The Effects of Soil Reaction Upon the Growth of Several Types of Bent Grasses

By Mary E. Reid

OUTLINE

Introduction

The view that bent grasses grow best in a soil with an acid reaction * has been held for a long time. This conception originated from results of a very limited amount of experimental work, supplemented by field observations in which two or more variable factors tended to confuse the issue. These field observations, although of interest, did not go far toward settling the question, as only by eliminating all variable factors but one could an answer be obtained. A partial change in our way of looking at the problem has come about as a result of experiments initiated at the Arlington turf garden in 1926. It had been observed previously that turf grasses, especially if grown in a naturally acid soil, heavily fertilized with sulphate of ammonia, might eventually become poor in quality, and especially so during the summer months. The results of the above tests showed that an unthrifty condition of this type could be corrected by liming. Other tests, conducted at the experimental gardens of the United States Golf Association Green Section near Chicago, have shown that even in soils which are definitely alkaline turf grasses fertilized with sulphate of ammonia may be somewhat benefited in summer by liming. Turf grasses in many other soils, however, have shown no improvement with liming at any season of the year. In other soils harmful effects to turf have been observed. It may readily be seen that questions arising as to the effects of liming and of the development of acid reactions in soils by the use of fertilizers are still not completely answered.

The experiments here to be described were undertaken to determine if bent grasses will respond to differences in soil reaction with all other experimental conditions uniform. It has been noted that the beneficial effects previously observed and ascribed to soil acidity are closely interrelated to climatic factors and are really due to

* The terms "reaction" and "pH value" are used to express the condition of the soil with respect to acidity, neutrality, or alkalinity. A soil with a pH value of 7.0 is neutral—that is, it is neither acid nor alkaline. A soil whose reaction is expressed by numbers lower than 7.0 is acid, and the lower the number the greater the acidity. Likewise, a soil whose reaction is expressed by a number higher than 7.0 is alkaline, and the higher the number the greater the alkalinity.

factors other than soil acidity. Even the harmful effects of excessive acidity may not be due to acidity itself. Likewise the effects of neutral and alkaline reactions are not to be attributed to a direct effect of neutrality or alkalinity. Although a grass may thrive considerably better at a certain reaction than at others in one soil, the best growth in another soil may be at a widely different reaction. It is not surprising that plants should vary in their response to reaction of very different types of soils. There may be not only the differences that were naturally inherent in the soils, such as chemical constitution and physical properties such as water- and air-holding capacity, but also differences that may have developed since the time of their first cultivation. Different fertilizers may have been added to a soil, different crops may have been grown upon it, and there may have been differences in the amount of rainfall to which it has been subjected. In one locality with an annual rainfall of 50 inches there is likely to be much more leaching out of plant nutrients than in a region in which the annual rainfall may be 20 inches less. Differences in light and temperature in different regions also have important effects. In some localities, particularly those which have comparatively cool summers, the bent grasses may thrive well in soils which are fairly acid. If there were certain types of mineral deficiencies in the soil, an attempt to duplicate such soil reactions in other sections having different climatic characteristics might lead to harmful results. It is because of the extremely wide variations in soil and climatic conditions in regions on which golf courses are located, that we are confronted with the necessity of analyzing these various environmental factors in their individual and combined effects and of determining methods of overcoming these effects when they are detrimental. As knowledge concerning the behavior to be expected of each of the turf grasses under different conditions of soil and climate develops, a basis will be furnished for making more specific recommendations than are at present available for an economical and efficient turf culture.

Experimental Methods and Reasons for Their Use

A large number of experiments were conducted at the Arlington turf garden during the past three seasons to study the effect of soil reaction upon the growth of certain bent grasses commonly used on putting greens. One of the two types of soil used chiefly was a light-brown clay loam obtained from the Arlington experimental farm of the United States Department of Agriculture from an area to which, so far as known, no fertilizers of any kind had ever been applied. The soil was chosen for its relatively low content both of organic matter and of plant nutrients. It was supposed that the use of a soil so deficient in plant food materials would show more clearly the response of the grass to certain changes in the soil reaction. The other soil, chosen to represent a fairly rich and well-balanced type of soil with respect to its plant nutrients, was a compost mixture prepared by mixing sand and partially decomposed organic matter with some of the above clay.

