EFFECTS OF SOIL TEMPERATURE, ACIDITY AND NITROGEN NUTRITION ON THE DEVELOPMENT OF KENTUCKY BLUEGRASS

ROBERT A. DARROW *

Few studies have been made in which grass has been grown under the combined influence of controlled nitrogen nutrition, temperature, and reaction of the culture medium. In the present series of experiments Kentucky bluegrass (*Poa pratensis* L.) was chosen as a representative grass. It is sometimes grown in the field under semi-controlled nutrient conditions and differs widely in development with seasonal variation in temperature and soil reaction. The experimental plants were grown in crocks in which the supply of nitrogen as nitrate or ammonium, the soil temperatures, and the acidity of the nutrient solutions were controlled. Measurements of leaf and root growth were taken to express development under the environmental conditions maintained and to determine the effects of periodic clipping.

METHODS

In these experiments, plants obtained by vegetative propagation from a single plant were grown in 2-gallon crocks filled with sand free of nutrients. Plants were supplied daily with nutrients in the form of solutions prepared from pure chemicals. Two nutrient solutions were prepared containing potassium phosphate, magnesium sulfate, and nitrogen. In one solution the nitrogen was in the form of calcium nitrate while the other solution contained sulfate of ammonia and calcium

* Assistant Professor of Botany, the University of Arizona, Tucson, Arizona. The work reported here was conducted at the University of Chicago, supported by a Research Fellowship of the United States Golf Association Green Section.

chloride. About 400 cc. (0.7 pint) of solution were added to each culture twice daily after flushing out the old solution with distilled water. By this periodic flushing with pure water and by addition of either hydrochloric acid or sodium hydroxide to the nutrient solutions, the reaction of the solution in each culture was adjusted twice daily to the desired pH.

The 2-gallon crocks containing the plants were set in a water-filled tank which was regulated at constant temperatures.

Results with Unclipped Plants

Tests have been made as to the effect of nitrogenous fertilizers on growth of Kentucky bluegrass at various soil acidities, both in the field and in greenhouse studies. The present experiment was set up to determine the effect of different soil temperatures on bluegrass grown with ammonium and with nitrate nitrogen at pH 4.5, 5.5, and 6.5.

Plants were grown for 11 weeks from March 3 to May 10, 1936, under greenhouse conditions with a relatively large amount of sunshine and at three different soil temperatures, 59°, 77°, and 95° F. Three sets of cultures were supplied with nitrate nitrogen in the form of calcium nitrate at pH 4.5, 5.5, and 6.5, respectively, and three other sets received ammonium nitrogen in the form of sulfate of ammonia at the same pH values. Four plants were used under each of these conditions.

The plants were allowed to grow uncut for a period of 11 weeks. At the end of this time they were removed and measurements taken as to length and number of leaves, number of rhizomes, and dry weights of leaves and roots. The information thus obtained is summarized in the tables on

pages 16 and 22. Nitrate-supplied plants were decidedly superior to plants receiving ammonium in the number and length of leaves and in the number of rhizomes produced at all temperatures and pH conditions with but one exception. This superiority of nitrate-supplied plants was more in evidence at pH 4.5 than at pH 6.5. Differences in reaction had no appreciable effect on leaf development of nitrate plants at 59° and 77°. At 95°, however, a slight increase in the number of leaves and rhizomes of pH 4.5 plants over the other plants at that temperature was noted. Ammonium-supplied plants showed the best development of leaves and roots at pH 6.5 under all temperature conditions and the least increase in length and number of leaves at pH 4.5.

Temperature effects on leaf development were also quite marked as shown in the table on page 16. High temperatures reduced the amount of leaf growth in length and numbers. The greatest number of leaves was produced at 59° under all conditions of acidity and nitrogen nutrition. Growth in length of leaves was found to be greater at 59° and 77° than at 95°. At 77° the largest number of rhizomes was produced.

The superiority of nitrate nitrogen over ammonium shows also in the green and dry weights of roots and tops as given in the table on page 22. The dry weights were approximately the same at 59° and 77° and much smaller at the higher temperature. Nitrate-supplied plants produced approximately equal weights of roots and shoots at all pH values except under high temperature conditions at which pH 6.5 plants were poorest. Ammonium-supplied plants produced the greatest weights of leaves and roots at pH 6.5.

