Greenhouse Studies on Growth of Kentucky Bluegrass

By C. M. Harrison

Several factors present in the environment of the grass plant influence to a great degree the production and maintenance of turf. Of primary importance among these factors are the value of different forms of nitrogen in relation to the acidity of the soil, seasonal variations in temperature, amount, intensity, and daily duration of exposure to sunlight, and cutting and fertilizing practices.

Disastrous results have been obtained from overwatering and overfertilizing grass that is cut short, especially during the hot summer months. The turf becomes thin, the production of new leaves ceases, and during the cooler, wetter period of fall the plants fail to recover. Environmental conditions may likewise influence the growth of roots and rootstocks. A condition favoring or retarding growth of the underground parts may, under some conditions, have a long-continued effect on the subsequent growth of the tops.

Experiments were conducted in the greenhouse at the University of Chicago in 1932 to gain information on the following problems:

1. Effect of ammonium and nitrate nitrogen in solutions of high and low acidities.
2. Effect of cutting and fertilizing.
3. Effect of differences in seasonal conditions.
4. Effect of cutting during the summer months on grass grown with and without an external supply of nitrogen.
5. Effect of cutting on growth at different temperatures.

In these experiments sections of Kentucky bluegrass from the same plant, each containing several buds, were grown in the greenhouse in two-gallon glazed pots containing sand which was free of nutrients. Only one small section containing several buds was planted in a pot. The plants were supplied with fertilizers prepared from pure chemicals and applied daily. Illustration 1 shows the way in which the cultures were supplied with fertilizer and water. The pans were the reservoirs for the solution. The small tube siphoned the solution into the pot. Because the tube was very small the solution lasted 24 hours, at the end of which time 1 quart of the fresh solution was washed through the sand to remove the residues of the old solution. The pans were then refilled with fresh solution, which slowly siphoned through the sand during the next 24-hour period.

The solutions used in all the experiments contained equal quantities of phosphorus, potash, calcium, and magnesium. Phosphorus and potash were used in the form of potassium phosphate, magnesium as magnesium sulphate, and calcium as calcium nitrate or calcium chloride. Nitrogen was used in the form of sulphate of ammonia or calcium nitrate. In experiments 1 and 2, in which the effects of nitrate and ammonium forms of nitrogen were compared, the same quantity of nitrogen as nitrate or as ammonium was used in the different solutions. In experiments 3, 4, and 5, in which growth with and without nitrogen in the nutrient solution was to be compared, calcium nitrate was added to one solution to furnish nitrogen and calcium; to the other solution, lacking nitrogen, calcium was added in equivalent amount as calcium chloride.

In some of the experiments it was necessary to adjust the reaction of the nutrient solution to different pH* values. Hydrochloric (muriatic) acid was added to lower the reaction to pH 4.0, and caustic soda to raise it to pH 6.5.

Experiment 1.—Effect of Ammonium and Nitrate Nitrogen in Solutions of High and Low Acidities

In the production of grass turf on the putting greens and fairways of the present-day golf courses, large quantities of nitrogenous fertilizers are used. The nitrogen in the various fertilizers appears in several forms, but chiefly as nitrate (as in nitrate of soda) or ammonium (as in sulphate of ammonia). Experimental evidence seems to indicate that the ammonium form of nitrogen is most useful to various kinds of plants if the pH value of the soil solution is neutral or somewhat alkaline. This experiment was conducted to find if this rule applies also to Kentucky bluegrass plants and to find at what soil reaction nitrate nitrogen is used to best advantage. Similar studies have recently been made on several crop plants.

Illustration 1.—Showing equipment used in experiments. A supply of nutrient solution sufficient for a 24-hour period was kept in the pans above and slowly siphoned into the pots in which the plants were growing

This experiment was begun in January. A solution containing nitrate nitrogen was used for the early growth of the plants in the sand. In April, after the plants were well started, as is shown in illustration 1, the sand was washed free of nitrate nitrogen with distilled water, after which the cultures were divided into sets for receiving different kinds of solutions. Two sets of cultures were supplied with a solution containing nitrogen in the nitrate form only. Two other sets of cultures were supplied with a solution containing nitrogen in the ammonium form. The reaction of the solution of one set of cultures receiving the ammonium and of another set receiv-

* pH is the symbol used in expressing acidity or alkalinity. The figures following the symbol show the degree of acidity. The smaller numbers are the more acid. pH 7.0 is considered neutral. Any number above 7.0 is considered alkaline and any number below 7.0 is considered acid.

ing the nitrate solution was adjusted to a pH value of 4.0, and that of the other two sets of nitrate and ammonium cultures to a pH value of 6.5. Another set of cultures received the solution containing ammonium nitrogen and another the solution containing nitrate nitrogen without any adjustment of the pH value.

Within one week after the first application, the plants in the cultures receiving the ammonium form of nitrogen, regardless of the pH value of the solution, turned from a yellowish green to a dark purplish green color, while the plants in the cultures supplied with nitrate nitrogen remained a yellowish green. Two weeks after the start of the test, the plants receiving ammonium nitrogen evidenced a browning and dying of the tips of the leaf blades. This was much more pronounced at pH 4.0 than at pH 6.5.

Approximately six weeks after the beginning of the test the plants in the cultures supplied with sulphate of ammonia at a pH value of 4.0 began to wilt especially during the sunny portion of the day. Practically all of the surplus nitrate nitrogen present in the leaf blades at the start of the pH test, which had been taken up from the solution used for the early growth, had disappeared at the time the wilting was noticed. As the days grew warmer, this wilting of the plants became more and more noticeable, and finally all of the leaf blades drooped through the sunny portion of the day but revived at night. During the hottest days near the end of the test the plants supplied with ammonium nitrogen at pH 6.5 wilted slightly during the middle of the day, whereas the leaves of the plants receiving nitrate nitrogen at either pH 6.5 or pH 4.0 remained turgid at all times. During the last few days that the test was running the plants receiving ammonium nitrogen at pH 4.0 did not revive from their wilted condition and active growth appeared checked, while all of the other plants were still actively growing.