Each of the two types of soil was sifted through a fine-meshed sieve, and thoroughly mixed so as to insure a uniform composition throughout the entire mass. Both clay and compost mixtures had a pH value of 5.3 in the earlier experiments and of 4.8 in the later experiments.

Differences in reaction in each of the two soils were obtained by using calcium oxide (burned lime), magnesium oxide, and caustic potash as alkalizing agents, and hydrochloric (muriatic), and sulphuric acids as acidifying agents. Hydrochloric acid is a substance which may be left in the soil as a residue from fertilizers. For example, it may be formed as plants remove potash from muriate of potash, a substance which is contained in many fertilizer mixtures. It may also be introduced into the soil through irrigation, as it is frequently formed in city water as a result of chemical treatment for purification. It is found in still higher concentrations in water from swimming pools, which is being used in a number of instances for the watering of golf courses. These practices raise the question as to whether the long-continued use of water containing hydrochloric acid and other chlorides may not eventually result in the development of unfavorable conditions for the growth of grass. If there is danger in these practices, the use of this water would be particularly hazardous during very dry seasons, when golf courses require frequent and abundant watering and when the water supply is apt to be more highly chlorinated than normally and the rainfall insufficient to wash the chlorides from the soil. The use of this acid in these experiments was accordingly designed to study some of the possible detrimental effects which it may have upon the growth of turf grasses.

Sulphuric acid, which was also used as a soil-acidifying agent in many of these experiments, is a substance which may be produced in the soil as the ammonia from sulphate of ammonia is taken up by plants. The extensive use of sulphate of ammonia as a fertilizer on golf courses, and particularly its use on courses located in regions in which the soil is naturally quite acid, may eventually produce unfavorable conditions for the growth of turf grasses. Naturally highly acid soils are located chiefly in regions in which there is a fairly high annual rainfall. The leaching action of the rain results in a low content of alkaline substances, such as calcium, magnesium, and potash. It is a well-established fact that the use of sulphate-containing fertilizers tends to promote leaching of these substances from the soil. Consequently, it is in connection with the use of sulphate fertilizers on soils deficient in these basic or alkaline substances that injurious effects are most liable to occur. There is probably no doubt that plants grown in alkaline soils containing an abundance of calcium, magnesium, and potash can tolerate fairly large accumulations of sulphates in the soils without very much danger of injury and may even be benefited by their addition to the soil. In acid soils of the types mentioned, however, the question of sulphate accumulation undoubtedly has a serious aspect. For these reasons it has seemed desirable to study the effects of sulphate accumulation by the use of laboratory methods. The question is still an open one in some respects; but some progress leading to a better understanding of the problem can now be reported.

Varying quantities of the acids and alkalies were added to different lots of soil in the experiments to produce a series of reactions ranging from pH 3.7 to pH 8.3. Usually a period of three to four weeks was allowed for the soil to come to a constant pH value before planting the grass.

Earthenware jars were used as containers for the soil, which was maintained at a favorable moisture content throughout the course of the experiment. All watering was done with distilled water. It was never added in quantities sufficient to allow drainage of the soil solutions from the pots. In this way the material originally present in the soil and the substances added to change the reaction were all retained. This condition was maintained in the investigation, since observations at the Arlington turf garden tended to show that the grasses were most affected by the soil reaction during hot weather when rainfall was scarce and hence little leaching of the soil took place. No fertilizers were added except in a few experiments, in which case the fact will be definitely stated in the description of such experiments.

Experiments were conducted under different environmental conditions. One series was grown out of doors during the hot summer months and another during the cooler autumn months. The same experiment was also conducted in the greenhouse during the short-day winter months, and during the spring months.

In the case of the creeping bents and velvet bent, stolons of approximately the same size and having one node each were used for planting. The same number of plants was grown in the soils at each of the different reactions. In the case of the grass grown out of doors during the summer or fall months the cultures were covered at night and during occasional rains with a canvas tent so as to protect the soil from washing and leaching. In many of the experiments the grass of half of the cultures was cut and that of the other half was left uncut. When a study of the roots was made, the plants were washed free of soil, after which they were examined and weighed before any wilting occurred.

