid (14) reports rather definite minimum and maximum soil temperatures for growth in tobacco, but the optimum temperature was not clearly defined since the best growth was distributed over a temperature range of from 76° to 90° F.

Lundegardh (19) expresses the opinion that the plant probably has different optimum temperatures for growth in different stages of development. Therefore, if the influence of temperature on the entire development and yield of an agricultural crop is determined, a strikingly low optimum is found. For example, grain yield of rye was found to increase sharply from 32° to 50° F., remain practically the same within the temperature range of 50° to 68°, and decline as the temperature increased from 68° to 104°.

Gregory (10) found growth by barley to be positively correlated with average day temperature and negatively correlated with average night temperature. Brenchley (4) reports that peas grown in water culture could withstand very high maximum temperatures provided there was a considerable drop to the minimum, but that they could not withstand the condition of high maximum and high minimum temperatures. She found that the plants made good growth in hot air provided the roots were kept cool. Cannon (6) also found unfavorable air temperatures to exert less influence on plant growth than unfavorable root temperatures.

Walster (27), who grew barley at two temperatures, found the lower temperature to induce a more upright character of growth because of a greater proportion of culm to leaf, a greater proportion of skeletal material in the leaf to all other plant substances, and a greater degree of lignification of conductive tissue than was found in plants grown under higher temperatures.

Nightingale (22) reports the character as well as the quantity of growth made by roots of young apple and peach trees to have been markedly influenced by soil temperature. With increase in temperature there was an increase in the rate of maturity and in the differentiation of primary tissue.

Harrison (11) shows that cultures of Kentucky bluegrass supplied with nitrogen and exposed to a 60° F. temperature, at first produced less new foliage after defoliation than similar cultures exposed to an 80° temperature. After several defoliations, however, the 60° cultures were producing a higher yield of new growth between defoliations than were the 80° cultures. The plants grew very little at 100° and a large part of the established cultures died during six weeks of exposure to this temperature. The 60° temperature was also more favorable to root growth by Kentucky bluegrass than higher temperatures. Light, too, appeared to influence the development of the bluegrass, for when the days were long and bright the active production of leaf-shoots was somewhat retarded, while rhizome production, on the other hand, was accelerated, and most of the rhizomes produced during this period remained below the soil line. Few new rhizomes developed during periods of short day length but those produced earlier showed an increased tendency to emerge above the soil line.

Blackman (3) states that when the average soil temperature was below 42° F. grasses made no growth. Within the temperature range of 42° to 47°, the grasses grew more rapidly if supplied with nitrogen in an available form, while above 47° there was a marked increase in growth which was not greatly influenced by the application of nitrogenous fertilizers.

Effect of Temperature on the Chemical Composition of Plants

Bushnell (5), Hurd-Karrer and Dickson (13), Lundegardh (19), Nightingale (21, 22), Nightingale and Blake (23), Tottingham (25), and Werner (28) all report that plants accumulate less carbohydrates as the temperature becomes higher. Lundegardh (19) explains this by showing that the temperature curve of carbon dioxide assimilation differs considerably from that of respiration, the optimum temperature for respiration being much higher than that for assimilation. Thus at temperatures above the optimum for photosynthesis, respiration may exceed assimilation and decrease the supply of carbohydrates in the plant.

Blackman (2) explains how the excessive respiration in a growing point might cause the decline in growth observed to accompany a rise in temperature above the optimum.

Nightingale (21, 22) found that nitrate nitrogen was readily absorbed by plants at temperatures near the minimum for plant growth, but that the reduction of the absorbed nitrate was inhibited or greatly retarded at low temperatures.

Curtis and Herty (8) report that translocation of carbohydrates from the leaf is retarded by lowering the temperature of the leaf petiole.

Effect of Temperature on the Absorption of Water and Minerals by Roots

Clements and Martin (7), Duncan and Cooke (9), and Arndt (1) found that the absorption of water by the sunflower, sugar cane, and cotton was greatly retarded by lowering the root temperature to a level approaching the minimum for growth. Therefore, either because of the influence of temperature on the water supplying power of the soil (16) or on the permeability of living protoplasm (1), root temperature exerts an important influence on the rate of water absorption, even though the force responsible for the intake of water, as shown by Kramer (15), may originate in the above-ground portion of the plant.

Hoagland and Broyer (12) found the temperature coefficient values for salt accumulation by excised root systems of barley and of entire barley plants to be from 2.5 to 5.5 within the temperature range of 43° to 75° F. They conclude that, "Temperature effects on salt accumulation are - - - indirect in the sense that it is the metabolism of the plant which is being affected - - -."

When it is realized that "it is the metabolism of the plant which is being affected," one is inclined to agree with Blackman (2) that "- - - the way of those who set out to evaluate exactly the effects of changes in a single factor upon a multi-conditioned metabolic process is hard - - -."

EXPERIMENTAL METHODS

Equipment

Thermo-regulated growth chambers. The equipment used for the control of temperature consists of three growth chambers equipped with thermostatically controlled heating and cooling units designed to permit their simultaneous operation at different temperatures. Each growth chamber consists of a modified soil temperature tank surmounted by a glass enclosed compartment, the air chamber, the temperature of which is regulated independently of that of the soil temperature tank.

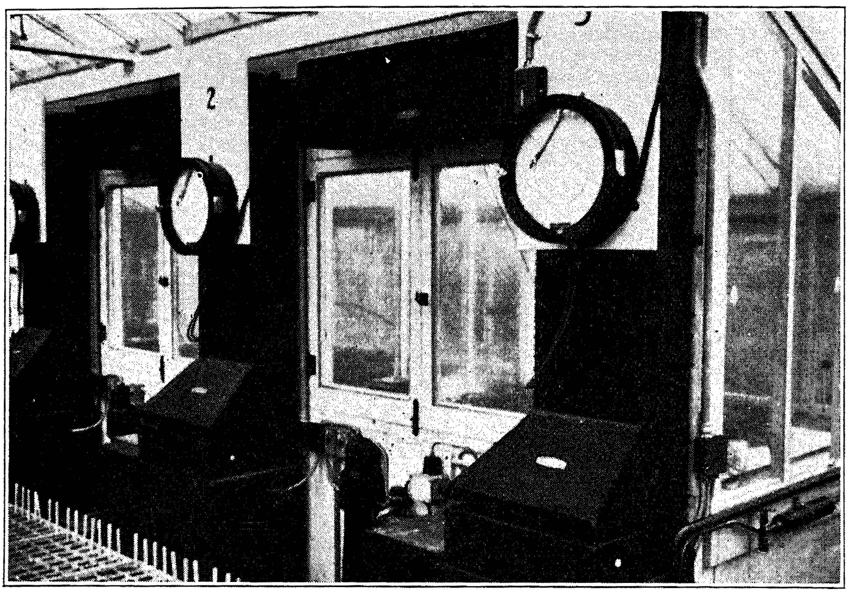

Fig. 1.—Interior view of greenhouse showing thermo-regulated growth chambers located along the south side.

These chambers are located within and along the south side of a greenhouse, the long axis of which extends east and west. The arrangement and construction of the chambers is such that the intensity of light admitted is at least equal to that received by an ordinary greenhouse and the three compartments are fully comparable with respect to light. This arrangement and the general appearance of the growth chambers, as viewed from the northwest corner of the greenhouse, is shown in Fig. 1.

Relative humidity, which was not controlled, was measured in each growth chamber by a Friez hygrograph.

Pots.—The grass cultures were grown in galvanized iron pots 20.3 cm. in diameter at the top, 17.8 cm. in diameter at the bottom, and 45.7 cm. deep.

Materials

Soil.—The soil used was Wabash silt loam taken from the surface six-inch layer of a cultivated field. Analysis showed this soil to be high in total exchangeable bases, readily decomposable organic matter, and available phosphate, and of a texture suitable for use in pots.

Plants.—All grass cultures were started from commercial seed.

Methods

Establishing the grass plants.—Kentucky bluegrass and orchard grass were planted directly in the potted soil but Canada bluegrass and Bermuda grass were started in flats of white sand and transplanted to the potted soil from one to two weeks after the seedlings had emerged. The stand was reduced to 25 plants per culture as soon as the seedlings appeared to be securely established.

Thirteen cultures of each species were established, 4 to provide a measure of the initial growth, and 9 for exposure to different temperatures—3 cultures of each species for each thermo-regulated growth chamber.

Initial growth.—All grasses were allowed an initial period of growth in order that the plants might become well established before exposure to controlled temperatures. The dates and duration of the initial growth period for each species in each series, as well as the temperature range and average day length which characterized each growth period, are tabulated in Table 1.[2] The amount of the initial growth by each species in each series is shown in Table 2.

Watering.—The moisture content of the soil was maintained as nearly as practicable at 20 per cent of the dry weight of the soil, both during the initial period of growth and during the period of exposure to controlled temperatures. Cultures were weighed frequently to check the soil moisture content.

Water was applied to the surface of the soil. This method resulted in a uniform distribution of water throughout the soil except at temperatures high enough to kill a considerable portion of the root system, in which case, water accumulated in the lower soil levels.

[2]All tables appear in the Appendix.

Defoliation.—The leaves of grass cultures in series 2 were not cut during either the initial growth period or the period of exposure to controlled temperatures. The tops of all grass cultures included in series 4 to 6 inclusive were cut back to a level of 7.5 centimeters above the soil line at the end of the initial period of growth, and in series 3 to 6 at the end of the first 4 weeks of exposure to controlled temperatures.

Temperature treatments.—All four species of grass were grown for approximately 8 weeks at soil and air temperatures ranging by 10° intervals from 40° to 100° F. Since only three thermo-regulated growth chambers were available, it was necessary to expose 3 series of grass cultures to progressively higher temperatures during successive periods of time in order to cover the desired range of temperature. The lowest temperature employed in each succeeding series duplicated the highest temperature of the preceding series so that the results obtained in one could be related to those obtained in another which followed or preceded it. Thus the grass cultures of series 2 were grown at temperatures of 40°, 50°, and 60° from January 11 to March 10; those of series 3 at temperatures of 60°, 70°, and 80° from March 18 to May 13; and those of series 4 at temperatures of 80°, 90°, and 100° from May 31 to July 26.

In series 5, the grasses were grown from July 28 to September 21 at air temperatures of 70°, 85°, and 100° F., with the soil temperature tanks held at a temperature of 70° in each growth chamber.

In series 6 the soil temperature tanks were again maintained at a constant temperature of 70° F. In one growth chamber the air temperature was also maintained at 70°. Air temperatures in the other two growth chambers, however, were varied, the diurnal range in one case being from 60° to 80°, in the other 50° to 90°. The higher temperature in each case occurred during the day, the lower temperature during the night. The daily duration of the periods of high and low temperature was adjusted so that the daily average soil temperature to a depth of 2.5 centimeters would closely approximate 70°. In the growth chamber in which the maximum air temperature was 80° this temperature was maintained from 8 A. M. to 10 P. M., while in the other growth chamber the 90° air temperature lasted from 8 A. M. to 7 P. M. on clear days and to 10 P. M. on cloudy days.

Measuring growth.—At the end of the initial growth period, the growth made by 4 cultures of each species was determined by the following methods:

The culms and leaf-shoots were cut at the base of the crowns, and after the adhering soil had been removed by washing, the herbage obtained from each culture was oven-dried and weighed separately. Clippings obtained when the tops were cut back during or at the end of the initial growth period were not included in this yield determination.

The soil with the underground plant parts which it contained was removed from each pot and cut at right angles to its depth 20 centimeters below the surface. In this way, the roots were divided into "0 to 20 centimeter" and "20 to 40 centimeter" portions, the latter actually varying from 20 to 25 centimeters in depth depending on the total depth of the soil in the pot. The roots were then washed over screens of 3/16-inch mesh hardware cloth by water under pressure. Foreign matter which could not be washed from the roots was picked out by hand. The roots were then oven-dried and weighed, the upper and lower root fractions being kept separate until their dry weights had been determined.

Rhizomes, when present, were separated from the roots immediately after washing, classified on the basis of whether their growing points had or had not emerged above the soil line, counted, and measured for length. The two classes from each culture were then composited, dried and weighed.

All "dry weights" or quantities of "dry matter" were determined by weighing the plant material after it had been oven-dried for a period of from 15 to 24 hours at a temperature of 170° F.

At the end of the period of exposure to controlled temperatures the quantity of oven-dry herbage, roots, and rhizomes was determined for each grass culture in the same manner as described for the measurement of the initial growth. To the final herbage yield was added the dry weight of the clippings obtained when the tops were cut back at the end of the first 4 weeks of growth at controlled temperatures. The number and length of rhizomes in each grass culture in which they occurred was also determined. The average increment in dry weight of herbage, roots, and rhizomes as well as the change in number and average length of rhizomes was then calculated by subtracting the average quantity determined for each grass at the end of the initial period of growth from that determined for each grass grown at a different temperature at the end of the period of exposure to controlled temperatures.

Chemical analysis.—The herbage obtained from the 4 cultures of each grass species measured for initial growth was composited and saved for chemical analysis. Composite samples of roots and of rhizomes were also saved. Similar samples from the 3 cultures of each grass grown at each temperature were saved when the final yield determinations were made.

All chemical analyses were made by the Department of Agricultural Chemistry, University of Missouri. The methods of analysis employed are described in Chapter 27 of Methods of Analysis of the Association of Official Agricultural Chemists, Fourth Edition.

EXPERIMENTAL RESULTS

Effect of Temperature on Growth when the Temperature of Soil and Air are the Same and Constant

Series 2, 3, and 4

Kentucky bluegrass.—The discontinuous temperature-growth curve in Figure 2 (Tables 4, 5, and 6) shows that the increment in

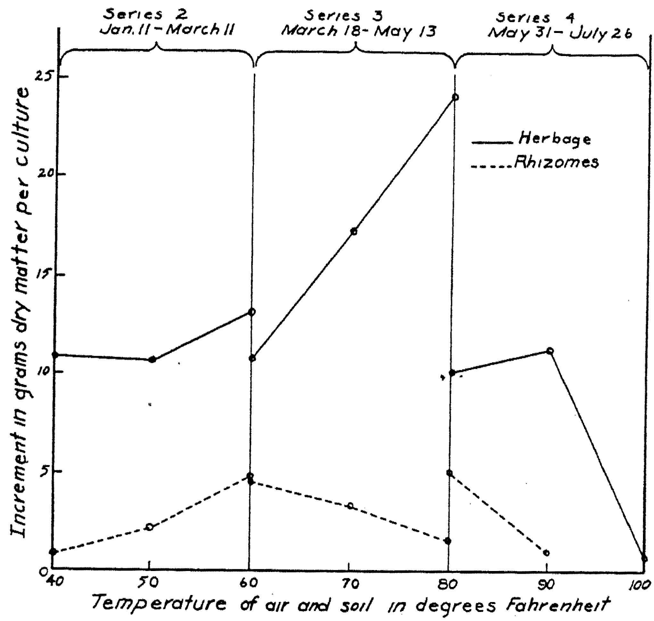

Fig. 2.—Relation of increment in dry matter of Kentucky bluegrass herbage and rhizomes to temperature.

dry weight of herbage produced by cultures of Kentucky bluegrass at like temperatures during successive periods differed materially, particularly at the 80° temperature in series 3 and 4. The growth curve for rhizomes, drawn in the same figure, is more nearly continuous within the temperature range of 40° to 80° covered by series

2 and 3, but at the 80° temperature, rhizome production proceeded at a much more rapid pace from May 31 to July 26 in series 4, than from March 18 to May 13 in series 3. The average day length from sunrise to sunset for periods in which the grass cultures were exposed to controlled temperatures was 10.8 hours in series 2, 13.2 hours in series 3, and 14.7 hours in series 4.

In spite of their discontinuity, however, these growth curves indicate that the 90° temperature, or some temperature between 80° and 90°, was more favorable for herbage production than higher or lower temperatures and that the 60° temperature was most favorable for the increase in dry weight of rhizomes.

Although the optimum temperature for foliage production by Kentucky bluegrass appears to be 90° or some temperature between 80° and 90°, considerable herbage production occurred at a temperature as low as 40°. Except for a lighter green color and the loss of chlorophyll at tips of the older leaves, which occurred to some extent at all temperatures but was more extensive at 40° and 50°, the foliage was normal in appearance at the lower temperatures.

The small amount of leaf growth made by Kentucky bluegrass at a temperature of 100° occurred during the first week of exposure after which no further growth was apparent. Visible symptoms of leaf injury at this temperature gradually increased until by the end of 4 weeks the leaves were severely wilted and depleted of chlorophyll, and after 8 weeks less than 10 per cent of the leaf shoots retained any green color.

Because of the severe injury suffered by Kentucky bluegrass at the 100° temperature and the apparent lack of any growth after the first few days, these cultures were removed from the growth chamber after 8 weeks of exposure and kept for 6 weeks at a temperature which did not exceed 90°. Less than 10 per cent of the injured plants failed to recover and renew their growth. New leaf growth in these cultures either originated from the crowns or resulted from the elongation of old leaves which had retained some green color near their base. However, all rhizomes were found to be living except the older ones, the tips of which had emerged and turned green during the initial period of growth. Most of the rhizomes appeared to be alive throughout their entire length and several exhibited leaf differentiation at the tips, although the growing points had not emerged and had not turned green. A few rhizomes which had several dead nodes at the proximal end were still alive and apparently growing at the distal end. One rhizome dead at both its distal and proximal ends had 3 living nodes from which lateral buds had begun to elongate. Although the growth of Kentucky bluegrass was stopped by an air and soil temperature of 100° and much of the plant tissue killed, yet enough of the tissue in the base of the leaf-shoots and in the rhizomes survived to permit a high degree of recovery when the plants were exposed to a lower temperature.

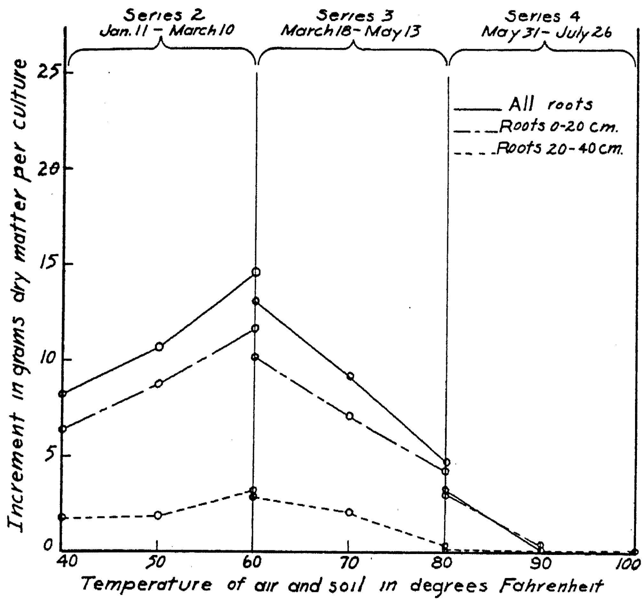

Fig. 3.—Relation of increment in dry matter of Kentucky bluegrass roots to temperature.

Figure 3 shows that Kentucky bluegrass roots made their maximum growth at 60°, although considerable growth occurred at the lowest temperature to which the cultures were exposed, 40.° As temperatures were raised above 60°, the growth rate declined sharply, approaching zero at 80° in the 20 to 40 centimeter level of soil and all root growth practically ceasing at 90°.

The average total increment in dry matter per culture of Kentucky bluegrass attained its maximum value at a temperature between 70° and 80°, being practically the same at these temperatures and only slightly lower at 60°. At temperatures below 60° or above 80° the total production of dry matter was much less, although the total production at 40° was substantial.