The pH of the solutions, after passing through the sand in the pots, became considerably changed. The solution containing sulphate of ammonia at pH 6.5 tended to become more acid. The solution containing sulphate of ammonia to which no alkali or acid had been added also tended to become more acid. The solution adjusted at pH 4.0, however, seemed to remain about the same as it was before passing through the sand. The solution containing nitrate nitrogen at pH 6.5 became slightly more acid as it passed through the sand, while the solution adjusted to pH 4.0 and that at pH 4.5 became much less acid, tending to reach a point between pH 5.5 and 6.0.

On June 29 the roots of the plants were washed free of sand; the roots, tops, and rootstocks were separated from each other and dried, and the weights recorded in grams.

The rolled condition of the leaves in the culture supplied with ammonium nitrogen at pH 4.0 is not noticeable in the photograph. There was no apparent difference in the two sets of plants supplied with nitrate nitrogen except a somewhat yellower green at pH 6.5. The plants receiving ammonium nitrogen at pH 4.0 had dark-colored roots and rootstocks. No new rootstocks were being produced and some of the tips of those already formed were dying. The plants supplied with ammonium nitrogen at pH 6.5 showed less browning of the roots and rootstocks than at pH 4.0. There were more rootstocks being produced at pH 6.5 and no dead tips were noticeable.

The rootstocks appeared greater in number at pH 6.5 than in the culture at pH 4.0 and of a whiter color. The plants supplied with nitrate nitrogen at both pH 4.0 and 6.5 had light-colored roots and many white rootstocks. Many new rootstocks were being produced. Illustration 2 gives a fair representation of the appearance of the plants when they were harvested. The dry weights of the harvested plants are recorded in table 1.

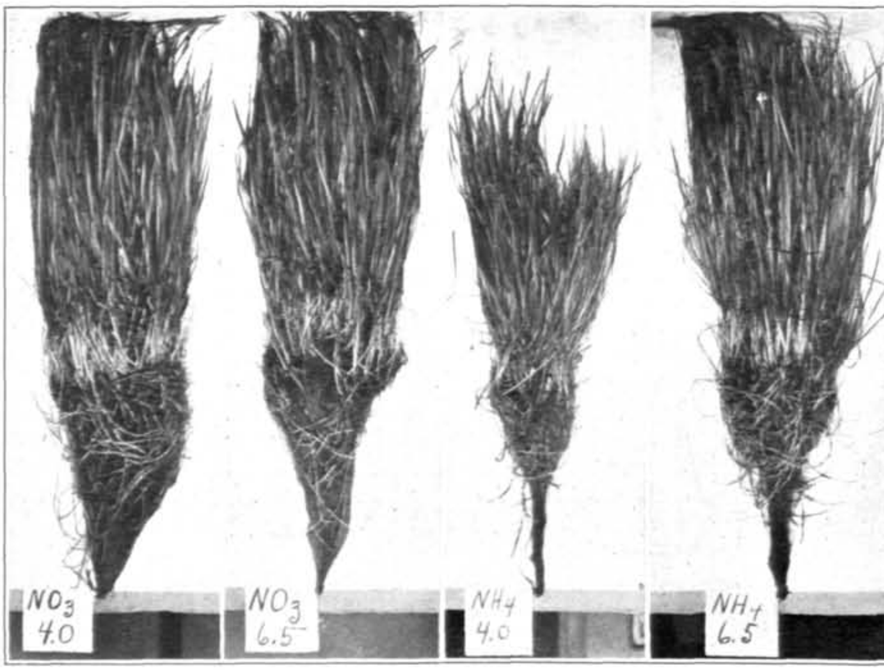

Illustration 2.—Appearance of the Kentucky bluegrass plants at end of experiment after sand was washed from the roots. The pH values indicated on the photograph represent the initial reactions of the different solutions. The final reactions of the pH 4.0 nitrate solutions were less acid than indicated whereas that of the ammonium solution remained about the same. The final reaction of the pH 6.5 sulphate of ammonia cultures was also more acid than indicated

Table 1.—Dry weights in grams of roots, tops, and rootstocks from grass grown with nitrate and ammonium nitrogen at high and low acidities. The figures shown are the average weights of three cultures in the solutions with unadjusted pH value and of five cultures where the solutions were adjusted to pH 4.0 and 6.5

	Ammonium nitrogen			Nitrate nitrogen		
		pH unadjusted			pH unadjusted	
	pH 4.0	pH 4.8	pH 6.5	pH 4.0	pH 4.5	pH 6.5
Roots	3.4	3.9	5.5	13.1	14.3	13.6
Tops	37.7	38.8	53.8	56.7	59.7	52.4
Rootstocks	4.6	4.7	4.7	13.1	10.1	10.6

The most outstanding features of the table are the very much greater growth of both roots and rootstocks in the solution containing nitrate nitrogen as compared with that in the solution containing ammonium nitrogen, regardless of the degree of acidity. The pH value of the solution did, however, appear to influence the growth of tops and, to a lesser extent, the growth of roots, in the solution containing ammonium nitrogen, pH 6.5 being much more favorable than pH 4.0 or 4.5. The results indicate that the degree of acidity does not strongly affect the utilization of nitrate nitrogen. Since the nutrient solutions were not maintained at an exact pH value, further study is required before an interpretation should be made of the results as being definitely due to differences in pH value. This test indicates that ammonium nitrogen may be of little use in the growth of bluegrass if the medium in which the plants are growing is sufficiently acid.