Limited observations on the root systems of these and other

grass plants grown for shorter periods showed considerable difference between plants grown at 59° and 95°. At the lower temperature, roots were large in diameter, white, and very succulent. High temperatures produced a densely tufted root system of small, light brown, finely-branched roots. It

LEAF AND RHIZOME DEVELOPMENT OF KENTUCKY BLUEGRASS PLANTS GROWN AT THREE SOIL TEMPERATURES WITH NITROGEN FROM CALCIUM NITRATE AND SULFATE OF AMMONIA RESPECTIVELY AT pH 4.5, 5.5, AND 6.5. THE FIGURES ARE AVERAGES FOR FOUR PLANTS.

Temperature and pH	Percentage of increase in length of leaves		Percentage of increase in number of leaves		Number of rhizomes	
	Nitrate	Ammonia	Nitrate	Ammonia	Nitrate	Ammonia
59° F.						
4.5	198	31	955	85	17	3
5.5	194	54	942	229	18	3
6.5	191	144	1,046	524	32	8
77° F.						
4.5	173	75	600	35	28	1
5.5	233	115	401	148	33	3
6.5	182	192	620	314	38	11
95° F.						
4.5	140	23	263	0	29	0
5.5	133	55	226	53	24	1
6.5	148	66	170	80	15	2

appeared that roots were produced more rapidly at the lower temperature. The unthrifty condition of ammonium-supplied plants grown at pH 4.5 and 5.5 was evident in the limited root system developed. On the other hand, little variation could be noted in the roots of nitrate-supplied plants with the different pH values of the nutrient solutions.

The leaves of plants grown for 11 weeks as well as of those grown under these same cultural conditions for shorter periods

of time showed marked differences in the degree of succulence with various acidities and temperatures. The leaves of both nitrate- and ammonium-supplied plants were more succulent at low temperatures than at high ones. The nitrate-supplied plants showed little difference with respect to pH value of the nutrient solution at any one temperature, but in the case of ammonium-supplied plants those grown at pH 6.5 were more succulent than plants grown at pH 4.5 and 5.5. This difference in succulence was more marked at 59° than at 95°.

Results with Clipped Plants

To furnish information more directly applicable to turf production, an experiment was initiated involving the clipping of Kentucky bluegrass plants at two heights. Plants were supplied with either nitrate or ammonium nitrogen at pH 6.5 and at a constant soil temperature of 77°. Plants were grouped into three series: clipped at 1 inch weekly, clipped at 2 inches weekly, and unclipped control. Ten plants were used for each combination of nitrogen nutrition and clipping height and the experiment was conducted from May 30 to September 14, 1936.

Clipping treatments were started on June 26 and were made weekly thereafter, and the number of leaves clipped and dry weights of clippings recorded. Weekly counts were also taken of the total number of leaves on all clipped and control plants to determine the effect of clipping on density of turf. The table on page 19 shows the percentage of increase in number of green leaves over the original number during the experimental period. These observations, given for 2-week intervals, show the effects of clipping in the smaller number of leaves

produced in the 1-inch and 2-inch series as compared with the unclipped control. Ammonium-supplied plants produced new leaves more rapidly than nitrate-supplied plants in the unclipped and in the 1-inch series and during the latter part of the experiment in the 2-inch series. There was, therefore, a greater improvement in the density of the grass when sulfate of ammonia was used as a source of nitrogen than when calcium nitrate was used. When grass is grown for turf purposes, the density of the turf, rather than the yield of clippings, is the primary consideration. This is particularly true during the hot summer months when leaf replacements are so desirable because of injuries caused by diseases, insects, and other factors.

Figures for the dry weights of the clippings for 2-week intervals are given in the table on page 25. Nitrate-supplied cultures showed consistently higher yields of clippings than the ammonium cultures, although at the 1-inch cut this difference was not so great as at the 2-inch cut. With the exception of a brief period in July in which insect infestation reduced the number of leaves, there was a consistent week-by-week increase in the yield of clippings in both the nitrate and ammonium cultures, throughout the experimental period. This was particularly striking in the series clipped at 2 inches. Comparison of the yields obtained from the 1-inch and 2-inch series shows that in the nitrate series the yield of the plants cut at 2 inches was approximately twice that of those cut at the 1-inch height. On the other hand, the total weight of clippings produced from the ammonium-supplied plants cut at 2 inches was only about one-third larger than that obtained from the 1-inch plants.