The curves in Figure 4 (Table 7) show that the increase in total number of rhizomes was most rapid at a temperature of 60°. The number of rhizomes produced at 60° in series 3 was smaller than the number developed at the same temperature in series 2 while the number produced at a temperature of 80° in series 4 exceeded that produced at a like temperature in series 3. However, the smaller number of rhizomes produced per culture in series 3 as compared with that in series 2 appeared to have been off-set by a greater in-

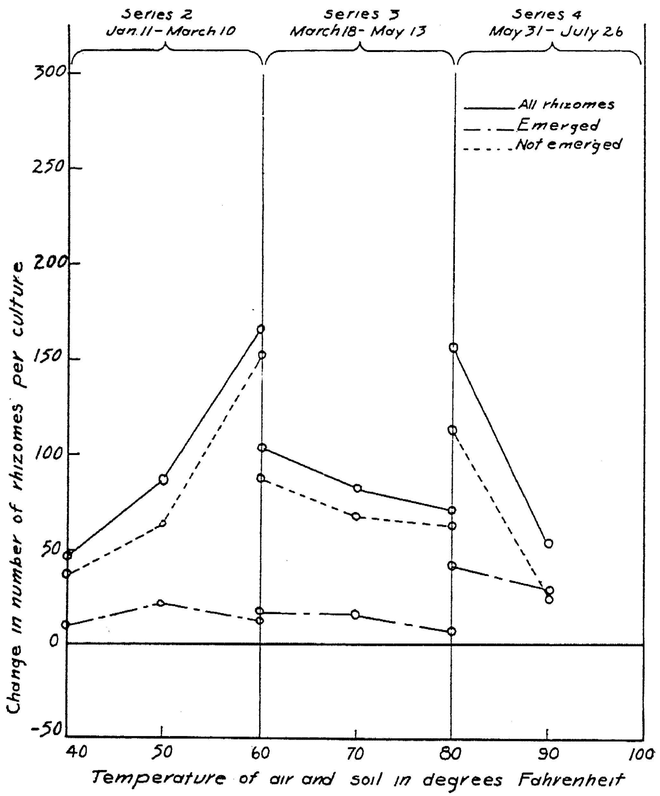

Fig. 4.—Relation of the number of rhizomes produced by Kentucky bluegrass and their emergence to temperature.

crease in size of the rhizomes produced in series 3, since the increment in dry weight of rhizomes was practically the same at 60° in the two series. That the rhizomes in the cultures of series 3 were actually longer than those in series 2 is shown in table 8. Since rhizome production as represented by both increase in number and increment in dry matter was larger at a temperature of 80° in series 4 than at the same temperature in series 3, it appears that the summer period—May 31 to July 26—was actually more favorable to rhizome production by Kentucky bluegrass than the earlier period with its shorter photoperiod.

The curves in Figure 4 also show that the majority of rhizomes remained below the soil line and that their emergence was not much influenced by temperatures between 40° and 80°. At 90°, however, the increase in number of emerged rhizomes slightly exceeded the increase in number remaining below the soil line, indicating a somewhat greater tendency for the growing points of rhizomes to emerge at the higher temperature.

Rhizomes of Kentucky bluegrass showed a greater tendency to elongate at temperatures of 60° and 70° than at higher or lower temperatures (Table 8).

Canada bluegrass.—Figure 5 (Tables 4, 5, and 6) shows that a considerable increment in the dry weight of herbage and rhizomes

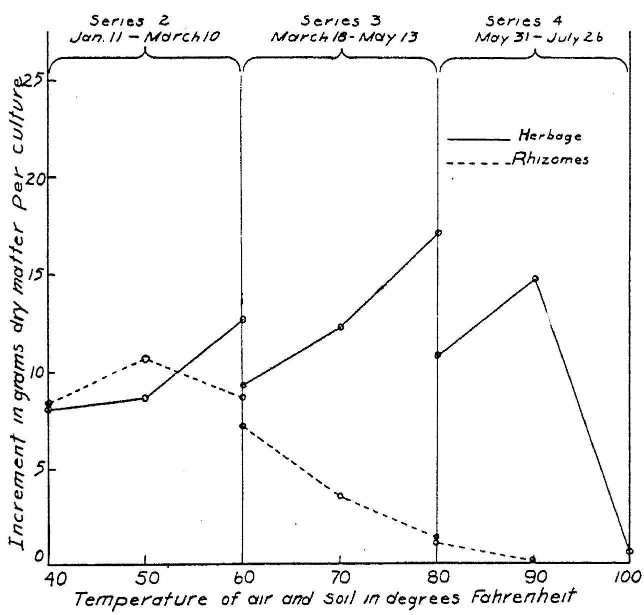

Fig. 5.—Relation of increment in dry matter of Canada bluegrass herbage and rhizomes to temperature.

occurred in cultures of Canada bluegrass at air and soil temperatures as low as 40°. Except for a loss of chlorophyll at the tips of the older leaves and a lighter shade of green color, the foliage of Canada blue grass exposed to a 40° temperature was entirely normal in appearance. Herbage production increased with rising temperature up to 90°, and then fell almost to zero at 100°. The temperature-growth curve for Canada bluegrass herbage, like that for Kentucky bluegrass, is discontinuous, as if each succeeding period of time from January 11 to July 26 was less favorable for growth than the one which preceded it.

Rhizome production, measured in terms of dry matter increment, attained its maximum value at 50°, at which temperature it considerably exceeded average herbage production per culture. At higher temperatures rhizome production declined rather sharply, almost ceasing at 90°.

Symptoms of heat injury appeared sooner at the 100° temperature in Canada bluegrass than in the case of Kentucky bluegrass. At the end of 4 weeks exposure the leaves were severely damaged and by the end of 8 weeks all foliage was entirely brown in one culture and less than 5 per cent of the leaf-shoots in the other two exhibited any green color even at their base.

The three cultures of Canada bluegrass exposed to the 100° temperature were retained for 6 weeks at a temperature which did not exceed 90° to determine whether the injured plants had actual-

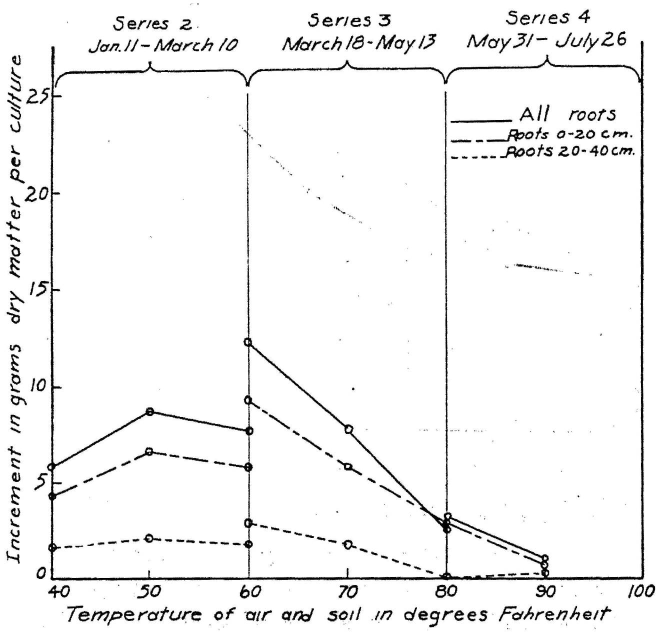

Fig. 6.—Relation of increment in dry matter of Canada bluegrass roots to temperature.

ly been killed. At the end of this period, slightly over 50 per cent of the plants appeared to be entirely dead, and those which recovered grew much more slowly than Kentucky blue grass plants exposed to the same temperature. Only one green shoot developed from a rhizome during the six weeks period, all others originating from crowns. No rhizome was found which was not dead at its distal end, most of them having emerged above the soil line before or during the first few days of exposure to the 100° temperature. The first 2 or 3 nodes at the proximal end of a few rhizomes were alive and lateral buds were beginning to elongate from these. One rhizome killed at both its proximal and distal ends had a living node from which a lateral shoot had developed and emerged above the soil line.

The temperature-growth curves in Figure 6 (Tables 4, 5, and 6) show 50° to be the optimum temperature for root growth by Canada bluegrass under the conditions of this experiment. Above 60°, root growth declined sharply with each 10° elevation in temperature so that total root growth at 80° was much less than that at 40.° As in Kentucky bluegrass, root growth in the lower soil levels, as represented by net increment in dry weight, ceased at 80°, while root growth in both levels was almost completely suppressed at 90°.

The maximum total production of dry matter was made by cultures of Canada bluegrass at 60° (Tables 4, 5, and 6), the larger herbage yields at higher temperatures being over-balanced by the decreased production of roots and rhizomes.

The total number of rhizomes produced by Canada bluegrass cultures was relatively high at an air and soil temperature of 40°, increased as the temperature rose to 50° and then fell with every elevation in temperature above that point (Table 7, Figure 7).

At a temperature of 40°, a large proportion of the rhizomes remained below the soil line, and as the temperature rose from 40° to 50°, this condition was only slightly altered. However, at 60° in series 2, the increase in number of emerged rhizomes considerably exceeded that of those which remained below the soil line, indicating an increased tendency for rhizomes to emerge as the temperature rises.

The increase in the number of rhizomes produced at a temperature of 60° in series 2 was more than double the number produced per culture at the same temperature in series 3 (Figure 7). Therefore, the period lasting from January 11 to March 10 having an average day length of 10.8 hours was apparently more favorable to the multiplication of rhizomes by Canada bluegrass than the period of March 18 to May 13 during which the average photoperiod was 13.2 hours. Furthermore, rhizomes seemed to have a greater tendency to emerge above the soil line during the period characterized by the longer day.

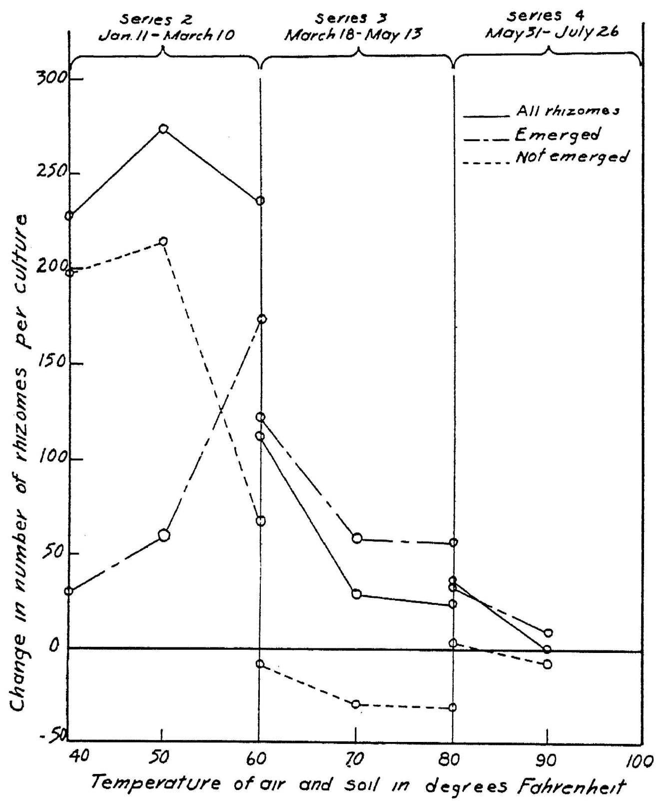

Fig. 7.—Relation of the number of rhizomes produced by Canada bluegrass and their emergence to temperature.

Rhizomes of Canada bluegrass decreased in average length with every rise in temperature above 40° (table 8).

The relative quantities of rhizomes produced by Kentucky and Canada bluegrass at the different temperatures are illustrated by Figure 8.

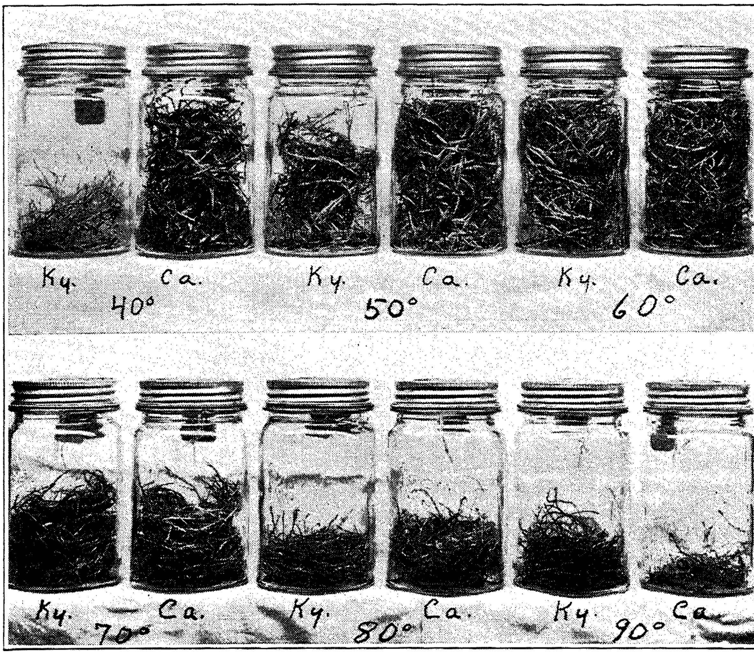

Fig. 8.—Quart jars each of which contains the rhizomes from 3 cultures of Kentucky or Canada bluegrass after 8 weeks' exposure to air and soil temperatures of 40°, 50°, 60°, 70°, 80°, and 90°F.

Orchard grass.—The curve in Figure 9 (Tables 4, 5, and 6) shows that herbage production by orchard grass reached its peak at 70°. However, the curve is very flat within a temperature range of 50° to 80°, indicating that within these limits foliage production is not greatly influenced by differences in air and soil temperatures. Top growth was fairly active at 40° but dropped abruptly when the temperature was elevated from 80° to 90° and practically ceased at 100°.

Symptoms of leaf injury appeared at the 100° temperature within the first week and as exposure to this temperature continued, it was evident that orchard grass was more severely injured than either Canada or Kentucky bluegrass. Many orchard grass plants appeared to be entirely dead by the end of 4 weeks of exposure and at the end of 8 weeks, only one of the 75 plants grown at this temperature retained any visible green color. However, during the next 6 weeks when these cultures were kept at a temperature ranging downward from 90°, four plants renewed growth, although their recovery was very slow.

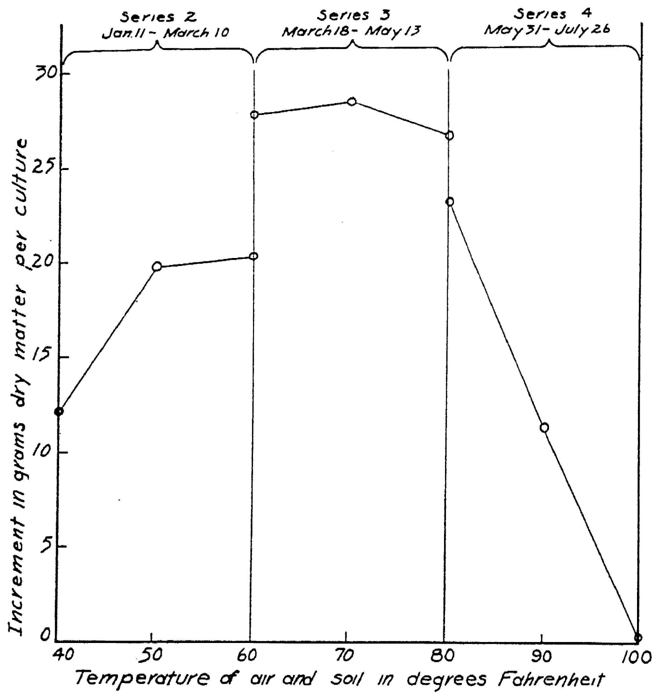

Fig. 9.—Relation of increment in dry matter of orchard grass herbage to temperature.

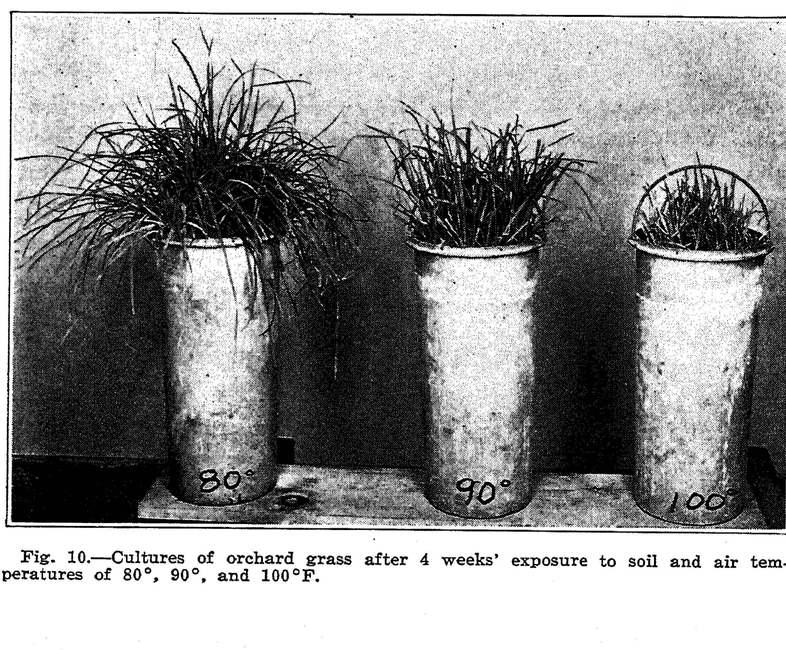

Fig. 10.—Cultures of orchard grass after 4 weeks' exposure to soil and air temperatures of 80°, 90°, and 100°F.

The general appearance of the orchard grass cultures grown at temperatures of 80°, 90°, and 100° is shown by Figure 10.

The curves in Figure 11 (Tables 4, 5, and 6) show that a substantial root growth occurred at a temperature of 40° and that the rate of growth increased with rising temperature up to 60°. The rate of total root growth reached at 60° was maintained at a temperature of 70°, declined sharply as the temperature rose to 80°, and practically ceased at 90°. In the lower soil levels—20 to 40 centimeters—root growth was not materially affected by changes in temperature from 40° to and including 80°.

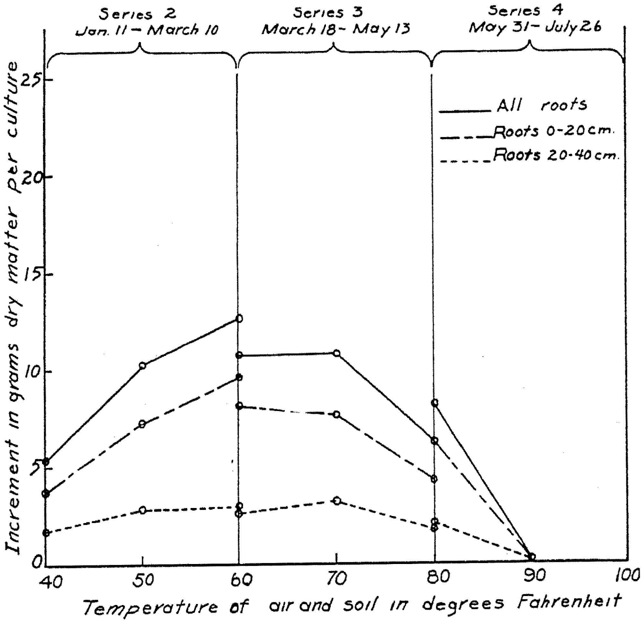

Fig. 11.—Relation of increment in dry matter of orchard grass roots to temperature.