By a study of the illustrations and the weights of the different plant parts listed in the table it will be seen that the plants receiving the solution containing nitrogen in the ammonium form at pH 4.0 made the least growth. They had practically as much weight of rootstocks as the plants supplied with this solution at pH 6.5, but they had a smaller amount of roots and a far lower weight of tops. Both of the sets of plants receiving the solution containing nitrate nitrogen produced about the same weight of tops as the sets receiving the solution containing ammonium nitrogen at pH 6.5, but approximately twice as many roots and rootstocks.

It was noted that plants receiving either nitrate or ammonium nitrogen make a different type of growth than when nitrogen is added in both forms to the same culture as was done in another experiment. Where both forms were added the plants appeared about half way between those produced by the addition of nitrate or ammonium nitrogen only, and hence tended to have the desirable qualities characteristic of both treatments.

Color has been one of the chief factors used in judging the health or vigor of grass, and at times this color response may be misleading, as in the case of plants supplied with ammonium nitrogen at a pH of 4.0. The color response of plants supplied with nitrate nitrogen at the low pH value may not be desirable because of the resulting yellowish green color, although the grass may be much more vigorous than if the ammonium form only is used. More work is necessary before definite statements can be made as to the responses that grass will make to the addition of these two forms of nitrogen at different temperatures and over wider ranges of acidity and alkalinity.

Experiment 2.—Effect of Cutting and Fertilizing

Results of experiment 1 had indicated that a fertilizer high in calcium nitrate might be effective in producing a greater growth of rootstocks than one high in sulphate of ammonia. Another experiment was conducted to find if these results might be repeated if slightly different procedures were followed.

This experiment was started in April. To one-half of the cultures was applied a solution in which four-fifths of the nitrogen was supplied as calcium nitrate and the remainder as sulphate of ammonia. The other solution contained four-fifths of its nitrogen in the form of sulphate of ammonia and the remainder as calcium nitrate. The high-nitrate solution had a pH value of 4.5 and the high-ammonium solution a pH value of approximately 4.8. The cultures were grown until the latter part of September, when some of the plants from the high-nitrate and the high-ammonium cultures were removed from the pots and the sand washed from the roots. Photographs were taken and the plants were divided into tops, roots, and rootstocks, which were dried and weighed. Illustration 3 gives an idea of the different type of growth in the two sets. Table 2 gives the weight of the plant parts in grams after drying.

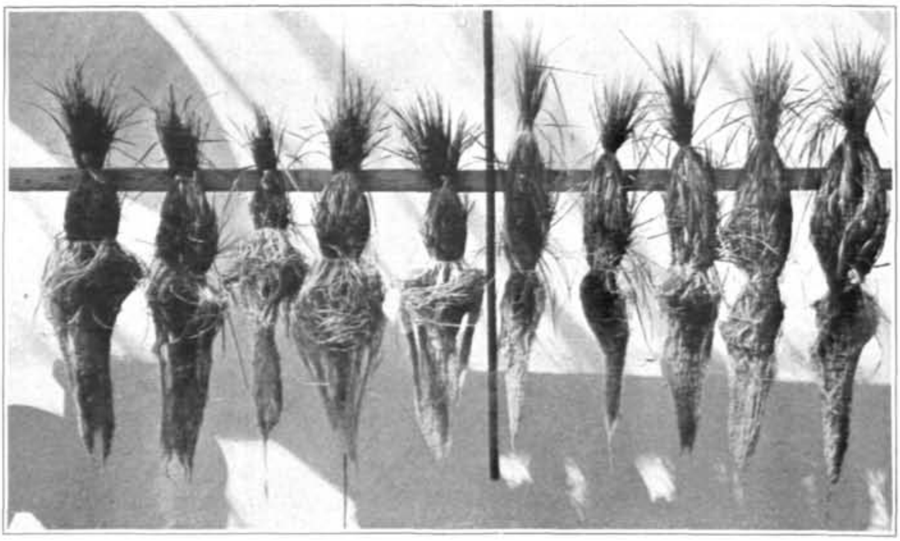

Illustration 3.—Kentucky bluegrass plants on the left were grown in the solution high in nitrate and low in ammonium nitrogen, while those on the right were grown in the solution high in ammonium nitrogen and low in nitrate nitrogen. Note the habit of growth and the difference in amount of rootstocks in the two sets

Table 2.—Grams dry weight of plant parts supplied with a high-nitrate or a high-ammonium solution

High-nitrate, low-ammonium solution

	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4	Plant No. 5	Average
Roots	9.5	9.1	9.5	8.5	5.2	8.3
Tops	44.5	41.2	39.0	32.5	23.5	36.1
Rootstocks	4.3	4.1	5.7	5.0	4.0	4.6

High-ammonium, low-nitrate solution

	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4	Plant No. 5	Average
Roots	7.5	7.3	6.5	3.7	3.5	6.3
Tops	42.5	38.0	30.5	19.0	16.5	29.3
Rootstocks	2.5	2.2	1.8	0.7	1.0	1.6

The plants receiving the solution high in ammonium and low in nitrate nitrogen had leaves that were from 15 to 22 inches long which lay flat or drooped over the sides of the pots and were very dark green in color. On the other hand, those supplied with the solution high in nitrate and low in ammonium nitrogen had leaves from 8 to 12 inches long which were a lighter green color and stood upright in the pots. As in the previous experiment, it was found that the number and weight of rootstocks of the plants supplied with the solution high in nitrate nitrogen were greater by far than of the plants supplied with the solution high in ammonium nitrogen. There were from 300 to 500 rootstocks in the cultures supplied with high-nitrate, as compared with 50 to 150 in the cultures supplied with high-ammonium. The rootstocks in the cultures supplied with a solution high in nitrate nitrogen were short and thick and considerably branched when compared with the long, thin, and unbranched ones in the cultures grown with the solution high in ammonium nitrogen. The tops of three of the five plants receiving the high-ammonium solution were equal in weight to those of the high-nitrate plants. There were relatively greater differences in the roots of the two groups of plants.