Results

Difference in rate of growth following the different soil treatments have not been the only factors taken into consideration in evaluating the experimental results. Increases in rate of growth are sometimes accompanied by undesirable changes in quality of turf, such as increased steminess or increased softness of tissues, with a consequent greater susceptibility to disease. Characteristics which have been considered as very important in determining good qualities in turf are abundant proliferation and leafiness close to the surface of the soil as aids in the maintenance of a perfect ground cover, good color, resistance to mechanical injury, and a relatively deep and extensive root system.

I. EFFECTS OF LIME

1. Growth of Tops

Creeping Bents.—In all the experiments conducted in clay soil the growth of creeping bent grasses has been increased by a heavy lime treatment which produced a soil reaction of pH 8.3. The stimulation was much greater during the summer than during the winter months; the response during the spring months being intermediate. The difference in growth at pH 8.3 during the summer months was evident in an improvement in color, increase in amount of proliferation, and in general vigor, as well as in increase in weight. In some of the experiments there was noticeable improvement in growth with a lighter lime treatment, which produced a reaction indicated by pH 7.3 in the clay soil; but in most cases the improvement with this amount of liming was not very conspicuous. There was no improvement with still lighter applications of lime (approximately 1,350 pounds of hydrated lime to an acre), which raised the reaction to only pH 6.3. Treatment of the compost mixture with lime led to somewhat different results. There was no significant difference due to liming even in the case of cultures grown in soil with a pH value as high as 8.3. This was true both of grass grown in summer and in other seasons.

Velvet Bent.—Only during the hot midsummer months was there any evidence of benefit from liming and then only in the case of grass grown in the clay soil. Neither light nor heavy liming of the compost, which produced reactions ranging from pH 6.0 to 8.3, yielded any improvement in growth compared with that in the unlimed soil. In experiments conducted somewhat later in the year, when most of the growth occurred during September and October, there was a marked depression in growth in the clay soil, due to liming both at reactions indicated by pH 7.0 and 7.8. Even the color of the grass in the soil at these pH values was inferior to that of grass growing in the unlimed soil. Experiments conducted in the greenhouse during the winter months yielded results comparable to those of plants grown out of doors during the autumn months. The best growth in both clay and compost was in the unlimed soil.

Colonial Bent.—This grass is between velvet and creeping bents in its response to liming of the soils experimentally employed. In the clay soil there was no significant difference in total growth in the greenhouse due to liming. There was the same total yield of grass from soils ranging in reaction from pH 4.8 to 8.2. There were, however, differences in the rate of growth at different pH values of the soil during the first and last halves of the growth period. At first the grass in the unlimed or very lightly limed soils grew the fastest, but later it was the grass in the limed soils which grew the fastest. Similar experiments with colonial bent have not yet been conducted out of doors in midsummer.

2. Growth of Roots

In the experiments with each of the three types of bents there has been a general tendency for the roots to grow fastest under those conditions which favor the most rapid growth of the tops. An exception, however, was noted in connection with seasonal differences in the growth of roots and in the proportions of tops to roots of Metropolitan bent at different soil reactions. Heavy liming of the clay soil, which produced a pH value of 8.3, promoted growth of roots as well as tops during the summer, but tended to produce an opposite effect on the roots during the winter, early spring, and late fall.

II. EFFECTS OF MAGNESIUM OXIDE

The marked improvement under some climatic conditions resulting from heavy liming of the clay soil suggested the possibility that traces of magnesium contained in the lime may have been a causal factor. Although supposedly pure calcium compounds had been used as alkalizing agents, traces of magnesium were undoubtedly present; and in using the quantities of lime sufficient to produce a pH value of 8.3 in this very acid soil (in some cases at a rate of 1.8 ounces to a square foot or 4,900 pounds of hydrated lime to the acre), the quantity of magnesium added may have been sufficient to produce a favorable response if the soil were deficient in magnesium. Several experiments were performed to determine if the creeping and colonial bent grasses will respond favorably to small additions of magnesium to the clay soil. There has been definite evidence that they will grow faster and have a better color if small quantities of magnesium are supplied. The results obtained furnish evidence that magnesium has probably been a factor in producing the favorable effects resulting from heavy liming. The cultures in soil at pH 6.3 and 7.3 to which magnesium was added were definitely superior to those at corresponding reactions with only the pure calcium oxide added. The degree of response, however, was not sufficient to account for the marked difference in growth at pH 8.3. Apparently the magnesium which was added with the lime has been a minor factor, but not the chief one in causing the improvement in growth at pH 8.3.