As compared with Kentucky and Canada bluegrass, orchard grass had a lower optimum temperature for top-growth, a higher optimum temperature for total root growth, and the growth of orchard grass roots in the 20 to 40 centimeter soil level was depressed to a much smaller extent by an 80° temperature. Like Canada bluegrass, orchard grass made its largest total production of dry matter at a temperature of 60°.

The larger herbage production by orchard grass cultures grown at a temperature of 60° from March 18 to May 13, than that of cultures exposed to the same temperature from January 11 to March 10 (Figure 9), indicates that the later period was more favorable for top-growth. The smaller herbage increment made by orchard grass cultures at a temperature of 80° in series 4 as compared with that produced at the same temperature by cultures included in series 3 is of doubtful significance because of the difference in the initial growth of these two series of cultures (Table 2). Whatever the factors responsible for differences in herbage production at like temperatures in successive periods may have been, their effect on root growth (Figure 11) appeared to be the opposite of their effect on top growth.

Bermuda grass.—Unlike Kentucky and Canada bluegrass and orchard grass, Bermuda grass made no growth at a temperature of 40°. Within 4 days after the beginning of exposure to this temperature some leaves showed symptoms of wilting. After 2 weeks of exposure to the 40° temperature Bermuda grass leaves were severely wilted and some had died and were drying up, while at the end of 4 weeks nearly all foliage appeared to be dead. When the cultures exposed to the 40° temperature were removed from the growth chamber on March 10, only a few pale green leaves in each gave evidence that the plants might still be alive. Therefore, these cultures were kept in the greenhouse at temperatures of from 60° to 70° to determine the extent to which they might recover from the effects of low temperature. After 10 days all except 3 apparently dead plants had renewed their growth, not only at the base of culms, but also from nodes considerably removed from the crowns. Although these cultures were not measured for growth, it was evident that none had occurred during exposure to the 40° temperature.

The cultures exposed to the 50° temperature also exhibited symptoms of severe injury to the foliage. Not only did the leaves partially wilt but approximately 25 per cent of them died, another 25 per cent had their green color obscured by the presence of anthocyanin, while the remainder were pale green in color. Except for the presence of anthocyanin in the culms and some leaves, the tops of Bermuda grass grown at the 60° temperature were normal in appearance. The anthocyanin content of culms and leaves, as indicated by visible red color, decreased with increasing temperature up to 100°, at which temperature no red color was observed. While there were no visible symptoms of injury to Bermuda grass at the 100° temperature, the leaves were somewhat darker green in color at 80° than at higher temperatures.

The temperature-growth curve for herbage increment in Figure 12 (Tables 4, 5, and 6) shows that top growth increased with each 10° rise in temperature from 40° to 100°, but that growth at like temperatures in each succeeding series was less than in the preceding series.

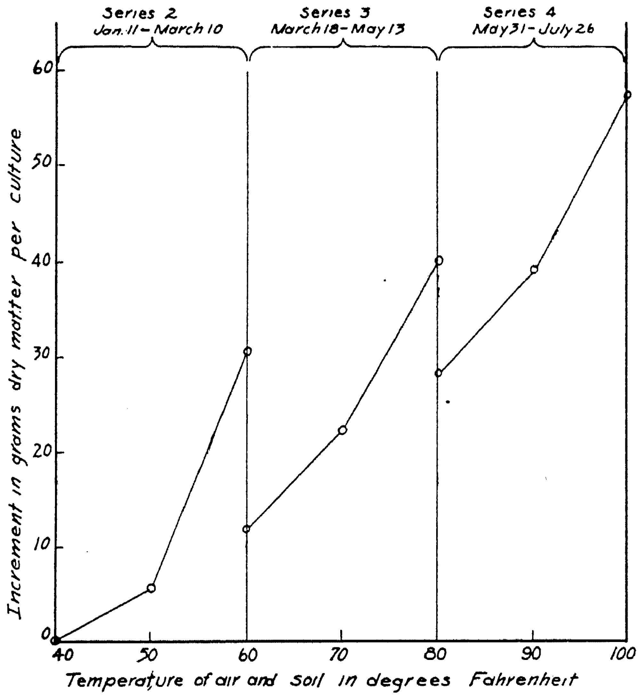

Fig. 12.—Relation of increment in dry matter of Bermuda grass herbage to temperature.

The general appearance of Bermuda grass cultures exposed to temperatures ranging from 40° to 60° and from 80° to 100° is shown by Figures 13 and 14.

Root growth, which was not determined for cultures grown at the 40° temperature, was quite small at 50° but increased sharply when the temperature was raised from 50° to 60°. Each additional 10° rise in temperature from 60° to 100° resulted in an increase in the rate of root growth. In considering the sharp break in the temperature-growth curves for Bermuda grass roots between series 2 and 3 (Figure 15) it should be recalled that the cultures included in series 2 received no defoliation while the cultures included in series 3 and 4 were cut back both before and during the period

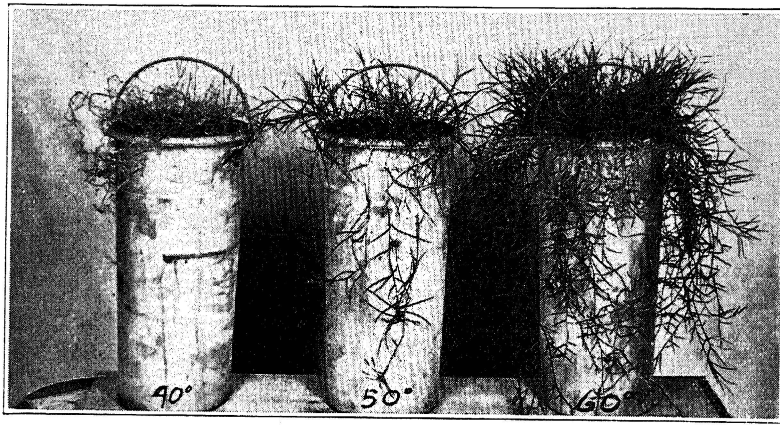

Fig. 13.—Cultures of Bermuda grass after 8 weeks' of exposure to soil and air temperatures of 40°, 50°, and 60°F.

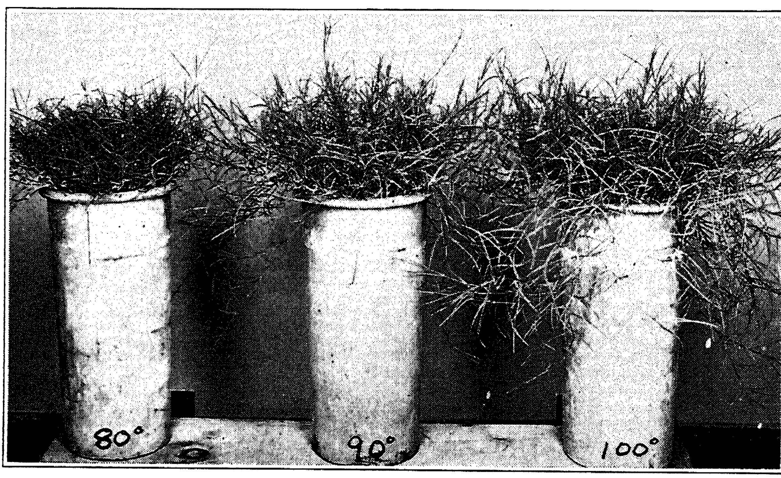

Fig. 14.—Cultures of Bermuda grass after 4 weeks' exposure to soil and air temperatures of 80°, 90°, and 100°F.

of exposure to controlled temperatures. Bermuda grass appeared to be more adversely affected by defoliation than the other grasses under investigation.

While Bermuda grass grown in the field produces rhizomes abundantly, none were produced in the cultures included in series 2, 3, and 4.

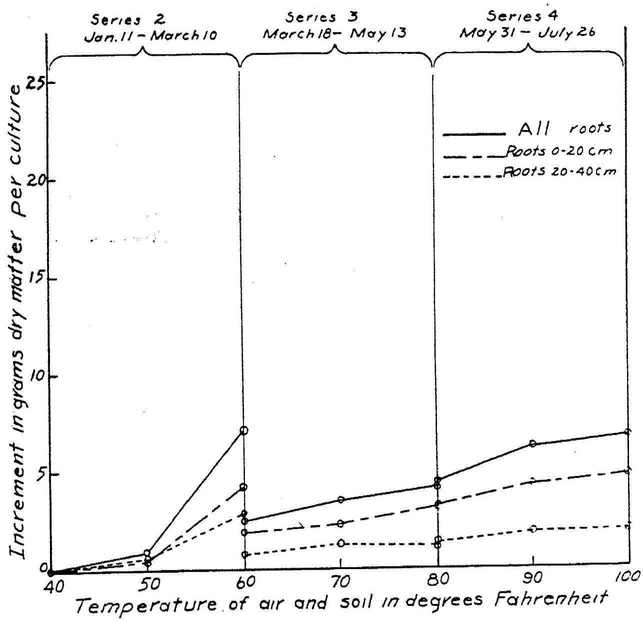

Fig. 15.—Relation of increment in dry matter of Bermuda grass roots to temperature.

Effect of Air Temperature on Growth. Series 5

In this series the cultures were exposed to continuous air temperatures of 70°, 85°, and 100° while the temperature maintained by the soil temperature tanks was 70° in all three growth chambers. Under these conditions, the temperature of the soil near the surface was influenced by the air temperature and by the radiant heat of the sun (Table 9). Thus, soil temperature measured to a depth of 2.5 centimeters at 1 P. M. on a clear day was 79° with an air temperature of 70°, 86° with an air temperature of 85°, 93° with an air temperature of 100°. At these same air temperatures, the soil temperature at a depth of 10.1 to 12.7 centimeters varied only slightly from the temperature of the tanks even on a clear day, being 71°, 72°, and 73° respectively. Presumably the temperature at lower soil levels was the same as that of the tanks. At 1 P. M. on a cloudy day, the soil temperature to a depth of 2.5 centimeters was 69° with an air temperature of 70°, 74° with an air temperature of 85°, and 79° with an air temperature of 100°. Under the same conditions, soil temperatures at a depth of 10.1 to 12.7 centimeters were 69°, 70°, and 70° respectively.

Kentucky bluegrass.—Herbage, rhizome, and root growth at the different air temperatures with the soil temperature tanks held at 70° are shown by the data in Table 10 and the curves in Figure 16.

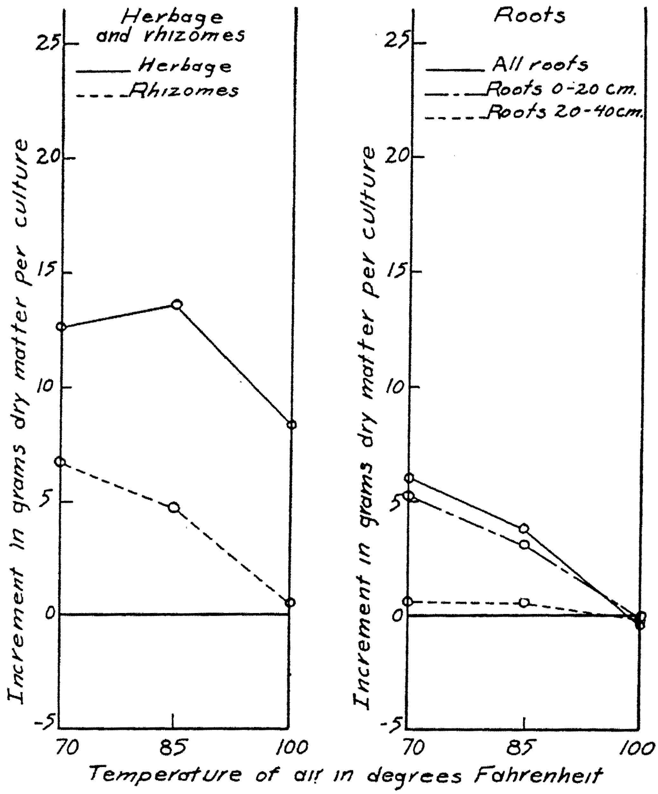

Fig. 16.—Relation of increment in dry matter of Kentucky bluegrass herbage, rhizomes, and roots to air temperatures.

Herbage production increased slightly with the elevation of the air temperature from 70° to 85° but declined rather sharply with a further rise in temperature to 100°. However, a considerable increment in foliage occurred at an air temperature of 100° when the soil, except in its upper levels, was maintained at a temperature of 70°, whereas it has been shown (series 4) that almost no leaf growth occurred when both soil and air temperatures were 100°. Furthermore, the leaves remained unwilted and fully green, except for small brown areas near the tips of some leaves, during 8 weeks of exposure to an air temperature of 100° while the foliage was withered and almost entirely brown at the end of a like period of exposure to a soil and air temperature of 100°.

Root and rhizome production declined with each rise in air temperature, accompanied as it was by a rise in the temperature of the upper soil levels. The growth of rhizomes practically ceased at the higher temperature while the roots showed an actual loss in dry weight at the 100° air temperature.

Total increment in dry matter also declined with each rise in air temperature from 70° to 100° (Table 10).

The curves in Figure 17 (Table 11) show that the rate at which Kentucky bluegrass rhizomes increased in number declined slightly

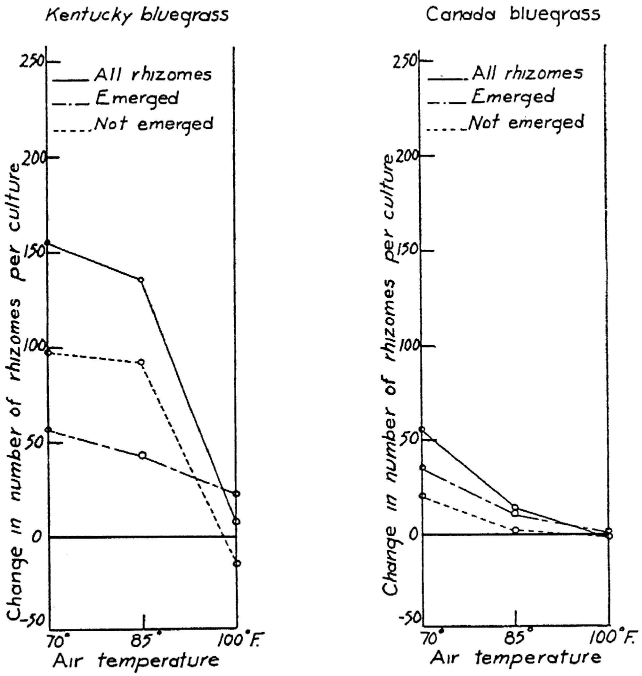

Fig. 17.—Relation of the number of rhizomes produced by Kentucky bluegrass and Canada bluegrass and their emergence to air temperature.

as the air temperature rose from 70° to 85° and abruptly with a further rise to 100°. At the higher temperature, however, the rhizomes exhibited a greater tendency to emerge above the soil line.

With each increase in air temperature, the average length of rhizomes was also reduced (Table 12).

What might have occurred had it been possible to maintain a temperature of 70° throughout the soil when the air temperature was 100° is problematical, but it is evident that an air temperature of 100° is less destructive in its effect on Kentucky bluegrass than an air and soil temperature of 100°.

Canada bluegrass.—Herbage, rhizome, and root increment in cultures of Canada bluegrass declined with each rise in air temperature (Table 10 and Figure 18). The dry weight increase in rhizomes,

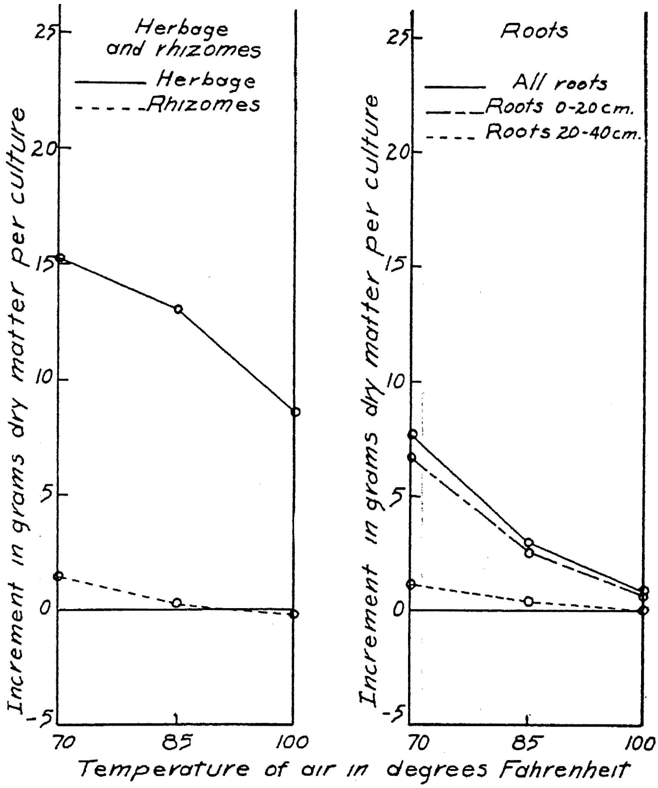

Fig. 18.—Relation of increment in dry matter of Canada bluegrass herbage, rhizomes and roots to air temperature.

and of roots in the 20 to 40 centimeter soil level, was rather small at all air temperatures employed in this series, the rhizomes showing a small net loss in dry weight at an air temperature of 100°. However, that the 100° air temperature was not nearly so destructive as a soil and air temperature of 100° is evidenced by the herbage increment at the higher air temperature and by the green unwilted condition of the leaves after 8 weeks of exposure.

The curves in Figure 17 show the increment in number of rhizomes to have diminished with each increase in air temperature and a somewhat more pronounced tendency for their growing points to emerge as air temperature was elevated. The elongation of rhizomes also decreased with increasing air temperature (Table 12).

Orchard grass.—Orchard grass resembled Kentucky bluegrass in that herbage increment increased with a rise in air temperature from 70° to 85° and then declined sharply with a further elevation to 100° (Table 10, Figure 19). Furthermore, a substantial top growth did

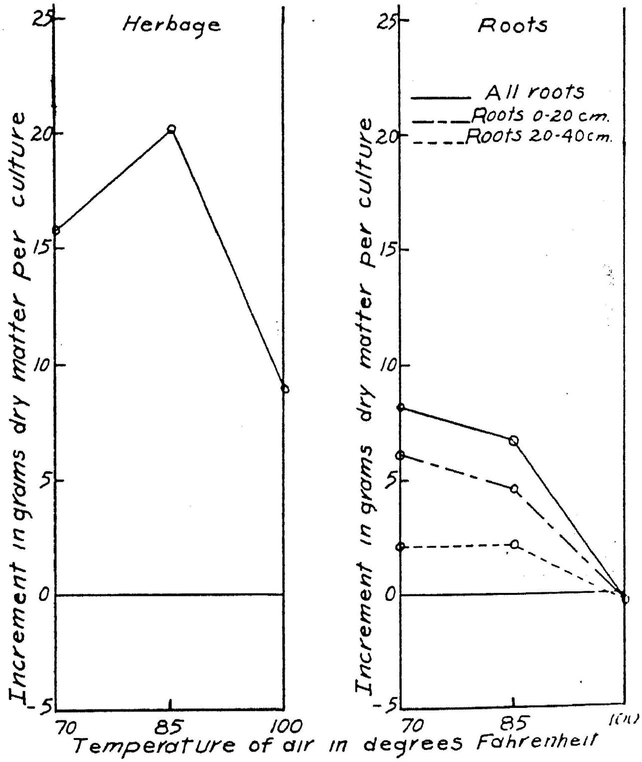

Fig. 19.—Relation of increment in dry matter of orchard grass herbage and roots to air temperatures.

occur at the highest air temperature and the foliage was apparently uninjured as contrasted with the almost complete death of leaf tissue at a soil and air temperature of 100°. Root growth declined in the upper soil levels as air temperature rose from 70° to 85° and ceased entirely in both levels at an air temperature of 100°.