On the same date (September 22) five similar plants of each series (high-ammonium and high-nitrate) were cut to ½ inch, five to 1 inch, and five to 2 inches. The clippings from this initial cutting were dried and weighed. One week later the grass was again clipped at the above heights. It was noticed that the shorter the cutting height, the shorter was the new growth made after cutting. In both sets the grass cut to ½ inch grew approximately 4 inches, that cut to 1 inch grew 5 inches, and that cut to 2 inches grew 6 inches. The measurements were taken above the point of the original cutting in each case. After the second cutting, during a period of high temperatures in the greenhouse, it was observed that the grass recovered more slowly than usual. The new leaf growth extended upward from 1 to 3 inches and then died back from the tips of the blades. It was much more noticeable in the plants grown with the solution high in sulphate of ammonia than in those supplied with the solution high in calcium nitrate. A considerable number of the aboveground buds soon failed to produce any more new leaves or to extend those which had been cut, and upon examination they were found to be dead. Most of the early death was in the center of the culture, which was the oldest portion. The plants started growth from the segment which was the original planting, and new rootstocks extended laterally from this segment. These new rootstocks were younger than the stem from which they had originated, and none of their young leaves had extended upward but were still contained within the bud. Consequently when cutting was begun, more of the leaf tissue of the older portion of the plant was removed than was the case with the rootstocks which had just pushed above the surface of the sand or were as yet buried beneath it. The number of leaves that a given bud will produce is determined quite early in its growth. The leaves in older buds had practically all unfolded and matured, whereas in the younger rootstocks the leaves had either just begun to unfold from the bud or as yet remained underground.

The underground parts were examined to see what was taking place under the conditions of frequent cutting, high fertilizing, and high temperatures. The rootstocks of both sets of plants were all below the soil line and all extending vegetatively and producing small white leaves before the cutting treatment was begun. On examination on October 15, after the two previous cuttings in September, it was found that every rootstock tip below the soil line, in each fertilized set and at all three cutting heights, was dead. The ends of the rootstocks were brown and beginning to decay. The death of the rootstock tissue back from the tip depended somewhat upon the amount of green top material remaining after cutting—the more of the top removed, the greater the degree of killing of the rootstock when measured from the terminal point. The growing ends or buds died first, and then successively the buds at the joints back from the tip. In most cases the entire rootstock became brown and decayed. The roots on the dead rootstocks died also, and in some cultures as much as 90 per cent of the original top died. The younger rootstocks toward the outside of the culture withstood the cutting treatment and survived. Any rootstock which had recently emerged above the soil line and was actively producing leaves survived. These new leaves were green even below the point of shortest cutting, and probably they had enough leaf area to manufacture sufficient carbohydrates such as starch and sugar to maintain the newly-emerged rootstock as an individual plant. The older stems, however, had a considerable number of dry leaf sheaths at their bases, and the new leaves produced had to grow through them for a considerable distance before emerging into the light. Consequently when these tips were removed by cutting no leaves were left to manufacture carbohydrates.

This experiment shows that plants fertilized with the solution high in calcium nitrate produced a much greater growth of the underground parts, particularly of the rootstocks, than those fertilized with the solution high in sulphate of ammonia, whereas the latter plants produced longer and greener leaves than the former. It also shows that severe cutting had more disastrous effects upon the high-ammonium than upon the high-nitrate plants. Severe cutting was found to be especially harmful to the rootstocks—the shorter the cutting height, the greater the injury.

Experiment 3.—Effect of Differences in Seasonal Conditions

Bluegrass plants were grown from shoots planted in April and supplied with a nutrient solution containing nitrogen in the form of calcium nitrate. The first new growth came out not only from the main bud on the stem but from new tiller-like buds produced at the place where the leaves come off from the stem. These new buds were green on emergence and grew upright from the start. Following this initial development, short stolons were produced above ground which grew an inch or two from the crown of the plant before they turned upward and began the production of leaves. In some cases roots developed at the joints, and short rootstocks were also produced which emerged a short distance from the crown and developed green leaves. This process continued until the pot was full of upright stems. Then later, when the days were long and bright, the active production of aboveground stems became somewhat retarded and there were a large number of rootstocks produced below the soil line. These did not emerge as long as the top of the plant was not cut off, as long as the nitrogen supply was not increased, or as long as light conditions remained satisfactory for growth.

These rootstocks elongated, many of them growing around the inside of the pot and sometimes down to the bottom. In late fall and early winter, as the daylight diminished, few new underground rootstocks were produced by the grass that was continually fertilized with nitrogen. The rootstocks which were produced below the soil level during the summer and early fall gradually turned upward at the growing point, emerged above the soil line, and produced leaves. The emergence of these rootstocks continued until none were left below the soil line. In the more heavily fertilized grass a considerable number of these underground rootstocks died during the dark winter period, probably because of a lack of available storage carbohydrates such as starch and sugars. Because of poor light conditions at this time not enough carbohydrates could be manufactured to meet the needs of the plant. No new roots or rootstocks were produced during this period to take the place of those which died.