Comparison of root and rhizome production in nitrate- and

ammonium-supplied plants showed in general the same relationship as in the previous experiments. Nitrate-supplied plants produced a greater number of crown roots than did those receiving ammonium although the average length of roots was greater in the case of ammonium-supplied plants. The unclipped plants showed the greatest number of roots and

PERCENTAGE OF CUMULATIVE INCREASE IN NUMBER OF LEAVES PRODUCED BY KENTUCKY BLUEGRASS PLANTS GROWN IN SAND AT pH 6.5 AND 77° F. WITH NITRATE AND AMMONIUM NITROGEN UNDER CLIPPED AND UNCLIPPED CONDITIONS. FIGURES ARE GIVEN FOR 2-WEEK INTERVALS EXCEPT FOR THE FINAL DATE.

Treatment	Percentage of cumulative increase of number of leaves					
	July 11	July 25	August 8	August 24	Sept. 8	Sept. 14
Nitrate:						
Check	10	72	130	181	219	243
2-inch cut	5	61	112	163	192	160
1-inch cut	6	39	70	93	100	100
Ammonium:						
Check	7	74	137	205	285	307
2-inch cut		51	105	165	209	201
1-inch cut	2	38	72	124	157	193

rhizomes with both forms of nitrogen and the plants cut at 1 inch showed the most poorly developed root systems. More rhizomes were produced in the nitrate than in the ammonium cultures.

TEMPERATURE RELATIONS

If the factor of temperature is considered apart from the complex of environmental conditions under which the plants were grown, certain relations of development to temperature differences may be established. The character of the top

growth varied considerably within the range of soil temperature used. Low temperatures appeared to be the most favorable both for the production of new leaves and the growth in length of leaves. The type of growth resulting at 59° was bushy with long, succulent leaves and numerous new leaves. Combined measurements of length and number of leaves showed the best growth temperature of those tested to be about 59°. At soil temperatures of 95° the plants were short and rigid, many of the leaves remaining erect when allowed to grow uncut for 3 months. Bud initiation and leaf production were limited under the high temperature conditions.

Bluegrass plants in the present experiments showed the greatest amount of root and top growth at the lower temperatures. Equal dry weights of top growth were produced by plants grown at 59° and 77°, whereas under soil temperatures of 95° the lowest weight of tops and smallest number of rhizomes were produced.

The character of the root systems produced was also influenced strongly by temperature. At the lowest temperature the roots of bluegrass were large in diameter, succulent, white, with few scattered branches, whereas at 95° the roots were small, light brown, and very finely branched into a dense tufted system. The entire root systems at 59° and 77° were almost twice as deep as those produced at 95°. As measured in terms of dry weight, the total root growth was approximately equal at 59° and 77° and the least amount was produced at 95°.

Acidity Relations

Under controlled nutrient conditions with nitrogen supplied in the form of calcium nitrate, the plants differed in top

and root development with varied pH, depending in part upon their age. After 6 and 11 weeks growth, plants grown under similar conditions showed no significant differences in weight of tops with pH at the lower temperatures, but at 95° plants grown at pH 6.5 were slightly inferior to those grown at pH 4.5 and 5.5. Under the condition of these experiments the range of pH used apparently had little effect upon absorption and assimilation of nitrate nitrogen except at a soil temperature of 95°. Root development and rhizome production in nitrate cultures were influenced by pH in the same manner as top development. Weight of roots varied little with differences in pH except at 95°, under which conditions the plants grown at pH 4.5 produced a greater weight of roots.

Plants supplied with nitrogen in the form of sulfate of ammonia at the three pH values showed best development in tops, roots and rhizomes at pH 6.5, throughout periods of 3, 6, and 11 weeks of growth at all temperatures. The roots of the plants grown in ammonium-supplied crocks at pH 6.5 showed the most extensive branching, whereas at pH 4.5 and 5.4 there was a predominance of stunted, knobby branches, particularly near the base of the main branches.