Bermuda grass.—Herbage production by cultures of Bermuda grass grown at an air temperature of 85° was more than double that produced by cultures exposed to the 70° air temperature (Table 10, Figure 20). However, a further rise in air temperature, while the temperature of a large portion of the soil was held at 70°, resulted in a slight decrease in the dry weight increment of herbage. Furthermore, the leaves exposed to an air temperature of 100° and a lower soil temperature, were slightly withered and somewhat lighter in color near their tips. No such evidence of leaf injury had appeared in cultures of series 4 exposed to a soil and air temperature of 100°.

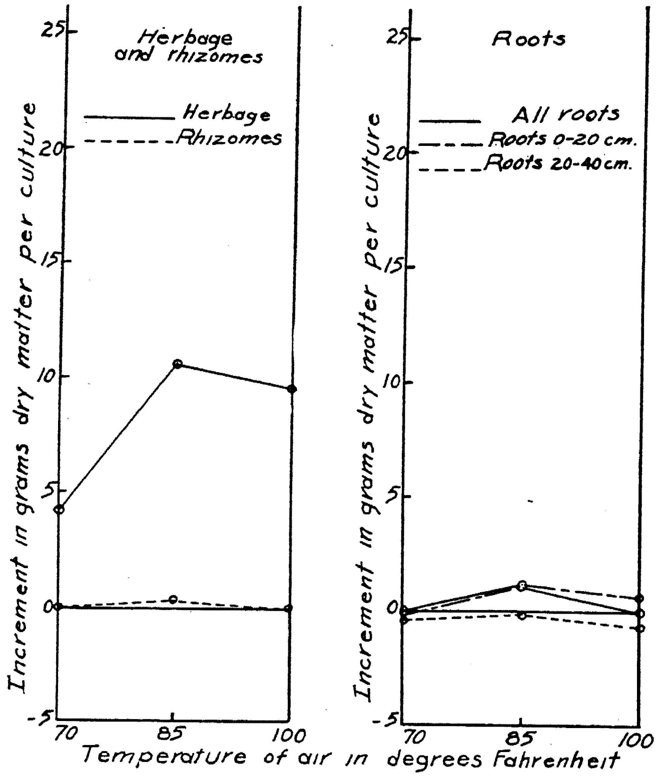

Fig. 20.—Relation of increment in dry matter of Bermuda grass herbage, rhizomes, and roots to air temperature.

Very little root growth occurred at any of the air temperatures employed in series 5, the total growth being slightly greater at an air temperature of 85° than at a lower or higher air temperature. Roots in the 20 to 40 centimeter soil level decreased slightly in dry matter at all three air temperatures.

The lack of any provision for the control of relative humidity in the growth chambers has been pointed out. However, relative humidity was measured and recorded during the exposure of each series of cultures to controlled temperatures. The data in table 3 show that the average relative humidity, from 6 A. M. to 6 P. M., as well as for the entire day, was considerably lower in the growth chamber having an air temperature of 100° (series 5) than in those in which lower air temperatures were maintained. The average relative humidity from 6 A. M. to 6 P. M. in growth chambers in which the air temperatures were maintained at 70°, 85°, and 100° was 56, 57, and 36 per cent respectively.

Effect of Diurnal Variations in Temperature on Growth. Series 6

The temperatures used in series 2 to 5 were constant except for variations occurring in the surface soil induced by variations in the intensity of the radiant energy of sunlight incident on the more or less exposed soil surface. In series 6, however, air temperatures were varied in one growth chamber from 60° at night to 80° during the day and in another from 50° to 90°. The air temperature in the third growth chamber and tank temperatures in all three were held constant at 70°. The change from night to day temperatures was made at 8 A. M. while the change from day to night temperatures was made at 10 P. M. except in the case of the 50° - 90° growth chamber following a clear day when the air temperature was lowered at 7 P. M. The relative duration of high and low air temperatures was adjusted on the basis of previous measurements to provide an average daily temperature of 70° in the surface 2.5 centimeter layer of soil.

Kentucky bluegrass.—The curves in Figure 21 (Table 13) show that herbage production by Kentucky bluegrass was higher at the variable temperatures and highest where the range in variation was greatest, but rhizome and root growth were less at variable than at constant temperatures. Comparing these results with those previously reported for series 3 and 4 (Tables 5 and 6) the general trend of the growth of both tops and underground portions was the same when the plants were exposed to temperatures of 70°, 80°, and 90° during only a part of the day (series 6) as when they were exposed to the same temperatures continuously. However, the increment in dry weight of rhizomes was not reduced to as low a level by an air temperature maintained at 90° during approximately one-half of each day as by a temperature maintained constantly at this level. The same is true of root production, particularly in the lower soil levels where the temperature did not vary from the 70° temperature at which the soil temperature tanks were maintained.

The increment in total dry matter per culture (Table 13) declined as the day temperature became higher, even though the temperature was lowered correspondingly at night.

The increment in number of rhizomes per culture of Kentucky bluegrass decreased as the spread between day and night tempera-

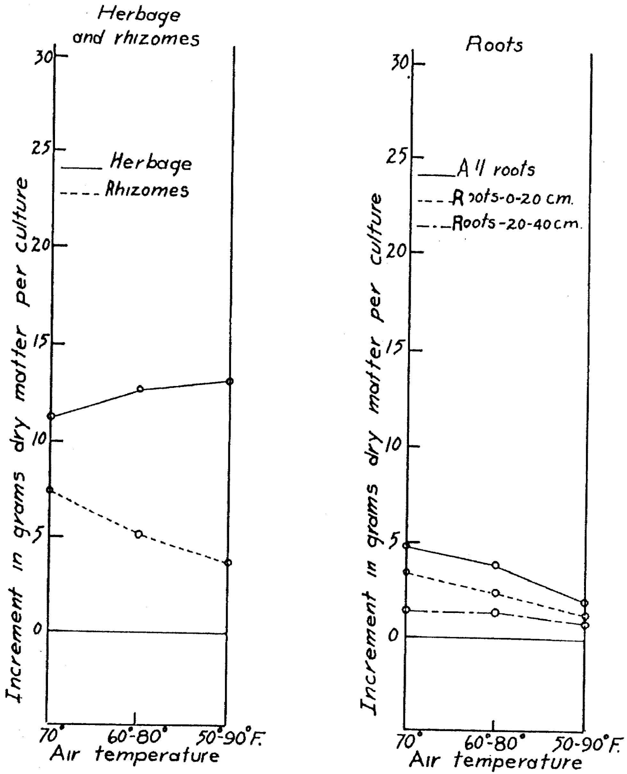

Fig. 21.—Relation of increment in dry matter of Kentucky bluegrass herbage, rhizomes, and roots to diurnal variations in temperature.

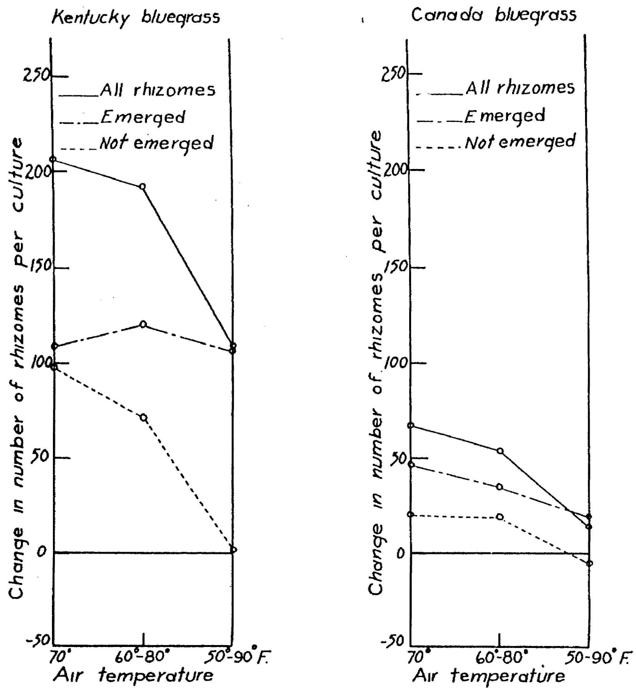

Fig. 22.—Relation of the number of Kentucky and Canada bluegrass rhizomes produced and their emergence to diurnal variations in temperature.

tures widened (Table 14 and Figure 22) and a larger percentage of the rhizomes emerged above the soil line. The average length of rhizomes was greatest at a constant temperature of 70° (Table 15), and least where the range in air temperature was from 60° to 80°.

Canada bluegrass.—Herbage production by Canada bluegrass differed little whether the temperature was held constant at 70° or varied daily 10° to 20° above and below 70° as an average (Table 13 and Figure 23). Rhizome production, which was low at all temperatures employed in this series, decreased as the day temperature became higher. The trend of root development was also downward as

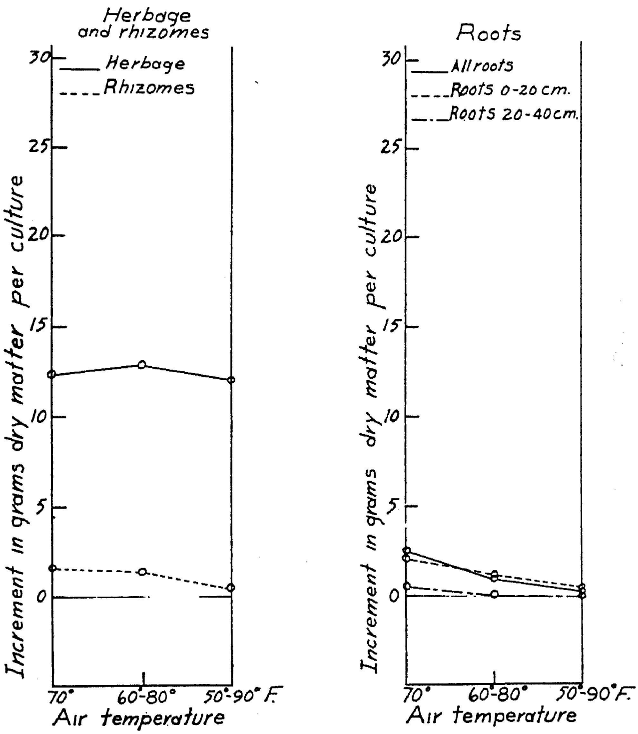

Fig. 23.—Relation of increment in dry matter of Canada bluegrass herbage, rhizomes and roots to diurnal variations in temperature.

the day temperature rose. Furthermore, the high day temperature of air and upper soil levels appeared to depress root growth even in the lower soil levels where temperature did not vary from 70°. The increment in total dry matter per culture became less as the variation in temperature from an average of 70° became wider.

The increment in number of rhizomes per culture of Canada bluegrass became less (Table 14 and Figure 22), a larger proportion of them emerged above the soil line, and they decreased in average length with each rise in the day temperature (Table 15).

Orchard grass.—Herbage production by orchard grass was increased to a slight extent by the relatively high day temperature of 90° and low night temperature of 50° as compared with the production at the constant 70° temperature, while root growth declined slightly (Table 13, Figure 24). However, since the decrease in root

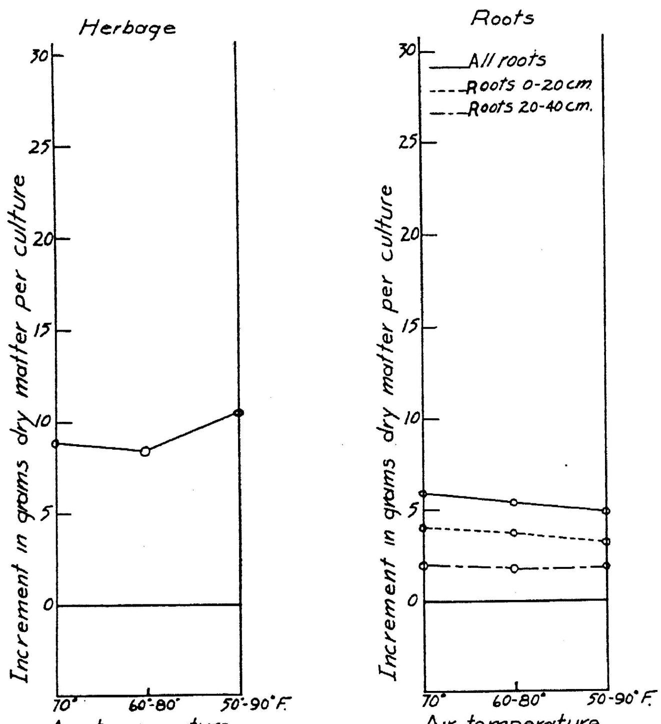

Fig. 24.—Relation of increment in dry matter of orchard grass herbage and roots to diurnal variations in temperature.

growth was less than the increase in top growth which accompanied the widest variation in temperature, the largest increment in total dry matter per culture of orchard grass occurred where the daily temperature range was from 50° to 90°.

Bermuda grass.—The curves in Figure 25 (Table 13) show that herbage production by cultures of Bermuda grass increased with increasing day temperatures even though the higher day temperature

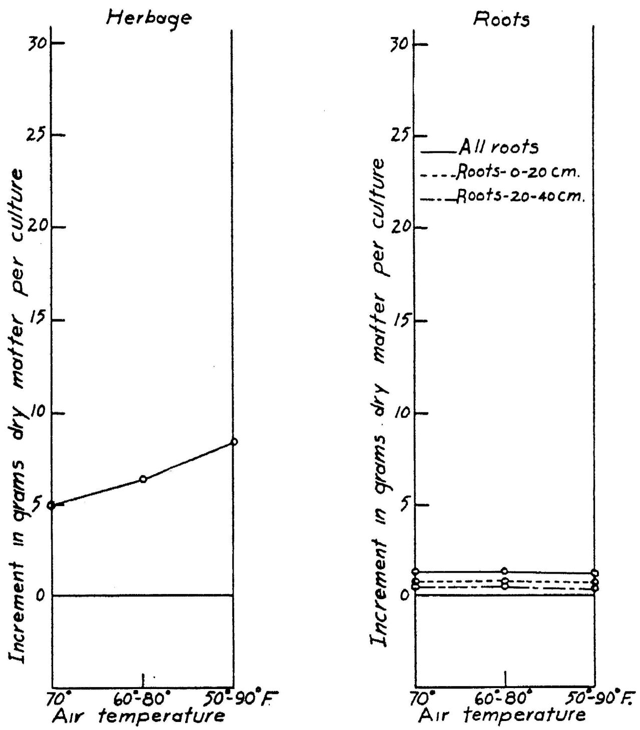

Fig. 25.—Relation of increment in dry matter of Bermuda grass herbage and roots to diurnal variations in temperature.

in each case was offset by a correspondingly lower night temperature. Root growth, however, was practically the same whether the temperatures varied or remained constant, so long as the average temperature remained the same.

Effect of Temperature on Chemical Composition when Air and Soil Temperatures are the Same and Constant. Series 2, 3, and 4.

Each sample was analyzed by the standard method used for feed analysis by which the moisture, ash, crude protein, ether extract, crude fiber, and nitrogen-free extract content were determined. The percentage of each constituent except water was then calculated on a water free basis.

Kentucky bluegrass.—The curves in Figure 26 (Tables 16 to 18) show that the nitrogen-free extract content of herbage, roots and rhizomes, with one exception, declined with each 10° rise in temperature from 40° to 90°. The percentage of this constituent in the rhizomes between the temperatures 60° and 80° is the exception, for a slight increase in nitrogen-free extract content occurred as the temperature rose. The roots and rhizomes contained a somewhat

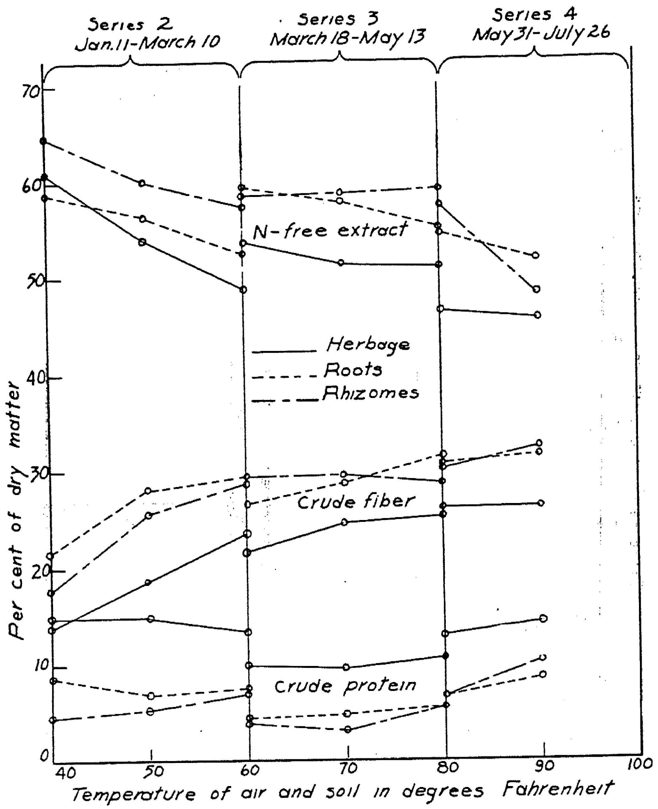

Fig. 26.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of Kentucky bluegrass to temperature.

higher percentage of nitrogen-free extract than the herbage at all temperatures employed, except 40°, at which temperature this constituent was higher in herbage than in roots.

Crude fiber content, on the other hand, showed an upward trend with each rise in temperature, except in the case of rhizomes between the temperatures of 60° and 80° in series 3. A smaller percentage of the dry matter in the herbage consisted of crude fiber than in either roots or rhizomes.

Variations in the crude protein content are smaller and their relation to temperature is less evident than that of the nitrogen-free extract and crude fiber content.

The data in tables 16 to 18 show that variations in the ether extract content of roots and rhizomes showed no definite trend in relation to temperature. However, an upward trend in the percentage content of this constituent in the herbage with rising temperature from 40° to 70° is indicated, while at higher temperatures the percentage of ether extract remained nearly constant.

Canada bluegrass.—The same downward trend in the nitrogen-free extract content, expressed as percentage of dry matter, previous-

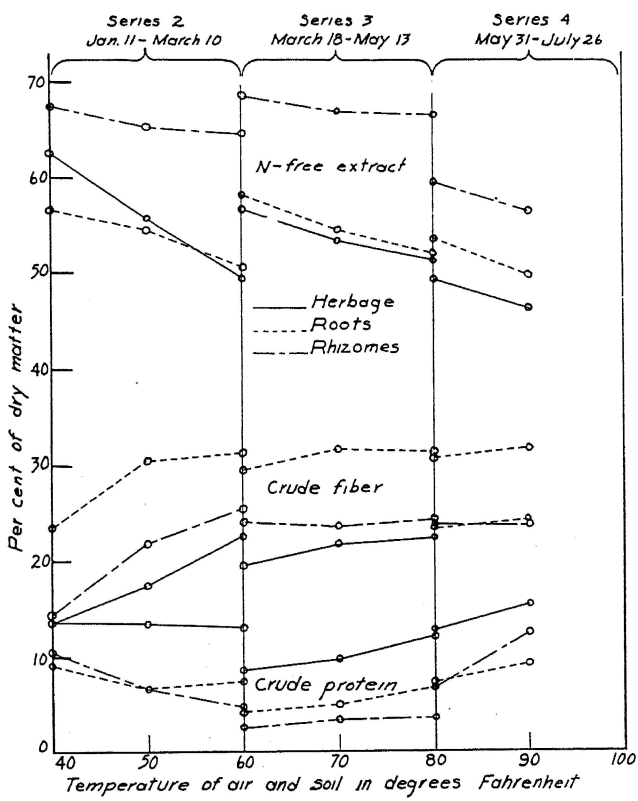

Fig. 27.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of Canada bluegrass to temperature.

ly shown to accompany a rising temperature in Kentucky bluegrass (Figure 26) also occurred in the herbage, roots, and rhizomes of

Canada bluegrass (Figure 27, Tables 19 to 21). At all temperatures employed in series 2, 3, and 4, the percentage content of nitrogen-free extract in the rhizomes was considerably higher than that in the herbage or roots.