Following the emergence of the underground rootstocks, the dormant buds at the bases of the leaves above ground commenced to grow, and many short tiller-like branches were produced, much the same as when the plants started growth from the original shoot. In other words, the 300 to 500 rootstocks which were produced below the soil line, during summer and early fall when the days were long and sunny, gradually emerged and started to produce leaves as the amount and intensity of light decreased due to shorter days and more cloudy weather. On the other hand, plants which were supplied after November 10 with a nutrient solution lacking nitrogen, produced by the first of February a considerable number of underground rootstocks which became stockier and remained below the soil line. The tops of these plants turned yellow when the days were short and cloudy and grew little if any, while the root system grew deeper and became more extensive. It appeared that nitrogen added at a time when the days were short and cloudy brought about the emergence above the surface of the soil of underground rootstocks, which were produced during the period of long sunny days. On the other hand, the plants which received no nitrogen but were exposed to the same short cloudy days actually increased the amount of roots and rootstocks, with a stopping of active top growth. There was some death of rootstocks and roots in the plants receiving nitrogen. After about eight months the plants supplied with the solution lacking nitrogen appeared to be at a standstill both below as well as above ground. It would thus appear that when the days were long and bright probably nitrogen was the limiting factor, while during the winter months lack of sufficient light necessary for carbohydrate manufacture in plants heavily fertilized with nitrogen was the limiting factor.

Table 3.—Weights of the clippings, in grams, produced by two plants, one having nitrogen and greenhouse light only, and the other having added artificial light but no nitrogen

	December 15 Initial cut		December 23	January 6
	Green weight	Dry weight	Dry weight	Dry weight
No nitrogen but added artificial light	173	46.7	2.8	1.4
Nitrogen and greenhouse light only	176	42.0	1.3	.3

Groups of plants were grown some with and some without nitrogen. Those grown without nitrogen were given artificial light after November 10 in addition to the natural daylight. It was found that cutting of the plants supplied with nitrogen was much more disastrous than cutting those not supplied with nitrogen but given extra light. Table 3 shows the weights of clippings obtained at different dates from the two groups of plants. It may be observed that the plants not given nitrogen but which had extra light produced a much greater yield than the plants given nitrogen but no extra light. The difference was even greater at the time of the second cutting than it was at the first. Withholding nitrogen from a plant tends to result in an accumulation of carbohydrates. Furnishing additional light at the time of year when natural light is very inadequate leads to an increased manufacture of carbohydrates by the leaves. Thus the carbohydrate supply for one group of plants in this experiment was increased in two ways over that available to the other group. There may have been other differences in factors affecting the growth of the two groups of plants in this experiment, but the difference in carbohydrate supply was doubtless the chief one. The importance of a supply of carbohydrates such as starch and sugar to the plant is thus exemplified in this experiment.

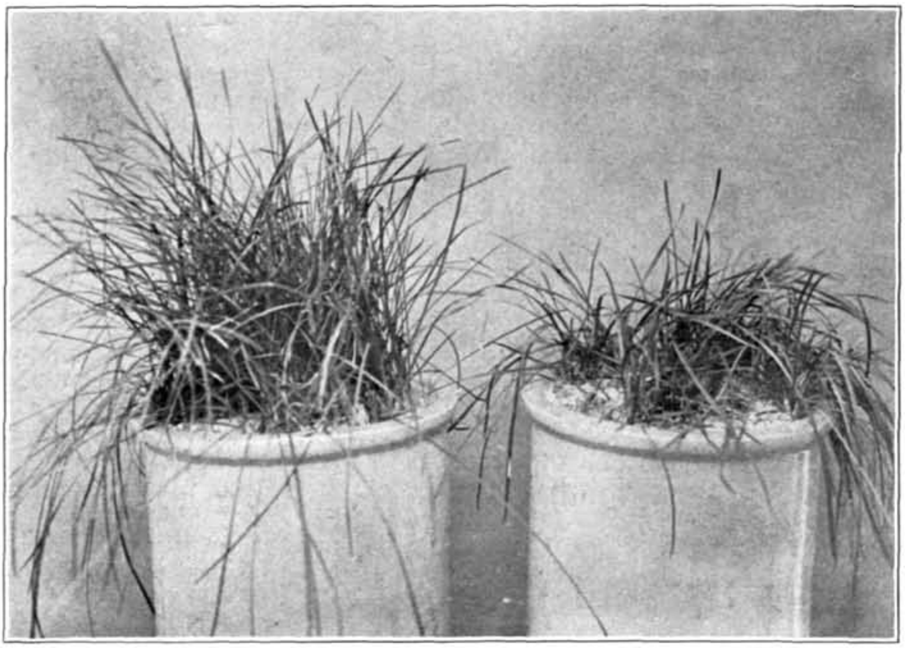

Illustration 4.—Growth of Kentucky bluegrass cultures made in two weeks after three successive cuttings to ½ inch on December 15 and 23, and January 6. The culture on the left had had no nitrogen but added artificial light since November 10, while the one on the right was continually supplied with nitrogen and given no additional light other than the ordinary greenhouse light at that period

Illustration 4 shows the appearance of the two plants about two weeks after cutting was stopped. The plant grown with nitrogen and greenhouse light only was about 90 per cent dead at the end of the three cuttings while the one grown with added artificial light without nitrogen was vigorous. The new growth produced by the latter, after cutting off the old yellow leaves, was dark green in color and appeared more succulent after each successive cutting. The plant supplied with the solution which had no nitrogen in it had a large number of stocky rootstocks below the soil line at the beginning of cutting while the plant supplied with nitrogen had only a few very spindling ones. The tips and finally the entire rootstocks died in the plant receiving nitrogen, while in the one receiving no nitrogen the ends of the rootstocks turned upward, produced leaves, and finally emerged above the soil line. Very few of the roots of this plant died, while the one receiving nitrogen showed a considerable number of dead roots as well as dead rootstocks. Ten days after the last of three cuttings the plant without nitrogen could be removed from the pot, all of the sand adhering to the roots which permeated the soil mass of the entire pot, while the culture supplied nitrogen lifted off the top, and only three or four inches of sand in the pot adhered to the roots. (The pots had 10 inches of sand in them.) At the beginning of the test both cultures would allow of removal, all of the sand coming out as a compact mass held together by many fine roots.