Nitrogen Relations

Unclipped Series

Within the pH range of the experiments, the plants supplied with nitrate nitrogen showed a markedly better development than those supplied with ammonium nitrogen, at soil temperatures of 59°, 77° and 95°. Throughout the duration of these experiments with unclipped grass from March 3 to May 10, the top growth of the nitrate-supplied plants was

superior to that of ammonium-supplied plants in both number and length of leaves produced as well as in dry weight of leaves. This superiority of nitrate nitrogen over ammonium nitrogen in producing an extremely vegetative plant under

DRY WEIGHTS OF KENTUCKY BLUEGRASS PLANTS GROWN FOR 11 WEEKS AT THREE SOIL TEMPERATURES WITH NITROGEN FROM CALCIUM NITRATE AND SULFATE OF AMMONIA RESPECTIVELY AT pH 4.5, 5.5, AND 6.5. THE WEIGHTS, EXPRESSED IN GRAMS, ARE AVERAGES FOR FOUR PLANTS.

Temperature and pH	Dry weight in grams			
	Leaves		Roots	
	Nitrate	Ammonia	Nitrate	Ammonia
59° F.				
4.5	3.40	0.26	4.06	0.85
5.5	3.48	0.58	3.96	1.07
6.5	3.59	1.71	4.50	2.65
77° F.				
4.5	2.58	0.24	5.62	0.91
5.5	3.27	0.88	4.25	1.10
6.5	3.13	1.77	4.78	2.00
95° F.				
4.5	1.62	0.14	3.31	0.44
5.5	1.56	0.27	2.91	0.65
6.5	1.13	0.43	2.21	0.87

these conditions is probably a result of more rapid assimilation of nitrate than ammonium nitrogen.

Rhizome and root production varied also with the type of nitrogen nutrition. The number of rhizomes to a plant was significantly greater in nitrate-supplied than in ammonium-supplied plants. Plants supplied with nitrate showed a greater dry weight of roots than corresponding plants supplied with ammonium, although the actual extent of the root systems of the two types was similar. More rapid elongation of roots

took place in nitrate-supplied plants at 59° and 77° than in ammonium-supplied plants, but at 95° the latter excelled slightly.

Clipped Series

The effects of clipping at 1- and 2-inch heights were studied on plants supplied with nitrate and ammonium nitrogen at pH 6.5 and a constant soil temperature of 77° from May 30 to September 14, 1936. The plants used in this series were transplants and were placed under cutting treatment soon after transferral, a fact which should be considered in the interpretation of the results obtained.

Weekly clipping yields showed a consistent increase over the 11 weeks from June 26 when clipping was begun to September 14, except for the few weeks in July when there was some insect injury. The increase was more pronounced in the series cut at 2 inches than in the plants of the series cut at 1-inch height.

Greater yields, as expressed in terms of dry weight of clippings, were obtained from nitrate-supplied plants than from those receiving ammonium. On the basis of the studies over a range of pH conditions, it may be concluded that nitrogen in the form of nitrate was more readily available even at pH 6.5 than was ammonium nitrogen, under the conditions of these experiments. Thus with a more readily available form of nitrogen, a greater stimulus was given to vegetative growth and yield with nitrate nutrition over the period in which the clipping studies were conducted.

Weekly observations of the number of leaves in the plants in this series showed a consistent and progressive increase in

the production of new leaves from May 30 to September 14. After the first few weeks, denser tufts with more new leaves were produced by the plants growing in the ammonium-supplied crocks than by those growing in the crocks receiving calcium nitrate. This held for both the unclipped control plants and the plants clipped at 1- and 2-inch heights. The unclipped plants, however, initiated most leaves, and those clipped at 1-inch the fewest leaves throughout the experiment, as shown in the table on page 19.

In growing Kentucky bluegrass for turf purposes, however, the density of the turf is of more concern than the yield of clippings, since an increase in yield simply involves the necessity of more frequent cutting. July and August are perhaps the most difficult periods for turf. Any fertilizer, therefore, such as sulfate of ammonia which will increase the density of the turf by increasing the production of new leaves, during that time particularly, will be highly desirable for turf purposes.