The percentage content of crude fiber in the roots increased with rising temperature from 40° to 50° and in the herbage and rhizomes up to 60°, and then remained nearly constant in all three plant parts with further temperature changes up to 90°. The crude fiber content of roots, on a percentage basis, was considerably above that of herbage or rhizomes at all temperatures.

The concentration of crude protein in the herbage changed little between temperatures of 40° and 60° and then increased with rising temperature up to 90°. The percentage content of this constituent declined in the roots as the temperature rose from 40° to 50° and in the rhizomes up to a temperature of 60° and then increased with each 10° elevation in the temperature beyond those points. The herbage contained a higher percentage of crude protein than roots or rhizomes.

As in the case of Kentucky bluegrass, the percentage content of ether extract in the roots and rhizomes showed little or no relation to temperature (Tables 19 to 21) while the concentration of this constituent increased in the leaves with rising temperature up to 80° and declined slightly with a further temperature rise to 90°.

Orchard grass.—The curves in Figure 28 show that the percentage of nitrogen-free extract in orchard grass herbage and roots steadily declined with each 10° rise in temperature from 40° to 90°. At the lower temperatures—40° to 60°—the concentration of this constituent was higher in the tops, but at temperatures above 70°, the roots contained the higher percentage of nitrogen-free extract.

The crude fiber content, expressed as percentage of dry matter, increased with rising temperature up to 60° in the roots and up to 80° in the herbage. Above these temperatures, crude fiber decreased relative to dry matter, although this decline in the roots was slight. At all temperatures compared the percentage of crude fiber in the roots considerably exceeded that in the herbage.

The percentage of crude protein in both roots and tops of orchard grass declined considerably as the temperature to which the cultures were exposed rose from 40° to 50° and then more gradually with a further 10° rise in temperature. At temperatures above 70° the concentration of crude protein increased with each rise in temperature and the curves became more steep as the temperature became higher.

The curve representing the crude protein content of foliage is nearly parallel with that for roots, the crude protein content of the herbage being higher at all temperatures.

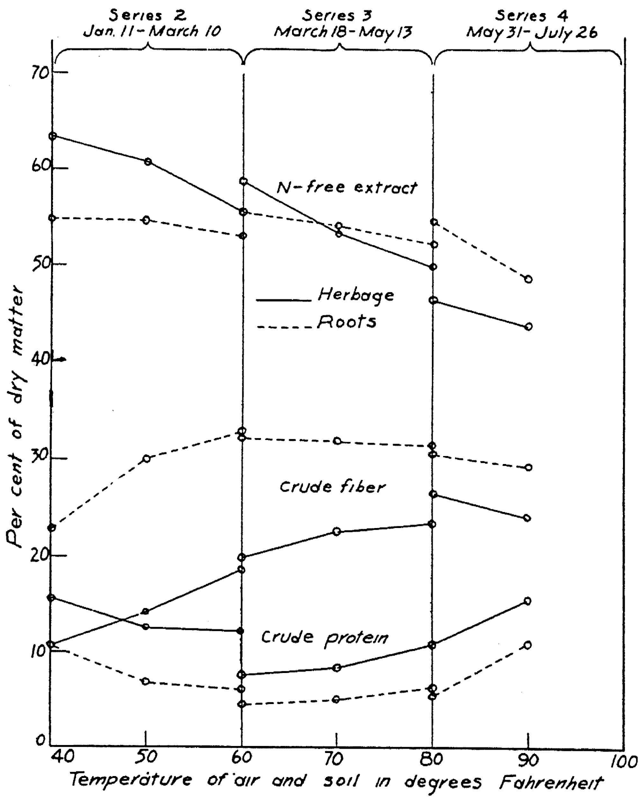

Fig. 28.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of orchard grass to temperature.

Tables 22 to 24 also show that the percentage of ether extract in both herbage and roots of orchard grass increased as the temperature rose from 40° to 60°, from 1.70 per cent to 3.26 per cent in the herbage and from 0.13 per cent to 0.50 per cent in the roots. At higher temperatures, there was little change in the percentage content of this constituent.

Bermuda grass.—The percentage of nitrogen-free extract found in herbage and roots of Bermuda grass, instead of decreasing with rising temperature as has been shown for Kentucky and Canada bluegrass and orchard grass, increased gradually with each 10° rise in temperature from 50° to 100° (Tables 25 to 27 and Figure 29.)

The percentage content of nitrogen-free extract was higher in herbage than in roots in each case.

The crude fiber content of Bermuda grass increased with a rise in temperature from 50° to 60° and remained practically unchanged

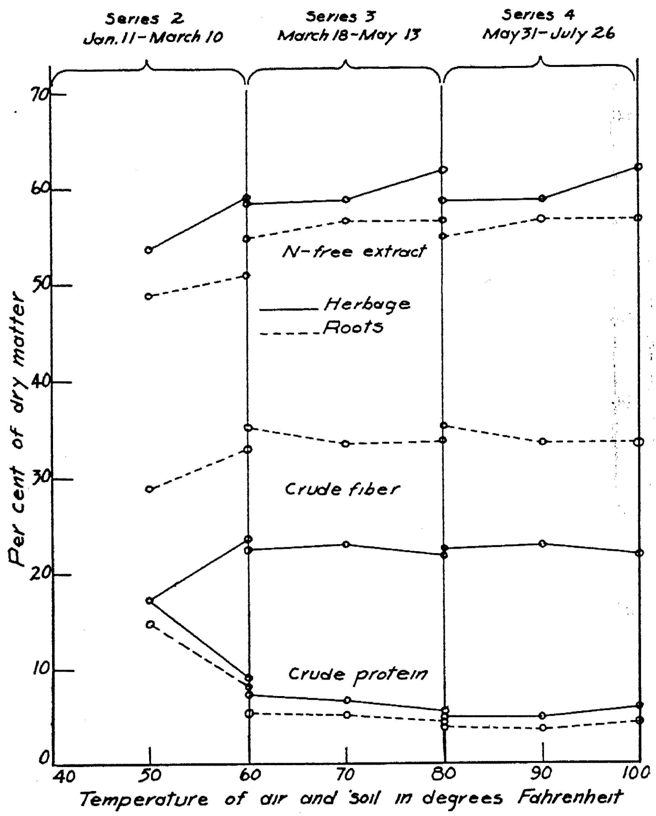

Fig. 29.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of Bermuda grass to temperature.

at higher temperatures up to 100°. The herbage of Bermuda grass contained a much smaller percentage of crude fiber than the roots.

The crude protein content of both herbage and roots decreased sharply in percentage as the temperature rose from 50° to 60°. A further rise in temperature was accompanied by a gradual decline in the crude protein content until the 90° temperature was reached beyond which a further 10° rise was accompanied by a slight increase. The herbage contained a slightly larger percentage of crude protein than the roots at all temperatures employed.

The percentage of ether extract in the herbage of Bermuda grass decreased slightly with each increase in temperature up to 80° and then did not change with further rises in temperature up to 100°. In the roots the percentage of ether extract increased as the temperature rose from 50° to 60° and then remained practically unchanged at higher temperatures.

Effect of Air Temperature on Chemical Composition. Series 5

In this series the grass cultures were exposed to air temperatures of 70°, 85°, and 100° while the soil temperature tanks were kept at a constant temperature of 70°. As a result, the roots of each grass were exposed to a temperature of 70° in the soil levels more than 15 centimeters below the surface, but nearer the surface the soil temperature was influenced by the temperature of the air above it. Therefore, differences in the chemical composition of these cultures as well as differences in their growth are due to differences in the temperature of the air and the surface soil.

Kentucky bluegrass.—The curves in Figure 30 (Table 28) show that the percentage of nitrogen-free extract, crude fiber, and crude

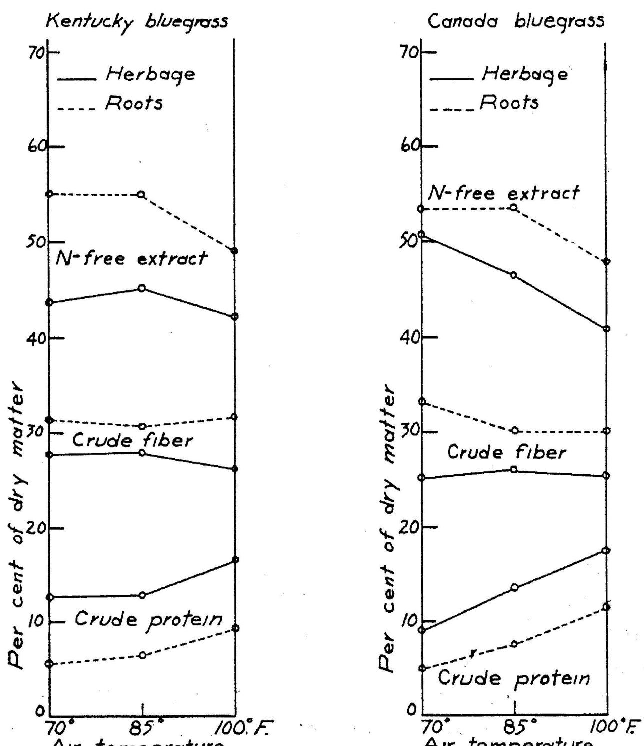

Fig. 30.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of Kentucky and Canada bluegrass to air temperature.

protein differed little in either the herbage or roots of cultures of Kentucky bluegrass grown at air temperatures of 70° and 85°. However, in cultures grown at an air temperature of 100°, the nitrogen-free extract was smaller and the crude protein content was larger in both herbage and roots. The percentage of crude fiber was higher in the roots and lower in the herbage of cultures grown at the 100° temperature. Ether extract (Table 28) decreased slightly in the herbage and markedly in the roots as the air temperature became higher.

The quantity of rhizomes produced at an air temperature of 100° was so small that no sample was obtainable for analysis from the cultures exposed to this temperature. Table 28 shows that the rhizomes of cultures grown at an air temperature of 85° contained a smaller percentage of crude protein and ether extract than those from cultures grown at the 70° air temperature. The percentage content of nitrogen-free extract was larger in rhizomes from cultures exposed to the 85° air temperature while the crude fiber content was practically the same at both temperatures.

At all temperatures employed in this series the herbage contained a larger percentage of crude protein and a smaller percentage of nitrogen-free extract and crude fiber than the roots.

Canada bluegrass.—The curves in Figure 30 (Table 29) show that the percentage of nitrogen-free extract in the herbage of Canada bluegrass was smaller as the air temperature became higher. In the roots the percentage content of this constituent was almost the same in cultures grown at air temperatures of 70° and 85°, but lower in those exposed to the 100° air temperature. The crude fiber content was much the same at all temperatures in the herbage but in the roots it decreased as the air temperature was raised from 70° to 85°, and remained unchanged with a further elevation of the air temperature to 100°. Crude protein increased in concentration in both the roots and herbage with each 15° rise in air temperature from 70° to 100°. The percentage of ether extract found in the herbage was lower at an air temperature of 85° and higher at 100° than at 70°, while the roots of cultures exposed to the higher air temperatures contained somewhat less ether extract than those of cultures grown at the 70° air temperature.

At each temperature the herbage contained a smaller percentage of nitrogen-free extract and crude fiber and a larger percentage of crude protein and ether extract than the roots.

Orchard grass.—The curves in Figure 31 (Table 30) show that the nitrogen-free extract content of the herbage decreased in percentage as the air temperature became higher while in the roots the percentage of this constituent did not vary appreciably with air temperature from 70° to 85°, but was less at the 100° air temperature.

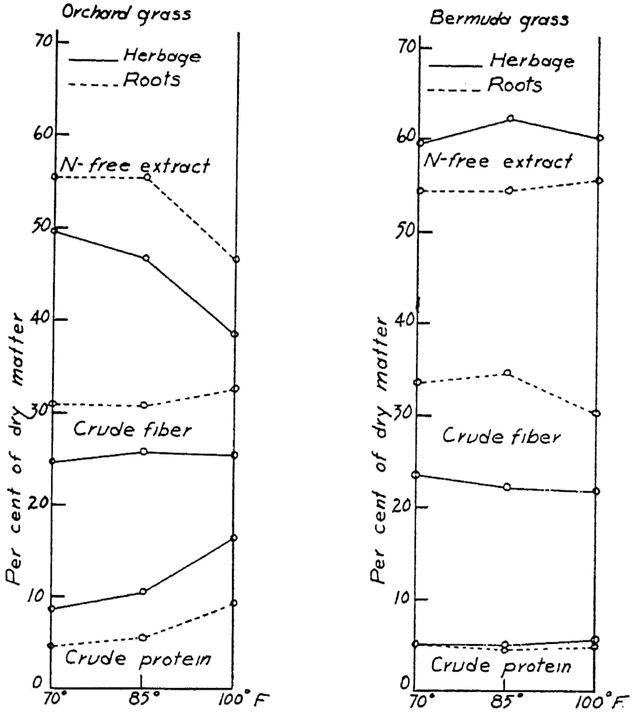

Fig. 31.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of orchard grass and Bermuda grass to air temperature.

The crude fiber content differed little in either herbage or roots at the different air temperatures employed, although the fraction of this constituent found in the roots was somewhat larger at the 100° air temperature than at the lower temperatures. Crude protein, however, was higher in percentage in both roots and herbage as air temperature became higher. The small variations which occurred in the ether extract fraction were of such a nature that little or no relation to differences in air temperature is evident.

As in the case of the two bluegrasses, the percentage of nitrogen-free extract and crude fiber was smaller in the herbage than in the roots, while the herbage contained the larger percentage of crude protein and ether extract, regardless of the air temperature to which the cultures were exposed.

Bermuda grass.—The curves in Figure 31 (Table 31) show that the percentage of nitrogen-free extract was higher in the herbage of Bermuda grass cultures grown at an air temperature of 85° than in those grown at 70° or 100°. It should be recalled here that the total production of dry matter was also highest at the 85° air temperature and that the leaves exhibited evidence of slight injury at an air temperature of 100° when the temperature of a considerable portion of the roots was maintained at 70°. The nitrogen-free extract content of the roots, expressed as percentage of the dry matter, did not differ much, although it was a little larger at the highest air temperature employed. The crude fiber content of the herbage was practically the same at all 3 air temperatures, while the percentage of this constituent found in the roots was slightly larger at 85° and substantially smaller at 100° than at 70°. The differences in the crude protein content of herbage and roots at the different air temperatures were so small as to be negligible. The ether extract content of both herbage and roots (Table 31) was somewhat larger at the 100° air temperature than at either of the lower temperatures.

Unlike the other three grasses included in this investigation, Bermuda grass contained a larger concentration of nitrogen-free extract in the tops than in the roots. The crude fiber content, however, was lower in the herbage than in the roots, while herbage and roots differed very little with respect to their percentage content of crude protein.

Effect of Diurnal Variations in Temperature on Chemical Composition. Series 6

In this series the grass cultures were exposed to a constant air temperature in one growth chamber and to a high day and a low night temperature in the two others. In one of these the upper temperature was 80° and the lower 60° while in the other the diurnal range in temperature was from 50° to 90°. In all three growth chambers the soil temperature tanks were kept at a temperature of 70°. However, the temperature of the upper soil levels varied in response to variations in air temperature, the amount of this variation decreasing with increasing depth until at soil levels more than 15 centimeters below the surface little or no variation from the 70° average occurred.

Kentucky bluegrass.—The curves in Figure 32 (Table 32) show that the nitrogen-free extract content was slightly larger in herbage and rhizomes in those cultures exposed to the highest day and the lowest night temperatures. In the roots, however, the percentage of this constituent was less in cultures exposed to the widest range in temperature—50° to 90°—than in those exposed to a constant or a less variable temperature. The percentage of crude fiber was a little higher and that of crude protein a little lower in the herbage exposed to the greatest diurnal range in temperature. Differences in the percentage content of crude fiber and crude protein found in roots and rhizomes of the cultures exposed to temperatures which did or did

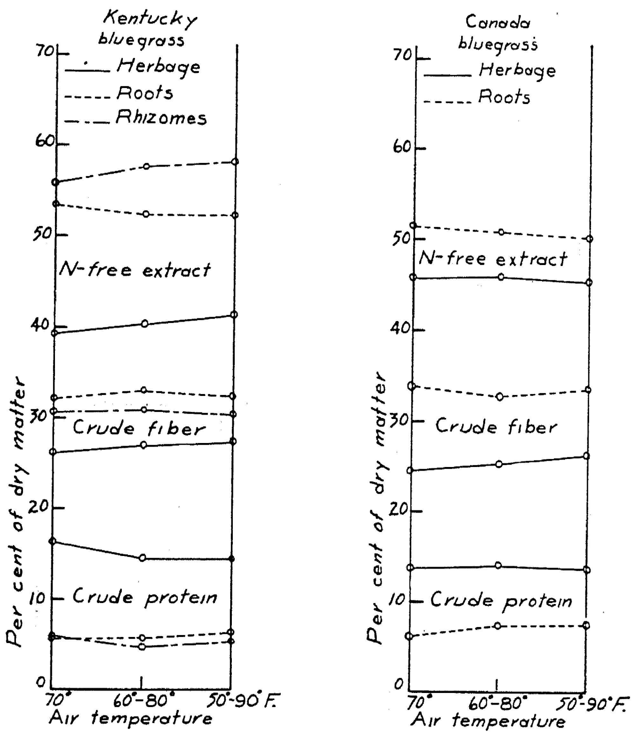

Fig. 32.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of Kentucky and Canada bluegrass to diurnal variations in temperature.

not vary from the average were too small to be significant. In fact, the most striking feature about the curves presented in Figure 32 is the almost complete absence of slope in any direction, indicating that so long as the average temperature remained unchanged, the chemical composition was not much affected by diurnal fluctuations in temperature as much as plus or minus 20°.

The curves further show that the herbage contained a higher percentage of crude protein than the roots or rhizomes while the reverse was true with respect to nitrogen-free extract and crude fiber. The rhizomes were particularly high in nitrogen-free extract content.

Canada bluegrass.—It is apparent that the curves which represent the chemical composition of Canada bluegrass in Figure 32 (Table 33) resemble those for Kentucky bluegrass with respect to flatness. It is doubtful if any of the variations in composition shown here are large enough to be significant. The curves further resemble those for Kentucky bluegrass in that the herbage contained the larger percentage of crude protein while the roots were higher in percentage content of nitrogen-free extract and crude fiber.

The quantity of rhizomes produced by cultures of Canada bluegrass included in this series was so small that no analysis of them was made.