When artificial light was given during the winter and nitrogen was withheld, the plants, if left uncut, turned yellow, the leaves became stiff and upright, and very few new stems were produced above ground, while a considerable number were produced as rootstocks below the soil line. When given added artificial light in the winter and a continual nitrogen supply the plants remained succulent and green, the dormant buds at the base of the leaves elongated above ground, producing green leaves, but there was very little, if any, production of underground rootstocks. As soon as the days became longer and brighter, in March and April, producing more favorable conditions for the manufacture of carbohydrates, the plants supplied with nitrogen produced not only a greater amount of top growth than those receiving no nitrogen but also more new roots and rootstocks.

Plants that were allowed to grow long with a continual nitrogen supply and then cut short underwent a process of reduction of the underground parts, namely, the roots and rootstocks. There seemed to be a balancing of the underground portion to the amount of top left on. Then, when cutting was suspended these plants began to produce new top growth, rootstocks, and roots much sooner than the uncut plants, and in two months of long sunny days with cool temperatures the cut and uncut plants appeared almost identical.

Experiment 4.—Effect of Cutting During the Summer Months on Grass Grown With and Without Nitrogen in the Soil

The results of the previous experiment had shown differences in the effects of cutting plants grown with and without nitrogen during the winter months. Experiment 4 was conducted to determine if similar effects would be obtainable in summer when light and temperature conditions were very different from the conditions in experiment 3.

Plants were started in November and were grown in the nutrient solution containing nitrogen in the form of calcium nitrate. In April the sand of some of the cultures was washed approximately free of nitrates, following which the nutrient solution lacking nitrogen was supplied. Other cultures were grown continuously in the solution containing calcium nitrate.

It took about six weeks for the nitrates accumulated in the leaves of the plants, now receiving no nitrogen, to disappear. In June, two months after the treatment without nitrogen was started, the plants in three cultures which had been receiving nitrogen and the plants in three which had received no nitrogen were dug up, the sand washed from the roots, and the plants separated into roots, rootstocks, and tops. The dry weights of the plant parts are shown in table 4.

Table 4.—Dry weight in grams of roots, tops, and rootstocks removed in June from six plants of Kentucky bluegrass, three of which were grown for two months, or since April, without nitrogen, and three with a continual supply of nitrogen during the same period

	Roots	Tops	Rootstocks
3 plants grown without nitrogen	16.3	41.7	20.6
	16.4	38.5	21.0
	20.1	46.5	27.6
3 plants grown with a continual supply of nitrogen	13.7	59.5	15.0
	14.0	64.7	13.2
	11.8	53.2	11.7

The average dry weight of an entire plant in the set grown without nitrogen was 82.9 grams, while that in the set grown with nitrogen was 85.6 grams. The difference in dry weight between the plants in the two treatments was very small, but the weights of the roots, tops, and rootstocks showed considerable variation.

The amount of tops of the plants which received the continual nitrogen supply was considerably greater than was the amount of tops in the set without nitrogen, but the weights of rootstocks and roots of the plants grown without nitrogen were much greater than those of the plants supplied continually with nitrogen. On June 21, the remaining plants of each set were cut down to ¾ inch measured from the level of the sand in the pot. The cutting was continued once each week thereafter.

The plants grown without nitrogen started growth very slowly the first week after the initial cutting. They grew about 1½ inches, while the plants supplied continually with nitrogen grew 4 inches. This difference in height of growth did not hold for more than one month, at the end of which the plants without nitrogen were making more growth in a week following cutting than those supplied with nitrogen. The plants grown without nitrogen changed color from a yellowish green at the start to a dark green, which was still maintained at the close of the experiment. The plants supplied with nitrogen were producing a very weak growth and were pale green in color at the end of the experiment. A considerable number of new stem tips appeared above ground in the plants grown without nitrogen, while in those supplied with nitrogen no new stem tips were visible.

A study of the underground parts of the plants showed some very interesting details. On June 30, no difference between the two sets of plants could be noticed, but on July 7, approximately two weeks after the first cutting, a large number of the rootstock tips in the plants supplied continually with nitrogen were dead. In those supplied the solution lacking nitrogen there were no dead rootstock tips observable, and those present were turning upward. A few were producing yellowish leaves which were emerging above the soil line. At no time did any rootstock tips or new leaves appear above ground in the plants supplied continually with nitrogen. On July 20, one month after the initial cutting and after three other cuttings one week apart, all of the rootstock tips in the plants supplied with nitrogen were dead and a considerable number of the entire rootstocks also. No dead rootstocks were found in the plants that had received no nitrogen since April 21, but a large number of them had emerged above the soil line and were actively producing leaves. The rootstocks in these plants branched some underground, but by the middle of August practically all of those present below ground at the start of the test had emerged above the soil line. No dead stems were noticeable. In the plants which had been supplied with nitrogen continually, all of the rootstocks, as well as the roots attached to them, died without the rootstocks having emerged above the soil line, and also about 60 per cent of the culms present at the beginning of the test. Illustration 5 shows the appearance of the rootstock tips of the two groups of plants.