III. EFFECTS OF CAUSTIC POTASH

Several experiments have been performed with Metropolitan and colonial bents grown in both clay and compost soils in which caustic potash has been used as an alkalizing agent. The soils to which the largest quantities of caustic potash had been added had a pH value of 7.6. Growth of both Metropolitan and colonial bents in soils thus treated was very poor in all the experiments. The yield of these grasses in the soils treated with caustic potash to produce reactions indicated by pH 6.3 and 7.3 was approximately the same as that of the check cultures in the soils to which nothing was added. There was, however, an improvement in color in some of the experiments. The poor response at the higher reaction was in striking contrast to that obtained with Metropolitan bent in the heavily-limed clay soil at pH values from 7.8 to 8.3. It shows conclusively that the nature of the alkalizing agent is of importance as well as the reaction itself.

IV. EFFECTS OF HYDROCHLORIC AND SULPHURIC ACIDS

1. Creeping Bents

The addition of relatively small quantities of hydrochloric or sulphuric acid to produce very slight changes in the reaction of these naturally acid soils usually resulted in somewhat better growth than was obtained from the untreated soil. This result has been obtained in both clay and compost, but there was usually a considerably greater increase in growth in the compost due to the acid treatment. Seasonal differences have frequently been observed in the responses. It has been found that plants grown out of doors during the summer months and fully exposed to the light are less likely to show stimulating effects as a result of slight acidification of the soil than plants grown in spring or fall or than those grown in the greenhouse during the winter months. There has been some evidence, although not yet conclusive, that plants can tolerate higher soil acidity under the three latter conditions than under the former. To what environmental factors this difference in tolerance may be attributed has not yet been definitely determined.

In experiments in which sufficient acid was added to the soil to lower the natural reaction from pH 4.8 to 4.3 or 4.4, the effects were often injurious, particularly in the case of plants growing in the clay soil. Plants in the unfertilized clay soil did not grow well at these reactions if produced by the addition of acid, at any season of the year. Plants grown in a rich compost during the winter months thrived at these reactions, and they even grew well in such a soil during the summer months if they were protected from strong light and wind until they were well rooted.

Plants grown in acid reactions at which there tended to be injury were characterized by having a dark metallic green color and narrow, somewhat rolled leaves with a tendency to tip-burn. Plants which tended to have these characteristics during their early stages sometimes recovered if the reaction of the soil shifted upward, even slightly. If the reaction did not change, improvement usually did not occur, and eventually the leaves yellowed and the plants died. Growth of roots of plants in these very acid soils tended to be even poorer than growth of the tops. There were few roots, a consequence of the small amount of branching, and they were very short and coarse. It seems probable that a shift toward greater acidity in soil in which grass is growing may have harmful effects, first upon the roots and later upon the tops.

The treatment of these soils with either hydrochloric or sulphuric acid had a very definitely shrinking effect, and it may be that certain factors associated with this tendency may interfere with the young roots' coming into close contact with the soil particles. Without such a contact with the soil particles, the young plants have difficulty in obtaining both water and essential nutrients. The plants grown in the very acid soils used in these experiments were more adversely affected by wind and dryness of the atmosphere than those grown in soils of higher reactions.