Orchard grass.—The relation of the composition of orchard grass to daily temperature variations is shown by the curves in Figure 33

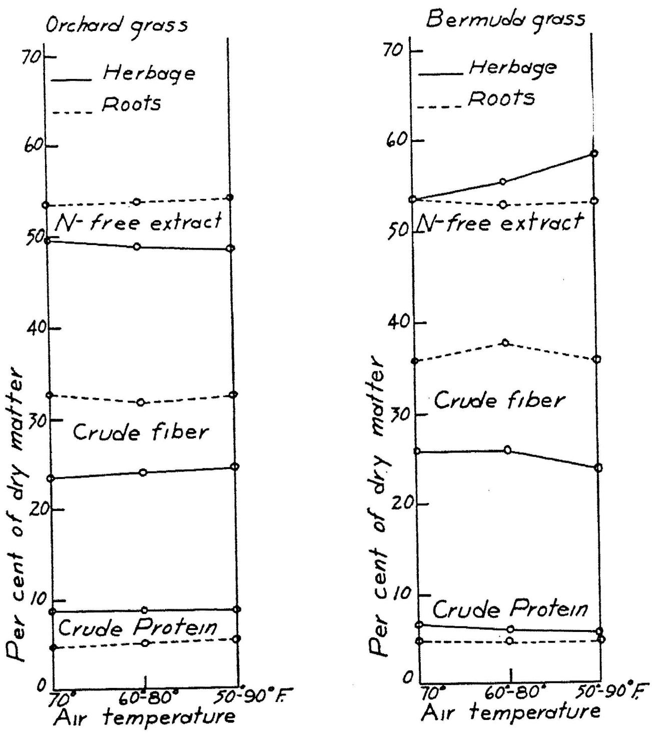

Fig. 33.—Relation of the nitrogen-free extract, crude fiber, and crude protein content of orchard grass and Bermuda grass to diurnal variations in temperature.

(Table 34). These curves, like those for the two bluegrasses, are distinguished by their flatness. They further resemble those for Kentucky and Canada bluegrass with respect to the relative percentages of nitrogen-free extract, crude fiber, and crude protein found in herbage and roots.

Bermuda grass.—The data in table 35, represented by curves in Figure 33, show that the nitrogen-free extract content of Bermuda grass herbage was larger as the cultures were exposed to higher day temperatures, even though the temperature was lowered correspondingly at night. The percentage of nitrogen-free extract found in the roots, however, did not change appreciably as day temperatures became higher and night temperatures lower. The crude fiber content of the herbage appeared to decrease slightly as the daily temperature range was increased from 10° to 20° plus or minus 70°. The highest percentage of crude fiber in the roots was found in those cultures exposed to a day temperature of 80° and a night temperature of 60°. The crude protein content of herbage and roots in cultures exposed to constant or variable temperatures differed very little. In fact, except for the apparent increase in the nitrogen-free extract content of the herbage which accompanied the widest daily temperature variation employed in this series, none of the differences in chemical composition appear to bear a significant relation to differences in temperature treatment.

The Bermuda grass herbage contained a higher percentage of crude protein than was found in the roots while the nitrogen-free extract content of the herbage exceeded that of the roots at the two variable temperatures but not at the constant temperature. The roots contained much the larger percentage of crude fiber.

DISCUSSION

Relation of Growth to Temperature

Kentucky and Canada bluegrass.—These two grasses, because of the similarity of many of their temperature-growth relations, can be conveniently discussed together. Thus, the adaptation of both grasses to low temperatures in northern latitudes or during early spring and late fall in regions of temperate climate (24, 26) is indicated by the amount of growth made at the lowest temperature employed, 40°. For both grasses a temperature of 90°, when soil and air were maintained at the same temperature, appeared to be more favorable for the production of herbage than did higher or lower temperatures. However, the roots of Kentucky bluegrass attained their maximum growth rate at a temperature of 60° and those of Canada bluegrass at 50°. Root growth declined sharply in both species as the temperature rose above these levels, practically ceasing in the lower soil levels at 80° and in all soil levels at 90°.

Under the conditions of this experiment in which the soil contained an abundance of readily available plant food and moisture, and defoliation was not close, the production of dry matter in the tops of the two bluegrasses did not appear to be seriously retarded by the reduced root growth which occurred at the 90° temperature. Under the less favorable conditions which usually occur in the field at a soil and air temperature of 80° or above, however, it is quite probable that the reduced root growth would soon become a limiting factor in the production of herbage. Therefore, under natural conditions, the retarding effect of high temperature on the root growth of Kentucky and Canada bluegrass is probably a more important factor limiting the production of herbage than the direct effect of temperature on top-growth.

While under the conditions of this experiment the optimum temperature for the production of herbage by both Kentucky and Canada bluegrass appeared to lie between 80° and 90°, both species were severely injured by 8 weeks of exposure to a constant soil and air temperature of 100°. This was not a case of sudden death since the evidence of injury appeared gradually. The high temperature was much more destructive to Canada bluegrass than to Kentucky bluegrass, as was indicated by the more rapid and more complete recovery of Kentucky bluegrass after its removal from the 100° temperature. These results support the statements by Piper (24) that Kentucky bluegrass languishes during summer heat but survives hot summer weather and makes good pasturage in the fall and spring. However, the comparative response of Kentucky bluegrass and Canada bluegrass to the 100° temperature does not agree with his opinion that Canada bluegrass is more resistant to summer heat than Kentucky bluegrass.

The destructive effects of the 100° temperature on Kentucky and Canada bluegrass appear to have resulted more from a high soil temperature than from a high air temperature for when the air alone was maintained at a constant temperature of 100° the tops of these grasses made some growth and exhibited no visible symptoms of heat injury. Furthermore, the temperature of that part of the soil lying near the surface appears to exert a greater influence on growth than that at lower depths. When the temperature of the soil to a depth of 2.5 centimeters varied between 79° and 93°, as was the case in the growth chamber having an air temperature of 100°, the growth of roots and rhizomes was effectively checked in spite of the fact that the soil temperature did not exceed 70° from a depth of 15 centimeters to the bottom of the pot. Under these conditions, the growth of roots in the 20 to 40 centimeter level was reduced just as much as those actually exposed to the higher temperature. Therefore, a temperature near 90° localized in the surface layers of soil exerted much the same effect on root and rhizome growth by Kentucky and Canada bluegrass as a 90° temperature applied to the entire root system.

This experiment was not designed to determine the influence of light on the growth of grasses. However, because of the limited number of growth chambers available the different series had to be grown during successive periods which differed with respect to length of day and light intensity. Thus the average length of day from sunrise to sunset was 10.8, 13.2, and 14.7 hours respectively for series 2, 3, and 4. Both Kentucky and Canada bluegrass responded to the increasing photoperiod by producing less and less herbage with each increase in the average length of day. Although the cultures used in separate series differed to some extent in their initial growth and series 2 and 3 differed with respect to defoliation, it seems unlikely that these differences can fully account for the decrease in herbage production at like temperatures in successive time periods.

The differences in root growth made by the two bluegrasses at like temperatures in successive time periods are small enough, with one exception, to be explained by differences in the initial growth of cultures used in the different series. However, root production by Canada bluegrass at the 60° temperature in series 3 was so much larger than that made at the same temperature in series 2 that the presence of some other factor is indicated. All Canada bluegrass cultures included in series 3 were contaminated with plants of Kentucky bluegrass which, due to the close resemblance of the two species, was not detected until the cultures were harvested at the close of the experiment. A separation of the two species at that time showed that 24 per cent of the dry herbage produced by Canada bluegrass cultures at 60° consisted of Kentucky bluegrass, 22 per cent at 70°, and 15 per cent at 80°. It was not possible to separate the roots of the two species, but it can safely be assumed that the fraction of Kentucky bluegrass roots present in the mixed cultures was as large as that of the herbage. Since 60° is the optimum temperature for the growth of Kentucky bluegrass roots while Canada bluegrass makes its maximum root growth at 50°, it is reasonable to suppose that the presence of the Kentucky bluegrass in the 60° cultures of series 3 resulted in a larger production of roots than would have occurred had only Canada bluegrass been present. In view of this possible explanation for the difference in root growth by Canada bluegrass at the 60° temperature in series 2 and 3 it does appear that the effect of the photoperiod on root production by Kentucky and Canada bluegrass was slight.

Both temperature and photoperiod influenced the production of rhizomes by Kentucky and Canada bluegrass. The latter produced the largest number and dry weight of rhizomes at a soil and air temperature of 50° while 60° was the most favorable temperature for the production of rhizomes by Kentucky bluegrass. Furthermore, at like temperatures, a short photoperiod appeared to be the more favorable for the development of rhizomes by Canada bluegrass while the summer period of long average day length was more conducive to rhizome production by Kentucky bluegrass. Therefore, it is evident that in the southern part of the region to which Kentucky bluegrass is adapted, temperatures above the optimum for rhizome development would probably exist during much of the season in which the more favorable photoperiod for rhizome production occurs. Consequently the failure of the period of optimum day length to coincide with the period of optimum temperature for rhizome production might be an important factor limiting the development and persistence of Kentucky bluegrass in regions which have high summer temperatures.

Rhizome production by Canada bluegrass, on the other hand, proceeds at a rapid pace at a temperature of 40° and reaches a maximum at 50°. Furthermore, the short days of late fall and late winter or early spring appear to be more favorable for rhizome production than the long days of late spring and summer. Therefore, temperatures and photoperiods favorable for rhizome production by this species would coincide under natural conditions existing in the southern portion of its region of adaptation. Furthermore, a deficient moisture supply would seldom limit growth during that part of the year in which Canada bluegrass is best adapted to produce rhizomes, while a soil moisture content too low for vigorous plant growth is a matter of frequent occurrence during the summer season when light conditions are suitable for the best development of rhizomes by Kentucky bluegrass. This difference shown by Kentucky and Canada bluegrass with respect to rhizome production in relation to light and temperature may have an important bearing on their adaptations and growth behavior under natural conditions.

The emergence of the growing points of rhizomes was also influenced by temperature and light. Only a small fraction of Kentucky bluegrass rhizomes emerged at temperatures between 40° and 80°. However, when the temperature was raised to 90°, the fraction of the rhizomes which emerged increased. A day temperature of 90°

followed by a low night temperature of 50° appeared to be just as effective in stimulating rhizome emergence as a continuous temperature of 90°. Furthermore, it is apparently necessary only to raise the temperature of the air and upper level of soil to the 90° temperature to induce an increase in rhizome emergence.

Rhizomes of Canada bluegrass tended to remain below the soil line so long as the temperature remained at 50° or lower and so long as the days were short. However, at temperatures of 60° or above the rhizomes exhibited a marked tendency to emerge above the soil line, a tendency which was accentuated by an increase in day length. These results indicate that during late fall, winter, and early spring when temperatures are above freezing this grass will produce a relatively large number of rhizomes. Then as the days lengthen in the spring and temperatures rise, the development of new rhizomes will diminish but those already present will emerge above the soil line and develop into aerial shoots. Since the rhizomes probably function as organs for the storage of organic food reserves as well as for vegetative reproduction, the difference in the observed response of Kentucky and Canada bluegrass to temperature and the photoperiod with respect to rhizome production may possibly explain and justify the opinion expressed by Piper (24) and held by others that Canada bluegrass is more resistant to summer heat than Kentucky bluegrass.

The results obtained by Gregory with barley (10) and Brenchley with peas (4) indicate that the adverse effects of high day temperatures on plant growth are offset by low night temperatures. However, this was not entirely true in the case of Kentucky and Canada bluegrass, for root and rhizome growth in these species decreased when day temperatures were raised to 80° and 90° even though the night temperatures were lowered to 60° and 50°. The results might have been different if this series had been run during a period of greater day length so that it would not have been necessary for the high temperatures to extend beyond the light period of each day in order to maintain an average temperature of 70°.

Orchard grass.—The root and herbage growth made by orchard grass at air and soil temperatures of 40° and 50° demonstrate the ability of this species to produce pasturage in early spring and late fall. In fact, herbage production did not differ materially at the different temperatures between 50° and 80° and root growth was fairly constant within a temperature range of from 50° to 70°. However, herbage production declined sharply when the temperature of both air and soil rose from 80° to 90° and soon stopped altogether at 100°.

The fact that under the conditions of this experiment herbage production by orchard grass declined when the temperature rose from 80° to 90° while herbage production by Kentucky and Canada bluegrass increased somewhat with the same change in temperature does not necessarily indicate that the same relation would hold under natural conditions. The retarding influence of a temperature of 80° or above on the root growth, especially in the deeper soil levels, and its probable effect on herbage production by Kentucky and Canada bluegrass under natural conditions has been shown. Orchard grass roots, on the other hand, made considerable growth both in the upper and lower soil levels at the 80° temperature. Therefore, it is not at all improbable that orchard grass would produce more herbage under field conditions than either of the bluegrass species at an average air and soil temperature of 80° or above and that its region of adaptation would extend somewhat farther south, as Vinall and Hein have shown (26).

An air and soil temperature of 100° lasting for 8 weeks was even more destructive to orchard grass than to Canada bluegrass. However, orchard grass exhibited no visible symptoms of injury when grown for 8 weeks at an air temperature of 100° when the maximum temperature reached in the surface soil was 93° and the soil below a depth of 15 centimeters was held at 70°. The fact that both herbage production and root growth were approximately the same under these conditions as when the air and entire soil mass were maintained at a temperature of 90°, strongly indicates that the temperature of the soil near the surface exerts a more important influence on the growth of this grass than either that of the air or of the soil at lower depths. Root growth at a depth of 20 to 40 centimeters was as completely checked as that in the 0 to 20 centimeter level by the high temperature of the air and upper soil level although the temperature in the 20 to 40 centimeter level did not exced 70°.

In orchard grass the adverse effects of high day temperature were counterbalanced to a large extent by a correspondingly low night temperature. Herbage production, which was much lower at a constant temperature of 90° than at 70°, was somewhat higher when a day temperature of 90° was followed by a night temperature of 50°. Root growth was only slightly depressed in the 0 to 20 centimeter layer and not at all in the 20 to 40 centimeter soil layer by a day temperature of 90° followed by a night temperature of 50°, as compared with root growth made at a constant temperature of 70°.

Orchard grass differed markedly from Kentucky and Canada bluegrass in response to day length. The cultures grown in series 2 and 3 were given almost exactly the same length of time for their initial growth and had made almost the same amount of root and top growth by the time they were placed in the growth chambers. In neither series were the tops cut back during the initial period, but the cultures in series 3 were clipped to a 3-inch level at the end of the first 4 weeks of growth at controlled temperatures. In spite of their similarity of treatment, the cultures grown at 60° in series 3 with an average day length of 13.2 hours produced much more herbage but somewhat less root growth than cultures grown at the same temperature but with an average photoperiod of 10.8 hours (series 2). With a further increase in day length to an average of 14.7 hours (series 4) growth was less at the 80° temperature than in series 3. However, the cultures used in series 4 were not entirely comparable to those used in series 3, because of the smaller initial growth which resulted from a shorter initial period of growth. Therefore, no conclusion as to the relative influence of day length can be drawn from a comparison of growth made at like temperatures in series 3 and 4, but the evidence that a photoperiod of 13.2 hours is more favorable to herbage production by orchard grass than one of 10.8 hours is rather convincing. If day length exerted any influence on root growth, its effect was the opposite of that exerted on herbage production.

Bermuda grass.—Bermuda grass, unlike Kentucky and Canada bluegrass and orchard grass, made no growth at an air and soil temperature of 40° and very little at 50°. Furthermore, a constant air and soil temperature of 100°, which was quite injurious to the other grasses, was more favorable to the growth of Bermuda grass than any lower temperature used in this investigation.

The decreased production of herbage at like temperatures during successive growth periods indicates that a short photoperiod is more favorable than a long photoperiod for the production of herbage by Bermuda grass. Moreover, since the larger root production made at the 60° temperature in series 2 as compared to that made at the same temperature in series 3 might be explained by the difference in defoliation imposed on the cultures, and since root growth at like temperatures in series which were comparable with respect to defoliation (series 3 and 4) was practically the same, there is no evidence that root growth was materially influenced by the photoperiod.

Although Bermuda grass made more growth at an air and soil temperature of 100° than at any lower temperature, growth was retarded slightly by raising the air temperature from 85° to 100° while at the same time holding the temperature of a large portion of the root system to 70°. The appearance of the leaves under these conditions indicated that the roots were unable to absorb enough water to maintain the turgidity of leaf tissue. This may have been due to the greater evaporating power of the air which existed at the 100° air temperature in series 5 as compared to series 4, for the average relative humidity during the day was 10 per cent lower in the 100° growth chamber in series 5 than in the 100° growth chamber in series 4. However, the other grasses grown under the same conditions in series 5 showed no symptoms of wilting at the 100° air temperature so that it seems probable that water absorption by Bermuda grass roots was somewhat slower at a root temperature of 70° than at 100°. That the absorption of water by Bermuda grass roots was retarded by root temperatures of 40° and 50° is apparent from the wilting which occurred at those temperatures in spite of the high moisture content maintained in the soil. The grasses naturally adapted to a cooler climate exhibited no evidence of wilting at the lower soil temperatures, but Bermuda grass resembled the sunflower (7), sugar cane (9), and cotton (1)— plants adapted to grow only in warm climates or in the warmer seasons of temperate climates—with respect to the retardative effects of low temperatures on water absorption by roots. Therefore, one of the causes for reduced growth by Bermuda grass at low temperatures may be the retarding effect of low root temperature on water absorption.

Herbage production by Bermuda grass was affected by diurnal variations in temperature as if the high day temperature were the dominant factor controlling growth, for herbage production increased as the day temperature became higher, even though the daily average did not change. Root growth was practically the same whether the temperature of air and surface soil remained constant at 70° or fluctuated 10° or 20° above and below the average.

Relation of Chemical Composition to Temperature

The importance of the chemical data presented here attaches to the fact that: (1) the nutritive value of the herbage is determined by its chemical composition; and (2) the effect of temperature on plant growth might be partially explained by the chemical changes which are associated with the growth rates made at different temperatures.

The methods of analysis employed are adequate for an evaluation of the feeding value of the herbage produced at the different temperatures. Nitrogen-free extract is the carbonaceous fraction of the dry matter which is considered to be digestible by animals. It consists of starch, sugars, and at least a part of the hemicellulose. However, whether this fraction is equally digestible by the plant and, therefore, available to it as a carbonaceous food reserve is open to some question. The constituent designated as crude fiber is that part of the carbohydrate which is not digestible by animals and represents, in large measure, the cellulose and ligno-celluloses which constitute the structural framework of the plant. Crude protein is simply the total nitrogen content multiplied by the factor 6.25 while ash is the noncombustible portion of the dry matter. Because the ash content bears no apparent relation to temperature, this constituent will not be discussed further. Ether extract, as the term implies, is that portion of the dry matter soluble in ether and includes waxes and chlorophyll as well as any fats or oil which might be present. The quantity of ether extract found in all tissues was so small as compared with the amount of nitrogen-free extract that it will not be discussed.

The methods of sampling and analysis employed in this investigation, however, are not sufficiently refined to provide satisfactory evidence concerning the effect of temperature on the internal factors which condition plant growth because: (1) it is not known to what extent the nitrogen-free extract actually represents the carbohydrate reserves of the plant; (2) the crude protein may consist entirely of organic nitrogen compounds or may include some inorganic forms of nitrogen; (3) the analyzed samples include both young and old tissue, so that the results may not be applicable to young, actively growing tissue; and (4) the samples for analysis taken as they were, before and after exposure to controlled temperature, represent only the end-product of chemical processes occurring during exposure to the different temperatures. It is with these limitations in mind that the chemical data are discussed.