Illustration 5.—Rootstock tips of Kentucky bluegrass grown in solution containing nitrogen. The three on the left were from uncut plants; the three on the right from plants cut short

Growth of tops was also influenced by temperature. During the week of July 21 to 28 the yield dropped considerably in both sets of plants when compared with that of the previous week or the following one. The week of July 21 to 28 was characterized by bright days and high temperatures. The day temperatures in the greenhouse during most of the week reached a maximum of 120 degrees F. and the night temperatures rarely went as low as 80 degrees. The following week the day temperatures reached a maximum of 90 degrees F. and the night temperatures frequently went as low as 65 degrees. The experiment was discontinued at the end of September. Two of the five plants which had received a continual supply of nitrogen were dead and a third was practically so. Of the two remaining, approximately 50 per cent of the original top growth was dead. The plant parts still remaining alive could be removed easily and were very shallow-rooted. All of the rootstocks on all five of the plants, along with the roots attached to them, were dead. It was impossible to remove the plant and the sand in the pot by pulling on the top, because the small remaining parts of the original plant pulled out of the sand evidencing a very shallow and unbranched root system. On the other hand, the plants which had been grown since April 21 without nitrogen could still be removed from the pots, all of the sand adhering to the many small roots still present and alive. These plants were beginning to show the need of some additional nitrogen, as evidenced by a yellowing of the leaves. A considerable number of rootstock tips were still present below the soil line and no dead tips were discernible.

Illustration 6.—Fertilized and unfertilized Kentucky bluegrass after 14 weekly cuttings June 21 to September 27 inclusive. In the top row are the five plants which were not supplied with nitrogen since April 21 and in the bottom row the plants which received a continuous supply up to September 27. The photograph shows the growth made in one week after the last cutting. It will be observed that the two end plants in the fertilized (lower) row are dead

Illustration 6 shows the nature of the top growth just before the experiment was discontinued. It shows the growth made by the two sets of plants between September 20 and 27.

The test shows that plants grown without a supply of nitrogen in the soil withstood the effects of cutting under greenhouse conditions better than plants grown with nitrogen continuously available. The plants grown without nitrogen not only recovered more rapidly after cutting, but the new growth was stronger and had a better color and the roots and rootstocks were superior both in amount of growth and in general condition.

Experiment 5.—Effect of Cutting on Growth at Different Temperatures

It has long been recognized that Kentucky bluegrass makes a better growth in cool weather than in hot. Several of these experiments have shown striking effects of cutting and fertilization with nitrogen on growth at different seasons. Differences in temperature and light were the chief variables in the conditions for growth which prevailed during the previous tests. In order to determine to what extent such effects might be due to temperature alone, special experiments were conducted in which pots of grass were placed in glass cases kept at constant temperatures of 60, 80, and 100 degrees F., respectively, by blowing air of regulated temperature through them. At the low temperatures the air was passed through a refrigeration plant, whereas steam was used to raise the temperature of the air in the case set at 100 degrees F. The humidity of the air was regulated so that it was approximately the same at all three temperatures.

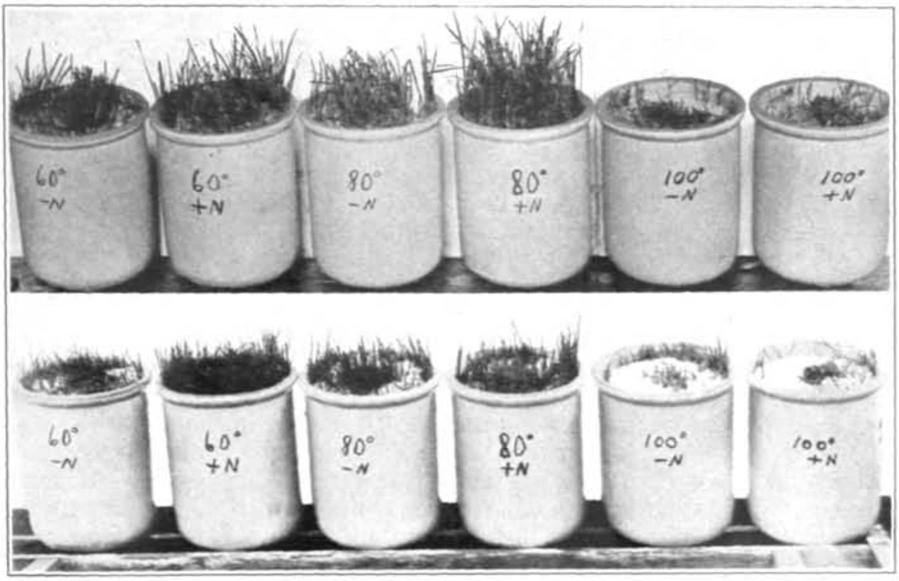

Illustration 7.—Kentucky bluegrass grown at different temperatures. Top section of photograph shows appearance of grass one week after the initial cutting; the lower section, its appearance one week after the final cutting. Note the thickening of the older (lower row) plants grown with nitrogen at 60 degrees F. and the spindling growth at 100 degrees F.

Table 5.—The average dry weight in grams of plants grown at 100 degrees, 80 degrees, and 60 degrees, F. with and without nitrogen

	100° F.		80° F.		60° F.	
Date	without nitrogen	with nitrogen	without nitrogen	with nitrogen	without nitrogen	with nitrogen
July 30......	0.29	0.25	1.5	2.5	1.1	1.8
August 9....	no growth		0.9	1.2	0.47	1.8
August 20...	no growth		0.8	0.8	0.4	1.8
August 31 ..	no growth		0.6	0.5	0.3	1.9
September 12	no growth		0.8	0.7	0.4	1.7

The grass, which was planted early in January, was given a complete nutrient solution containing nitrogen in the form of calcium nitrate until the latter part of May, when it was given the solution lacking nitrogen. On July 15 eight plants were placed in the cases at each of the different temperatures. Four of the plants in each case were given a solution containing calcium nitrate while the other four received the solution lacking nitrate.