Comparison of the results from the series of clipped plants with those from comparable portions of the unclipped series brings out several discrepancies with regard to the best nutrient conditions for leaf production. In the first 11 weeks series from March 3 to May 10, the nitrate-supplied plants grown in sand with a temperature of 77° and pH 6.5 showed almost twice as great an increase in number of leaves as ammonium-supplied plants. In the last series from May 30 to September 14, the unclipped plants receiving nitrates had but one-third as much leaf production as corresponding plants grown under the same conditions of acidity and soil temperature for the same length of time in the earlier series. However, the am-

monium-supplied plants showed almost identical production of new leaves in the two series. These discrepancies may be due in part to the differences in length of day, atmospheric temperature, or other environmental conditions over the two experimental periods. As noted from the first series, the greatest number of leaves was produced under the lower soil temperature conditions, and thus the higher air temperatures pre-

DRY WEIGHT IN GRAMS OF CLIPPINGS OBTAINED FROM KENTUCKY BLUEGRASS PLANTS GROWN IN SAND WITH NITRATE AND AMMONIUM NITROGEN AND CLIPPED AT 1- AND 2-INCH HEIGHTS. FIGURES ARE GIVEN FOR 2-WEEK INTERVALS.

Treatment	Dry weight in grams of clippings						
	July 11	July 25	August 8	August 24	Sept. 8	Sept. 14	Total
Nitrate:							
2-inch cut	0.74	0.51	1.54	2.45	3.09	1.00	9.33
1-inch cut	0.67	0.47	0.76	1.12	1.12	0.49	4.64
Ammonium:							
2-inch cut	0.47	0.36	0.72	0.98	1.79	0.59	4.92
1-inch cut	0.60	0.43	0.63	0.73	0.92	0.38	3.68

vailing during the later series may have played some part in reducing the leaf production of the unclipped nitrate-supplied plants. However, the ammonium-supplied plants showed almost identical production of new leaves in the two series. The reasons are not clear for this difference in leaf-production of nitrate-supplied plants in the two series of experiments. These discrepancies indicate the necessity for further investigations before the full value of these two forms of nitrogen for bluegrass turf can be thoroughly understood.

The number of rhizomes produced on the clipped plants was much smaller than on the unclipped plants under both

forms of nitrogen, a fact which has been observed by many workers.

Summary and Discussion

Kentucky blugrass plants were grown in sand in crocks under greenhouse conditions in one series of experiments from March 3 to May 10, 1936, and in another series from May 30 to September 14 of the same year. Nutrients were added in the form of solutions of pure chemicals.

One-half of the crocks in all of the experiments in both the first and second series received nitrogen in the form of calcium nitrate and the remaining ones received it in the form of sulfate of ammonia.

In the first series of experiments the effects of soil temperatures of 59°, 77°, and 95° combined with soil acidities of pH 4.5, 5.5 and 6.5 on the growth of leaves, roots, and rhizomes of the grass were observed.

In the second series of experiments the sand in all of the crocks was maintained at a temperature of 77° and a pH of 6.5 but the grass in some of the crocks was clipped at 1- and 2-inch heights, whereas that in others was left unclipped as controls in order to follow the effect of height of cut on the development of leaves, roots, and rhizomes.

Plants grown at 59° produced tall, succulent, bushy top growth with many new leaves, while those grown at 95° produced erect, non-succulent, short top growth with few leaves. Root systems of the low temperature plants were large, white, succulent, and coarsely branched, while roots of high temperature plants were small in diameter, light brown, and densely tufted. The largest number of rhizomes was produced at 77°.

Plants grown with nitrogen from sulfate of ammonia showed best leaf, root, and rhizome development at pH 6.5, whereas plants receiving calcium nitrate showed little difference within a range of pH 4.5 to 6.5.

In the first series of experiments, the nitrate-supplied plants were superior in leaf, root, and rhizome development to ammonium-supplied plants under the conditions of soil temperature and soil acidity in force throughout the experimental period.

In the second series of experiments from May 30 to September 14, however, although the yield of clippings was greater in the nitrate-supplied plants the number of new leaves produced or density of the grass was greater in the ammonium-supplied plants. It should be borne in mind that when Kentucky bluegrass is grown for turf purposes, the yield of clippings is not so important a consideration as is the density of the turf, particularly during July and August which are the most difficult months for turf.

Both number of new leaves and dry weight of clippings were greatest in unclipped plants and least in those plants cut at 1-inch height, regardless of whether the plants received sulfate of ammonia or calcium nitrate.

When sulfate of ammonia is added to ordinary well-drained soil, the microorganisms present in the soil convert part of the ammonium nitrogen into nitrate nitrogen. In reality, therefore, when plants are grown in soil fertilized with sulfate of ammonia they are supplied with both nitrate and ammonium nitrogen.