Because of the similarity of the effects of temperature on their chemical composition, Kentucky and Canada bluegrass and orchard grass can be discussed together. In all three grasses, the nitrogen-free extract content of the herbage declined with rising temperature so that the energy value of the forage also decreased. The increase in crude fiber content which accompanied a rise in temperature from 40° to 50° or 60° indicates that the herbage produced at temperatures below 60° would be more digestible, and possibly more palatable than that produced at higher temperatures. The percentage of crude protein in the herbage decreased slightly as the temperature rose from 40° to 60° and then increased as the temperature rose from 70° to 90°. Since the decline in digestible carbohydrates which occurred as the temperature rose from 40° to 60° was much greater than the decrease in protein content and since with further increases in temperature the nitrogen-free extract content continued to decline while protein content remained constant or increased, the nutritive ratio decreased with each 10° rise in temperature.

At temperatures of from 60° to 100° the chemical composition of Bermuda grass herbage was so nearly the same that differences in its nutritive quality are extremely small. The content of nitrogen-free extract and crude fiber was much lower and the protein content much higher at 50° than at 60°. However, the total production of herbage at the 50° temperature was so small that the effect of this temperature on the chemical composition and feeding value of the herbage is of little practical importance.

Nightingale (21, 22) reports that at low temperatures— 55° or lower—certain plants absorb nitrates rapidly but assimilate the nitrogen slowly, apparently because the plants are not able to reduce the nitrates readily. Under these conditions, it would be reasonable to expect nitrate nitrogen to accumulate in the plant tissues. While the percentage of nitrogen, as represented by crude protein, was somewhat higher in roots and herbage of the bluegrasses and orchard grass at a temperature of 40° than at 60°, the differences are too small to justify the conclusion that growth at the lower temperature was limited by a retarded reduction of nitrates. However, the percentage content of nitrogen in Bermuda grass grown at the 50° temperature was more than double that of plants grown at high temperatures. Here is strong evidence that nitrogen in some form tended to accumulate in the plant at a temperature too low for its normal development, whatever the cause of the nitrogen accumulation may have been. However, the possibility that growth may have been limited at the lower temperatures by the slow rate of organic matter decomposition and nitrification in the soil which Blackman (3) found to occur in pastures at temperatures between 40° and 47° appears to be precluded by the fact that every grass included in this investigation contained a higher percentage of nitrogen at temperatures below the optimum than at the optimum. These results do not disprove Blackman's conclusions, for, of course, the soil conditions in an old established pasture may differ materially from those in potted soil.

The somewhat general belief (2, 5, 11, 19, 21, 22, 23, 25, 28) that at super-optimal temperatures the carbohydrate balance of the plant is disturbed by the failure of carbon assimilation to keep pace with carbon loss by respiration is supported here by the fact that the net increment of nitrogen-free extract in the whole plant declined with rising temperature in Canada bluegrass at continuous air and soil temperatures above 50° and in Kentucky bluegrass and orchard grass above 60°. Furthermore, the decrease in the net gain of carbohydrates set in at a lower temperature in the roots than in the tops, and it has been shown that the optimum temperature for root growth by these grasses is lower than the optimum for herbage production.

While the percentage content of nitrogen-free extract declined with each rise in temperature in Kentucky and Canada bluegrass and orchard grass and the net increment in the plant as a whole decreased with rising temperatures above 60°, this did not occur in Bermuda grass. Evidently photosynthesis more than kept pace with respiration in this species with rising temperature from 50° to 100°. The capacity shown by Bermuda grass to accumulate nitrogen-free extract at high temperatures agrees with Lundegardh's statement that in tropical plants a high position of the assimilation maximum is generally to be expected (19).

Curtis and Hertz (8) found the translocation of carbohydrates from the leaves to be retarded by chilling the petioles to temperatures between 33° and 40°. That translocation from leaves to roots may have been retarded in Kentucky and Canada bluegrass and orchard grass at a temperature of 40° and in Bermuda grass at 50° is indicated by the fact that the ratio of nitrogen-free extract content of the roots to that in the leaves was lower at the lower temperature in each case. However, there was no similar evidence that translocation from leaves to rhizomes in Kentucky and Canada bluegrass was retarded by the 40° temperature.

Lundegardh's statement (19) that the net assimilation of carbonaceous food materials by the plant is materially influenced by diurnal variations in temperature is partially supported by the results obtained in series 6. The percentage content of nitrogen-free extract of Kentucky and Canada bluegrass and orchard grass exposed to an air temperature which averaged 70° but which varied from a high of 90° during the day to a low of 50° at night, differed little from that of the same species grown at a constant temperature of 70°. However, root and rhizome growth in Kentucky and Canada bluegrass and root growth in orchard grass were less at the 90° day temperature although the concentration of nitrogen-free extract in the rhizomes and roots was not reduced. Therefore, some internal factors other than carbohydrate concentration in the roots or rhizomes as a whole must have been responsible for the reduced growth at the 90° day temperature. It is entirely possible, of course, that the concentration of carbohydrates in the actively growing tissues was not the same as that in the whole rhizome or root, which consisted in large measure of mature tissues.

If considered apart from the results obtained by other investigators the data presented here would not justify any conclusions as to the internal factors responsible for the observed relation of growth to temperature. However, when these data are considered in conjunction with the results of other experiments to which reference has been made, the following conclusions appear to be reasonable:

(1) The reduction of the growth rate with falling temperature below the optimum but above the minimum is due to the retarding effect of low temperature on water absorption, nitrogen assimilation, translocation of carbohydrates or to other factors.

(2) The decrease in growth rate with rising temperature above the optimum but below the maximum is conditioned by the increased respiration which, because it is not accompanied by a similar increase in photosynthesis, reduces the net assimilation of carbonaceous food materials or by other factors. It is probable that "other factors" greatly outnumber those specified and that the effects of temperature on growth, like its effects on salt accumulation (12) are "- - - indirect in the sense that it is the metabolism of the plant which is being affected - - -."

(3) Whatever the nature of the internal growth factors conditioned by temperature, it is evident that they do not respond to a given temperature is the same manner or to the same degree in different species or even in different parts of the same plant.

SUMMARY

1. A partial review of literature dealing with the effect of temperature on the growth and chemical composition of plants is presented.
2. Established cultures of Kentucky bluegrass, Canada bluegrass, orchard grass, and Bermuda grass were grown in thermo-regulated growth chambers and the effect of different temperature treatments on growth and chemical composition was determined for periods of approximately 8 weeks.
3. Kentucky and Canada bluegrass and orchard grass made considerable growth at 40° F., the lowest temperature employed,

while Bermuda grass made no growth at this temperature and very little at 50°.

4. The optimum temperature for herbage production, under the conditions of this experiment, was between 80° and 90° for Kentucky and Canada bluegrass, and 70° for orchard grass. Herbage production by Bermuda grass was larger at 100° than at any lower temperature.
5. The optimum temperature for root and rhizome production was 60° for Kentucky bluegrass and 50° for Canada bluegrass. Orchard grass made its maximum root growth at a temperature of 70° while root growth by Bermuda grass increased with each 10° rise in temperature to 100°, the highest temperature employed.
6. Kentucky and Canada bluegrass and orchard grass were severely injured by a continuous air and soil temperature of 100°, Kentucky bluegrass being least and orchard grass most severely injured. The injury appeared to result in large measure from the high soil temperature rather than the high air temperature.
7. Rhizomes of Kentucky bluegrass tended to remain below the soil line at a temperature of 80° or lower, those of Canada bluegrass at a temperature of 50° or lower. Higher temperatures stimulated the emergence of the growing points of rhizomes above the soil line.
8. In Kentucky and Canada bluegrass and orchard grass, the percentage content of nitrogen-free extract declined with rising temperature but in Bermuda grass, this constituent increased in concentration as the temperature rose.
9. In all four grasses, the crude fiber content increased in percentage as the temperature rose from 40° to 60° and changed little with further rises in temperature.
10. The percentage of crude protein declined slightly in Kentucky and Canada bluegrass and orchard grass as the temperature increased from 40° to 60° and then increased slightly as the temperature rose above the optimum for growth. In Bermuda grass the crude protein content was much greater at 50° than at 60°.
11. The significance of differences in chemical composition with respect to the nutritive quality of the herbage and their possible significance in explaining the effects of temperature on growth is discussed.
12. When the plants were exposed to variable temperatures, the effects of a high day temperature appeared to be counterbalanced

by the low night temperature so far as the chemical composition of the plant was concerned. This was also true of the growth of orchard grass but the other three species responded to the diurnal variations in temperature as if the high day temperature exerted a greater influence on growth than the low night temperature.

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APPENDIX

Table 1.—Periods of initial growth of experimental cultures with day lengths and temperatures existing during each period.

Grass	Series	Date seeded	Ave. date of seedling emergence	End of initial growth period	Growth period (days)[1]	Temperature range (°F.)	Ave. day length (hours)[2]
Kentucky bluegrass	2	Oct. 16	Oct. 25	Jan. 11	78	65–75	9.8
	3	Dec. 16	Dec. 25	March 18	83	60–70	10.6
	4	March 10	March 20	May 31	72	65–90	13.2
	5	May 11	May 18	July 28	71	80–90	14.7
	6	June 25	July 1	Sept. 24	85	80–90	13.5
Canada bluegrass	2	Sept. 21	Oct. 5	Jan. 11	98	65–75	10.2
	3	Nov. 20	Dec. 5	March 18	103	60–70	10.3
	4	March 4	March 15	May 31	77	65–90	13.2
	5	May 11	May 18	July 28	71	80–90	14.7
	6	June 25	July 1	Sept. 24	85	80–90	13.5
Orchard grass	2	Nov. 7	Nov. 15	Jan. 11	57	65–75	9.7
	3	Jan. 16	Jan. 25	March 18	52	60–70	11.1
	4	April 19	April 25	May 31	36	65–90	14.0
	5	June 1	June 8	July 28	50	80–90	14.7
	6	July 1	July 5	Sept. 24	81	80–90	13.6
Bermuda grass	2	Sept. 21	Oct. 10	Jan. 11	93	65–75	10.2
	3	Nov. 7	Nov. 18	March 18	120	60–70	10.3
	4	March 17	March 30	May 31	62	65–90	13.5
	5	May 11	May 22	July 28	67	80–90	14.7
	6	June 25	July 5	Sept. 24	81	80–90	13.5

1. Number of days from the time one-half of seedlings had emerged to end of period.
2. From sunrise to sunset.

Table 2.—Average initial dry weight of herbage, roots, and rhizomes per culture in each experimental series.

	Dry matter per culture in grams				
	Series 2	Series 3	Series 4	Series 5	Series 6
Kentucky bluegrass					
Herbage	5.10	8.27	6.10	4.40	5.10
Roots	1.42	2.33	2.53	2.47	2.05
Rhizomes	0.16	0.08	0.71	0.53	2.09
Total	6.68	10.68	9.34	7.40	10.14
Canada bluegrass					
Herbage	6.35	9.27	7.22	4.97	9.18
Roots	1.52	2.96	2.38	1.76	3.01
Rhizomes	0.16	1.24	0.65	0.15	0.20
Total	8.03	13.37	10.25	6.88	12.39
Orchard grass					
Herbage	4.38	4.35	2.85	4.43	6.78
Roots	0.92	1.10	1.48	2.38	3.03
Total	5.30	5.45	4.33	6.81	9.81
Bermuda grass					
Herbage	5.35	9.05	6.92	9.97	8.57
Roots	1.03	2.65	3.28	5.03	3.48
Total	6.38	11.70	10.20	15.00	12.05

Table 3.—Relative humidity in growth chambers at different air temperatures in the different experimental series.

Series and Period	Growth chamber	Air temperature (°F.)	Relative humidity in per cent			
			Average	Ave. day*	Ave. daily minimum	Ave. daily maximum
2 Jan. 11 to March 10	1	40	82	76	55	96
	2	50	68	66	50	84
	3	60	59	59	48	73
3 March 18 to May 13	1	60	56	53	38	71
	2	70	65	62	48	80
	3	80	54	53	42	64
4 May 31 to July 26	1	80	59	57	42	77
	2	90	50	47	32	67
	3	100	47	46	38	55
5 July 28 to Sept. 21	1	70	66	56	31	86
	2	85	59	57	40	75
	3	100	36	36	28	44
6 Sept. 24 to Nov. 19	1	70	59	57	41	75
	2	60-80	66	57	38	89
	3	50-90	56	41	20	91

* Six A. M. to 6 P. M.

Table 4.—Average increment in dry matter per culture of Kentucky bluegrass, Canada bluegrass, orchard grass, and Bermude grass grown from January 11 to March 10, at temperatures of 40°, 50°, and 60°F. Series 2.

	Increment in grams		
	40°F.	50°F.	60°F.
Kentucky bluegrass			
Herbage	10.93	10.60	13.07
Roots 0-20 cm.	6.47	8.70	11.64
Roots 20-40 cm.	1.79	1.89	3.06
All roots	8.26	10.59	14.70
Rhizomes	0.89	2.17	4.84
Total	20.08	23.36	32.61
Canada bluegrass			
Herbage	8.15	8.55	12.72
Roots 0-20 cm.	4.43	6.63	5.73
Roots 20-40 cm.	1.54	2.05	1.86
All roots	5.97	8.68	7.59
Rhizomes	8.47	10.74	8.74
Total	22.59	27.97	29.05
Orchard grass			
Herbage	12.09	19.72	20.29
Roots 0-20 cm.	3.73	7.39	9.64
Roots 20-40 cm.	1.77	2.87	3.00
All roots	5.50	10.26	12.64
Total	17.59	29.98	32.93
Bermuda grass			
Herbage		5.65	30.85
Roots 0-20 cm.		0.47	4.13
Roots 20-40 cm.		0.51	2.94
All roots		0.98	7.07
Total	.	6.63	37.92

Table 5.—Average increment in dry matter per culture of Kentucky bluegrass, Canada bluegrass, orchard grass, and Bermuda grass grown from March 18 to May 13, at temperatures of 60°, 70°, and 80°F. Series 3.

	Increment in grams		
	60°F.	70°F.	80°F.
Kentucky bluegrass			
Herbage	10.85	17.19	24.09
Roots 0-20 cm.	10.03	7.08	4.32
Roots 20-40 cm.	2.97	2.05	0.31
All roots	13.00	9.13	4.63
Rhizomes	4.60	3.45	1.60
Total	28.45	29.77	30.32
Canada bluegrass			
Herbage	9.32	12.36	17.16
Roots 0-20 cm.	9.29	5.94	2.98
Roots 20-40 cm.	2.99	1.80	–0.30
All roots	12.28	7.74	2.68
Rhizomes	7.26	3.52	1.48
Total	28.86	23.62	21.32
Orchard grass			
Herbage	27.81	28.45	26.51
Roots 0-20 cm.	8.15	7.67	4.39
Roots 20-40 cm.	2.62	3.27	1.95
All roots	10.77	10.94	6.34
Total	38.58	39.39	32.85
Bermuda grass			
Herbage	11.98	22.21	40.04
Roots 0-20 cm.	1.81	2.29	3.03
Roots 20-40 cm.	0.65	1.17	1.02
All roots	2.46	3.46	4.05
Total	14.44	25.67	44.09

Table 6.—Average increment in dry matter per culture of Kentucky bluegrass, Canada bluegrass, orchard grass, and Bermuda grass grown from May 31 to July 26, at temperatures of 80°, 90°, and 100°F. Series 4.

	Increment in grams		
	80°F.	90°F.	100°F.
Kentucky bluegrass			
Herbage	10.02	11.42	0.89
Roots 0-20 cm.	3.01	0.24	
Roots 20-40 cm.	0.09	-0.03	
All roots	3.10	0.21	
Rhizomes	5.03	1.39	
Total	18.15	13.02	0.89
Canada bluegrass			
Herbage	10.81	14.84	0.59
Roots 0-20 cm.	3.05	0.67	
Roots 20-40 cm.	0.15	0.32	
All roots	3.20	0.99	
Rhizomes	1.40	0.16	
Total	15.41	15.99	0.59
Orchard grass			
Herbage	23.08	11.35	0.42
Roots 0-20 cm.	6.33	0.27	
Roots 20-40 cm.	2.03	0.07	
All roots	8.36	0.34	
Total	31.44	11.69	0.42
Bermuda grass			
Herbage	28.18	39.11	57.72
Roots 0-20 cm.	3.09	4.42	4.79
Roots 20-40 cm.	1.06	1.80	1.93
All roots	4.15	6.22	6.72
Total	32.33	45.33	64.44

Table 7.—Average number of rhizomes per culture of Kentucky and Canada bluegrass grown at temperatures of from 40° to 90°F. Series 2, 3, and 4.

	Average number per culture							
	Series 2			Series 3			Series 4	
	40°	50°	60°	60°	70°	80°	80°	90°F.
Kentucky bluegrass								
Emerged								
Final	15	28	19	18	17	8	52	39
Initial	6	6	6	2	2	2	11	11
Difference	9	22	13	16	15	6	41	28
Not emerged								
Final	59	86	173	97	76	73	166	77
Initial	22	22	22	9	9	9	52	52
Difference	37	64	151	88	67	64	114	25
All rhizomes								
Final	74	114	192	115	93	81	218	116
Initial	28	28	28	11	11	11	63	63
Difference	46	86	164	104	82	70	155	53
Canada bluegrass								
Emerged								
Final	63	92	202	159	95	93	60	35
Initial	33	33	33	37	37	37	26	26
Difference	30	59	169	122	58	56	34	9
Not emerged								
Final	225	242	93	41	21	19	16	5
Initial	27	27	27	51	51	51	14	14
Difference	198	215	66	-10	-30	-32	2	- 9
All rhizomes								
Final	288	335	295	200	116	112	76	40
Initial	60	60	60	88	88	88	40	40
Difference	228	275	235	112	28	24	36	0

Table 8.—Average length of rhizomes in cultures of Kentucky and Canada bluegrass grown at temperatures of from 40° to 90°F. Series 2, 3, and 4.

	Average length in centimeters							
	Series 2			Series 3			Series 4	
	40°	50°	60°	60°	70°	80°	80°	90°F.
Kentucky bluegrass								
Final	4.1	6.2	9.3	12.4	12.1	8.3	7.9	6.6
Initial	5.9	5.9	5.9	4.7	4.7	4.7	5.7	5.7
Difference	−1.8	0.3	3.4	7.7	7.4	3.6	2.2	0.9
Canada bluegrass								
Final	8.2	7.0	6.0	7.8	7.1	5.6	3.0	3.1
Initial	2.6	2.6	2.6	5.6	5.6	5.6	3.8	3.8
Difference	5.6	4.4	3.4	2.2	1.5	0.0	−.8	−.7

Table 9.—Soil temperatures measured to a depth of 12.7 centimeters in grass cultures exposed to a temperature of 70°F. in the soil temperature tanks and air temperatures of 70°, 85°, and 100°F. Series 5.

Time and date	Depth (centimeters)	Soil temperature (°F.)		
		70°F.	85°F.	100°F.
1 P. M., Aug. 6 (Clear)				
	0– 2.5	79	86	93
	2.5– 5.1	78	82	88
	5.1– 7.6	75	78	81
	7.6–10.1	73	74	76
	10.1–12.7	71	72	73
1 P. M., Aug. 22 (Cloudy)				
	0– 2.5	69	74	79
	2.5– 5.1	69	73	77
	5.1– 7.6	69	72	74
	7.6–10.1	69	70	72
	10.1–12.7	69	70	70

Table 10.—Average increment in dry matter per culture of Kentucky bluegrass, Canada bluegrass, orchard grass, and Bermuda grass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F. with the soil temperature tanks held constant at 70°F. Series 5.