After being in the case for five days all of the grass at 100 degrees F. was beginning to turn a watersoaked, yellowish color whereas that at 80 and 60 degrees which had been supplied with nitrogen was turning a dark green. No color change could be noted in the plants receiving no nitrogen at the two temperatures. Only 9 days after the plants were placed in the temperature chambers and 4 days after the first cutting on July 20 the tips of the rootstocks of the plants kept at 100 degrees F. were dying rapidly. Those of plants supplied with nitrogen appeared to be dying faster than those not supplied with nitrogen. There was no death of rootstocks in any of the other four sets of plants at this time.

Following the first cutting on July 20 the grass was cut to a height of 1 inch every 10 days until the close of the experiment. The dry weights of tops removed from the plants are recorded in table 5. The appearance of the plants one week after the final cutting the latter part of September is shown in the lower section of illustration 7. It may be observed from table 5 and illustration 7 that the grass kept at 100 degrees F. and grown both with and without nitrogen grew very little after being cut. After the second cutting these plants did not produce any new top growth until after the exposure to 100 degrees F. was discontinued near the end of August, at which time the pots were removed from the case and placed on a bench in the greenhouse where the temperature at night reached a minimum of 70 degrees F. By the middle of September, a few spindling, light green shoots grew out from lateral buds of the rootstocks. The terminal buds were dead.

At 80 degrees F. recovery after cutting of the plants receiving nitrogen was very rapid but much slower in those grown without nitrogen. The leaf blades of the latter plants were short and broad, whereas those of the plants receiving nitrogen were long and narrow. None of the rootstocks, known to be present at the beginning of the experiment, had begun to appear in either set. On closer examination, it was observed that a good many rootstock tips were dying underground in the case of plants receiving nitrogen, whereas those not supplied with nitrogen were turning upward and growing toward the surface of the sand. The weight of the clippings removed after the first ten days from the plants grown without nitrogen in the solution was approximately one-half of that removed from those receiving nitrogen. One month later, the clippings removed were approximately the same in both sets, with or without nitrogen.

At 60 degrees F. the first observable growth response was the appearance above the soil line, in the plants supplied with nitrogen, of a large number of rootstock tips. A large number of those which were underground at the beginning of the test grew rapidly upward and soon emerged above the soil line. Tiller-like buds at the bases of the leaves of the older aboveground stems were also beginning to grow and produce leaves. The top growth of these plants thickened considerably, and although the grass did not grow as tall as it did at 80 degrees F. with nitrogen, the weight of new growth of the two groups of plants made after cutting was almost equal. The results in the table show that one month after the initial cutting the plants at 60 degrees F. supplied with nitrogen were producing over twice the weight of tops in comparison with those receiving nitrogen at 80 degrees F. This difference was largely due to the increased number of new aboveground stems of the plants at 60 degrees F. At the latter temperature, the rootstocks grew upward and thickened the turf when fertilized with nitrogen, while at 80 degrees F. they died and no new tiller-like buds were produced.

Much more green tissue was left after cutting in the case of the grass grown at 60 degrees F. with nitrogen than at 80 degrees F. This was because the new stem tips produced leaves which were green on emergence from the soil, and as a result considerable leaf area was left below the cutting point, whereas most of the green tissue was removed from the plants at 80 degrees F. The old dead leaves of the latter plants completely encased the growing buds. The tops of the plants grown at 60 degrees F. without nitrogen recovered very slowly from cutting. Upon closer examination it was noted that they were actively producing new roots, which was not observable in any of the other sets of plants. Even after the fourth successive cutting, these plants were still producing new roots.

Table 6.—Average dry weight in grams of plant parts at the end of the test

	100° F.		80° F.		60° F.	
	without nitrogen	with nitrogen	without nitrogen	with nitrogen	without nitrogen	with nitrogen
Roots	10.5	8.9	12.2	9.3	16.4	11.2
Rootstocks	6.1	7.0	7.4	7.7	12.9	9.2
Live tops	0.25	0.16	7.7	2.8	8.4	12.3
Dead tops	4.5	4.5	1.6	4.9	none	none

Table 6 gives the dry weights of different parts of the plants at the end of the experiment. A study of this table shows that the roots and rootstocks of the plants grown without nitrogen at 60 degrees F. weighed far more at the end of the test than any of the others. It also shows that there were no dead tops in the plants grown at 60 degrees F., whereas there were considerable at the other two temperatures. The table shows that either high temperatures or nitrogen may bring about the lessening of the weight of the underground storage portions of the plant.

Conclusions

These results as a whole indicate that fertilization of bluegrass with nitrogen fertilizers during periods of close and frequent cutting when high temperatures prevail is of little use and may even be harmful. Several factors, such as short and frequent clipping, shade, short cloudy days, nitrogen fertilizing, heavy watering, and high temperatures, tend toward the using up of the supply of stored carbohydrates, manufactured by the top of the plant, which if carried to extremes ultimately will bring about death of the plant. Short and frequent cutting and nitrogen fertilizing may help considerably in thickening turf, provided the plants have a carbohydrate reserve and the weather remains cool and bright. On the basis of the present studies it has been indicated that the application of nitrogen fertilizers to fairway turf should be largely confined to the cooler periods of the year, spring and fall, and greatly reduced during the hot summer months. Grass which shows a yellowish cast during cool weather and which has stiff upright leaves will use nitrogen advantageously but grass that is dark green and succulent has very little need of applications of nitrogen fertilizers.

There is no royal road to anything. One thing at a time, all things in succession. That which grows fast, withers as rapidly; that which grows slowly endures.

J. G. Holland