	Increment in grams		
	70°F.	85°F.	100°F.
Kentucky bluegrass			
Herbage	12.57	13.53	8.44
Roots 0-20 cm.	5.40	3.27	−0.12
Roots 20-40 cm.	0.66	0.60	−0.15
All roots	6.06	3.87	−0.27
Rhizomes	6.77	4.83	0.50
Total	25.40	22.23	8.67
Canada bluegrass			
Herbage	15.20	13.03	8.57
Roots 0-20 cm.	6.63	2.53	0.64
Roots 20-40 cm.	1.02	0.46	0.18
All roots	7.65	2.99	0.82
Rhizomes	1.50	0.37	−0.09
Total	24.35	16.39	9.30
Orchard grass			
Herbage	15.94	20.17	8.97
Roots 0-20 cm.	6.10	4.70	−0.11
Roots 20-40 cm.	2.07	2.18	−0.13
All roots	8.17	6.88	−0.24
Total	24.11	27.05	8.73
Bermuda grass			
Herbage	4.03	10.63	9.56
Roots 0-20 cm.	−0.03	1.24	0.54
Roots 20-40 cm.	−0.25	−0.10	−0.54
All roots	−0.28	1.14	0.00
Rhizomes	0.00	0.35	0.00
Total	3.75	12.12	9.56

Table 11.—Average number of rhizomes per culture of Kentucky and Canada bluegrass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F. with the soil temperature tanks held constant at 70°F. Series 5.

	Average number per culture		
	70°F.	85°F.	100°F.
Kentucky bluegrass			
Emerged			
Final	60	47	26
Initial	4	4	4
Difference	56	43	22
Not emerged			
Final	147	140	33
Initial	48	48	48
Difference	99	92	−15
All rhizomes			
Final	207	187	59
Initial	52	52	52
Difference	155	135	7
Canada bluegrass			
Emerged			
Final	36	11	1
Initial	1	1	1
Difference	35	10	0
Not emerged			
Final	24	7	2
Initial	4	4	4
Difference	20	3	−2
All rhizomes			
Final	60	18	3
Initial	5	5	5
Difference	55	13	−2

Table 12.—Average length of rhizomes in cultures of Kentucky and Canada bluegrass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F. with the soil temperature tanks held constant at 70°F. Series 5.

	Average length in centimeters		
	70°F.	85°F.	100°F.
Kentucky bluegrass			
Final	10.2	8.8	6.6
Initial	4.4	4.4	4.4
Difference	5.8	4.4	2.2
Canada bluegrass			
Final	4.4	2.6	2.0
Initial	2.4	2.4	2.4
Difference	2.0	0.2	−0.4

Table 13.—Average increment in dry matter per culture of Kentucky bluegrass, Canada bluegrass, orchard grass, and Bermuda grass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F. with the soil temperature tanks held constant at 70°F. Series 6.

	Increment in grams		
	70°F.	60°-80°F.	50°-90°F.
Kentucky bluegrass			
Herbage	11.20	12.67	13.20
Roots 0-20 cm.	3.36	2.39	1.19
Roots 20-40 cm.	1.41	1.35	0.76
All roots	4.77	3.74	1.95
Rhizomes	7.34	5.08	3.64
Total	23.31	21.49	18.79
Canada bluegrass			
Herbage	12.42	12.89	11.99
Roots 0-20 cm.	2.00	0.94	0.30
Roots 20-40 cm.	0.45	−0.08	−0.12
All roots	2.45	0.86	0.18
Rhizomes	1.64	1.39	0.46
Total	16.51	15.14	12.63
Orchard grass			
Herbage	8.82	8.45	10.42
Roots 0-20 cm.	4.00	3.63	3.17
Roots 20-40 cm.	1.92	1.69	1.79
All roots	5.92	5.32	4.96
Total	14.74	13.77	15.38
Bermuda grass			
Herbage	5.06	6.43	8.50
Roots 0-20 cm.	0.87	0.82	0.83
Roots 20-40 cm.	0.55	0.56	0.49
All roots	1.42	1.38	1.32
Total	6.48	7.81	9.82

Table 14.—Average number of rhizomes per culture of Kentucky and Canada bluegrass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F., with the soil temperature tanks held constant at 70°F. Series 6.

	Average number per culture		
	70°F.	60°-80°F.	50°-90°F.
Kentucky bluegrass			
Emerged			
Final	125	136	123
Initial	16	16	16
Difference	109	120	107
Not emerged			
Final	180	154	84
Initial	82	82	82
Difference	98	72	2
All rhizomes			
Final	305	290	207
Initial	98	98	98
Difference	207	192	109
Canada bluegrass			
Emerged			
Final	52	40	24
Initial	5	5	5
Difference	47	35	19
Not emerged			
Final	37	36	12
Initial	17	17	17
Difference	20	19	– 5
All rhizomes			
Final	89	76	36
Initial	22	22	22
Difference	67	54	14

Table 15.—Average length of rhizomes in cultures of Kentucky and Canada bluegrass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F., with the soil temperature tanks held constant at 70°F. Series 6.

	Average length in centimeters		
	70°F.	60°-80°F.	50°-90°F.
Kentucky bluegrass			
Final	12.0	10.1	10.9
Initial	9.0	9.0	9.0
Difference	3.0	1.1	1.9
Canada bluegrass			
Final	3.8	3.3	2.7
Initial	2.6	2.6	2.6
Difference	1.2	0.7	0.1

Table 16.—Chemical composition of Kentucky bluegrass grown from January 11 to March 10, at temperatures of 40°, 50°, and 60°F. Series 2.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
	Initial	13.12	25.83	3.83	22.33	34.89
Herbage	40	8.23	14.93	2.04	13.80	61.00
	50	10.57	14.89	1.78	18.79	53.97
	60	11.82	13.12	2.82	23.54	48.70
	Initial	11.65	12.38	1.10	29.33	45.54
Roots	40	9.81	8.79	0.98	21.54	58.88
	50	8.17	6.95	0.58	28.03	56.27
	60	10.00	7.26	0.76	29.56	52.42
	40	4.47	11.91	1.05	17.78	64.79
Rhizomes	50	5.18	9.03	0.00	25.83	59.96
	60	6.88	6.74	0.26	28.76	57.36

Table 17.—Chemical composition of Kentucky bluegrass grown from March 18 to May 13, at temperatures of 60°, 70°, and 80°F. Series 3.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
	Initial	13.17	23.71	3.80	23.59	35.73
Herbage	60	12.49	9.77	2.28	21.75	53.71
	70	11.82	9.42	2.70	24.66	51.40
	80	10.52	10.68	2.64	25.19	50.97
	Initial	8.93	10.46	1.58	32.91	46.12
Roots	60	8.38	4.27	1.61	26.50	59.24
	70	7.57	4.65	1.21	28.69	57.88
	80	7.27	5.54	0.73	31.47	54.99
	60	6.46	3.94	1.36	29.68	58.56
Rhizomes	70	8.05	3.04	0.69	29.65	58.57
	80	5.69	5.40	1.22	28.65	59.04

Table 18.—Chemical composition of Kentucky bluegrass grown from May 31 to July 26, at temperatures of 80° and 90°F. Series 4.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
	Initial	12.34	11.88	2.56	26.85	46.37
Herbage	80	11.73	12.93	2.97	26.01	46.36
	90	11.04	14.22	2.99	26.15	45.60
	Initial	8.05	8.20	1.43	32.54	49.78
Roots	80	7.40	6.56	0.59	30.82	54.63
	90	7.69	8.42	0.43	31.60	51.86
	Initial	7.70	8.48	1.10	34.42	48.30
Rhizomes	80	5.20	6.62	0.34	30.57	57.27
	90	7.95	10.13	1.72	32.10	48.10

Table 19.—Chemical composition of Canada bluegrass grown from January 11 to March 10, at temperatures of 40°, 50°, and 60°F. Series 2.

	Temperature (°F.)	Per cent of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	N-free extract
	Initial	13.97	28.58	4.40	21.54	31.51
Herbage	40	7.78	13.33	2.52	13.59	62.78
	50	10.22	13.44	2.79	17.69	55.86
	60	11.37	13.02	3.13	22.80	49.68
	Initial	13.10	14.36	1.07	27.06	44.41
Roots	40	10.35	9.15	0.16	23.53	56.81
	50	7.48	6.63	0.77	30.53	54.59
	60	10.01	7.26	0.63	31.33	50.77
	40	7.61	10.53	0.14	14.34	67.38
Rhizomes	50	5.82	6.80	0.23	21.93	65.22
	60	5.29	4.78	0.09	25.20	64.64

Table 20.—Chemical composition of Canada bluegrass grown from March 18 to May 13, at temperatures of 60°, 70°, and 80°F. Series 3.

	Temperature (°F.)	Per cent of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	N-free extract
	Initial	12.89	19.77	3.86	22.35	41.13
Herbage	60	11.94	8.70	2.90	19.70	56.76
	70	12.01	9.88	3.10	21.76	53.25
	80	11.30	12.01	3.28	22.23	51.18
	Initial	9.31	9.32	1.54	32.03	47.80
Roots	60	6.66	4.15	1.50	29.65	58.04
	70	7.70	4.93	1.33	31.52	54.52
	80	9.03	6.87	0.90	31.29	51.91
	60	4.02	2.69	0.69	24.04	68.56
Rhizomes	70	5.33	3.36	0.83	23.53	66.95
	80	4.97	3.64	0.77	24.16	66.46

Table 21.—Chemical composition of Canada bluegrass grown from May 31 to July 26, at temperatures of 80° and 90°F. Series 4.

	Temperature (°F.)	Per cent of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	N-free extract
	Initial	12.00	14.03	3.54	24.79	45.64
Herbage	80	11.05	12.99	3.30	23.56	49.10
	90	10.98	15.78	3.00	24.05	46.19
	Initial	7.64	7.97	0.97	36.60	46.82
Roots	80	7.58	7.10	0.91	30.73	53.68
	90	8.39	9.06	0.95	31.90	49.70
	Initial	11.46	8.39	1.26	31.32	47.57
Rhizomes	80	8.98	7.85	0.13	23.79	59.25
	90	5.47	12.66	1.50	23.91	56.46

Table 22.—Chemical composition of orchard grass grown from January 11 to March 10, at temperatures of 40°, 50°, and 60°F. Series 2.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	10.00	28.99	4.86	21.86	34.29
	40	8.42	15.66	1.70	10.65	63.57
	50	11.02	12.31	2.15	13.92	60.60
	60	10.73	12.01	3.26	18.45	55.55
Roots	Initial	11.19	12.62	1.24	29.57	45.38
	40	11.56	10.65	0.13	22.75	54.91
	50	6.94	6.88	0.39	31.09	54.70
	60	7.69	6.04	0.50	32.70	53.07

Table 23.—Chemical composition of orchard grass grown from March 18 to May 13, at temperatures of 60°, 70°, and 80°F. Series 3.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	15.87	32.37	4.75	17.63	29.38
	60	9.83	7.69	3.99	19.76	58.73
	70	12.12	8.38	3.74	22.50	53.26
	80	12.34	10.70	3.86	23.30	49.80
Roots	Initial	14.84	13.35	1.18	27.61	43.02
	60	6.32	4.62	1.22	32.31	55.53
	70	8.06	5.02	1.19	31.82	53.91
	80	8.93	6.37	1.07	31.46	52.17

Table 24.—Chemical composition of orchard grass grown from May 31 to July 26, at temperatures of 80° and 90°F. Series 4.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	16.64	21.49	3.66	23.93	34.28
	80	12.56	10.73	3.92	26.43	46.36
	90	12.67	15.59	3.93	24.07	43.74
Roots	Initial	11.39	10.88	0.94	32.29	44.50
	80	8.19	5.48	1.02	30.66	54.65
	90	9.87	10.95	1.13	29.25	48.80

Table 25.—Chemical composition of Bermuda grass grown from January 11 to March 10, at temperatures of 50° and 60°F. Series 2.

	Temperature (°F.)	Per cent of dry matter: Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	12.51	23.10	3.08	21.49	39.82
	50	10.29	17.14	1.46	17.25	53.86
	60	7.81	9.00	0.85	23.46	58.88
Roots	Initial	7.50	13.36	1.19	32.91	45.04
	50	7.21	14.86	0.14	28.88	48.91
	60	7.52	8.02	0.74	32.80	50.92

Table 26.—Chemical composition of Bermuda grass grown from March 18 to May 13, at temperatures of 60°, 70°, and 80°F. Series 3.

	Temperature (°F.)	Per cent of dry matter Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	14.50	13.90	2.73	25.59	43.28
	60	9.82	7.27	2.01	22.39	58.51
	70	10.19	6.56	1.78	22.93	58.54
	80	9.27	5.58	1.49	21.81	61.85
Roots	Initial	7.10	8.20	1.58	35.59	47.53
	60	3.65	5.24	1.29	35.08	54.74
	70	3.99	5.00	1.40	33.21	56.40
	80	4.29	4.45	1.13	33.57	56 56

Table 27.—Chemical composition of Bermuda Grass grown from May 31 to July 26, at temperatures of 80°, 90°, and 100°F. Series 4.

	Temperature (°F.)	Per cent of dry matter Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	11.65	9.37	1.94	28.08	48.96
	80	11.80	4.86	1.58	21.93	59.83
	90	8.35	4.71	1.50	23.56	61.88
	100	8.35	5.94	1.59	22.04	62.08
Roots	Initial	5.60	7.27	0.98	37.18	48.97
	80	4.68	3.86	1.18	34.75	55.53
	90	3.33	3.45	1.19	34.51	57.52
	100	3.35	4.24	1.03	32.16	59.22

Table 28.—Chemical composition of Kentucky bluegrass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F., with the soil temperature tanks held constant at 70°F. Series 5.

	Air temperature (°F.)	Per cent of dry matter Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	13.51	17.66	2.42	26.95	39.46
	70	12.89	12.75	2.63	27.88	43.85
	85	11.81	12.96	2.23	27.94	45.06
	100	12.91	16.58	2.21	26.12	42.18
Roots	Initial	4.99	10.28	1.42	32.01	51.30
	70	7.17	5.56	1.03	31.18	55.06
	85	7.07	6.34	0.84	30.65	55.10
	100	9.79	9.31	0.32	31.61	48.97
Rhizomes	70	5.07	9.76	0.73	31.51	52.93
	85	4.28	5.14	0.32	31.00	59.26

Table 29.—Chemical composition of Canada bluegrass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F., with the soil temperature tanks held constant at 70°F. Series 5.

	Air temperature (°F.)	Per cent of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	12.17	18.59	3.48	26.36	39.40
	70	12.08	8.96	3.03	25.07	50.86
	85	11.92	13.47	2.41	25.93	46.27
	100	12.88	17.25	3.70	25.31	40.86
Roots	Initial	9.25	10.78	1.25	33.36	45.36
	70	7.47	4.93	1.32	33.01	53.27
	85	8.39	7.46	0.78	30.02	53.35
	100	10.21	11.18	0.84	30.07	47.70

Table 30.—Chemical composition of orchard grass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F., with the soil temperature tanks held constant at 70°F. Series 5.

	Air temperature (°F.)	Per cent of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	17.56	18.18	3.46	24.12	36.68
	70	13.41	8.79	3.39	24.65	49.76
	85	13.93	10.20	3.30	25.73	46.84
	100	15.19	16.49	4.10	25.50	38.72
Roots	Initial	9.94	6.69	0.98	30.43	51.96
	70	7.87	4.57	1.21	30.96	55.39
	85	7.59	5.41	0.63	30.79	55.58
	100	9.51	9.22	1.78	32.74	46.75

Table 31.—Chemical composition of Bermuda grass grown from July 28 to September 21, at air temperatures of 70°, 85°, and 100°F., with the soil temperature tanks held constant at 70°F. Series 5.

	Air temperature (°F.)	Per cent of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	N-free extract
Herbage	Initial	11.50	10.46	1.78	25.10	51.16
	70	10.89	4.95	1.34	23.54	59.28
	85	9.50	4.98	1.07	22.16	62.29
	100	9.97	5.61	2.29	22.03	60.10
Roots	Initial	4.36	5.07	1.14	34.99	54.44
	70	5.42	4.94	1.80	33.59	54.25
	85	4.75	4.76	1.23	34.71	54.55
	100	5.53	4.91	2.48	31.23	55.85

Table 32.—Chemical composition of Kentucky bluegrass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F., with the soil temperature tanks held constant at 70°F. Series 6.

	Air temperature (°F.)	Ash	Crude protein	Per cent of dry matter: Ether extract	Crude fiber	N-free extract
Herbage	Initial	13.70	15.72	3.02	29.02	38.54
	70	14.48	16.31	3.63	26.37	39.21
	60–80	14.86	14.54	3.57	26.92	40.11
	50–90	13.35	14.46	3.38	27.46	41.35
Roots	Initial	8.42	9.89	1.65	29.78	50.26
	70	6.81	5.62	1.91	32.08	53.58
	60–80	6.94	5.69	2.07	33.01	52.29
	50–90	7.35	6.39	1.75	32.20	52.31
Rhizomes	Initial	5.67	11.67	1.67	32.95	48.04
	70	6.10	6.02	1.23	30.69	55.96
	60–80	4.97	4.87	1.44	30.95	57.77
	50–90	4.72	5.27	1.28	30.54	58.19

Table 33.—Chemical composition of Canada bluegrass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F., with the soil temperature tanks held constant at 70°F. Series 6.

	Air temperature (°F.)	Ash	Crude protein	Per cent of dry matter: Ether extract	Crude fiber	N-free extract
Herbage	Initial	13.29	16.66	3.05	26.26	40.74
	70	12.58	13.68	3.64	24.41	45.69
	60–80	11.53	13.95	3.47	25.25	45.80
	50–90	11.46	13.71	3.48	26.23	45.12
Roots	Initial	8.69	9.25	1.98	32.30	47.78
	70	7.01	6.05	1.75	33.72	51.47
	60–80	7.23	7.17	1.96	32.75	50.89
	50–90	7.26	7.54	1.66	33.51	50.03

Table 34.—Chemical composition of orchard grass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F., with the soil temperature tanks held constant at 70°F. Series 6.

	Air temperature (°F.)	Ash	Crude protein	Per cent of dry matter: Ether extract	Crude fiber	N-free extract
Herbage	Initial	17.53	14.89	3.56	26.66	37.36
	70	14.21	8.72	3.89	23.53	49.65
	60–80	14.38	8.76	4.08	23.96	48.82
	50–90	14.55	8.73	3.70	24.58	48.44
Roots	Initial	8.26	8.54	1.58	32.98	48.64
	70	7.53	4.62	1.57	32.69	53.59
	60–80	7.79	5.02	1.70	31.70	53.79
	50–90	7.18	5.18	1.45	32.19	54.00

Table 35.—Chemical composition of Bermuda grass grown from September 24 to November 19, at air temperatures of 70°, 60° to 80°, and 50° to 90°F., with the soil temperature tanks held constant at 70°F. Series 6.

	Air temperature (°F.)	Ash	Crude protein	Per cent of dry matter Ether extract	Crude fiber	N-free extract
Herbage	Initial	11.16	6.14	1.75	26.25	54.70
	70	11.71	6.55	2.41	25.76	53.57
	60–80	11.23	5.83	1.98	25.85	55.11
	50–90	10.75	5.33	1.95	23.79	58.18
Roots	Initial	4.58	5.16	1.46	36.22	52.58
	70	4.61	4.78	1.70	35.65	53.26
	60–80	3.41	4.57	1.65	37.50	52.87
	50–90	4.09	4.82	2.36	35.73	53.00