The leaves of plants grown out of doors in summer in soils acidified with hydrochloric acid to pH 4.2 eventually developed a whitish appearance as though a deposit of salt had formed on the surface. The grass in the soil treated with sulphuric acid grew somewhat more at corresponding reactions in the lower ranges than that in the hydrochloric-acid-treated soils. In other words, the plants could tolerate somewhat greater acidity if the soil was acidified with sulphuric than if acidified with hydrochloric acid. If the poor growth at pH 4.2 were entirely due to the high concentration of hydrogen or acid particles, one should expect the same amount of growth of grass from the sulphuric- and hydrochloric-acid-treated soils. If the two soils have the same reaction they must have the same concentration of hydrogen or acid particles. The sulphates in the sulphuric-acid-treated soils, being less soluble than the corresponding chlorides of the hydrochloric-acid-treated soils, possibly entered the roots more slowly and hence did not produce such unfavorable concentration effects within the plants. It may also be that the chlorides are somewhat more toxic than sulphates at similar concentrations within the plant. It is probable also, as shown in results of other investigators, that the two acids may have had somewhat different effects upon the solubility of some of the mineral substances, such as aluminum compounds, which may exert a toxic effect upon the plants.

Although the soils used in the experiments which have been described were allowed to stand from 3 to 4 weeks following their treatment with much diluted mineral acids, objection might be raised against this method of acidification as being too drastic and harsh a procedure. The sudden change in reaction of a soil by the addition of mineral acids even when much diluted may result in harmful effects upon the soil microörganisms which play such an important rôle in connection with soil fertility. With the object of determining the effects of more natural methods of soil acidification, some of the soils had sulphur incorporated into them and were kept in a greenhouse at a favorable moisture content for bacterial activity for about two months. The action of the soil bacteria upon the sulphur progressed rapidly. Eventually sulphuric acid was formed. The reaction of the soil of some of the cultures which was pH 4.6 at the time the grass was planted, had dropped to pH 4.0 at the end of the experiment. The grass in these cultures grew fairly well under greenhouse conditions, although the weight of plants produced was considerably less than that of the check cultures in the untreated soil (pH 5.3). In none of the experiments with the clay soil to which sulphuric acid was added directly was there a fair amount of growth at pH values of 4.6 to 4.0. The results suggest that Metropolitan bent can tolerate lower reactions if the acidity is allowed to develop slowly than it can if the acidity is developed by a single addition of dilute sulphuric or hydrochloric acid. Undoubtedly this is partly due to the fact that the acidity progressed during the course of the experiment and that the initial reaction to which the plants in the young stage were subjected was less acid than that which was found when the plants were older. There has been evidence in all the experiments with bents grown in artificially acidified soils, that established plants can endure considerably lower soil reactions than young plants which are not well rooted.

The grass started to grow in other lots of soil to which more sulphur had been added, but as the experiment progressed the soil became so acid (pH 3.6) that all of the grass died. The addition of lime to some of the soil similarly treated with sulphur caused a marked improvement of the grass. The indications were that liming overcame the principal detrimental effects resulting from the sulphur treatment. These effects thus appeared to be largely, although possibly not entirely, due to acidification. Further work will be required, however, to answer the question as to whether or not an increase in acidity and an increased tendency toward leaching of basic substances, such as calcium, potash, and magnesium, from the soil by rain, as shown by the work of other investigators, are the only harmful effects resulting from an accumulation of sulphates in the soil. The favorable response to liming of soils in which sulphates tend to accumulate is in agreement with results obtained in the previously-mentioned experiments at the Arlington turf garden.

2. Velvet Bent

The addition of small quantities of sulphuric acid to the clay and compost soils in most of the experiments resulted in a marked improvement in the growth of velvet bent. The results with hydrochloric acid did not indicate similar stimulating effects, but possibly such responses might have occurred if somewhat less acid had been added. The soil treated with hydrochloric acid was slightly more acid than that treated with sulphuric acid. Growth of roots at the different reactions varied approximately in proportion to growth of the tops. In all of the experiments, velvet bent showed a tendency to respond favorably to acid treatments (which produced reactions as low as pH 4.6) of the soil during spring, fall, and winter, but not definitely so during the summer months. These plants did, however, respond favorably in summer to mild acid treatment which lowered the reaction only slightly. That velvet bent can grow under conditions of relatively high soil acidity is also indicated by its thrifty appearance in putting greens having soil reactions as low as pH 4.6.

3. Colonial Bent

In clay soil.—Not many experiments have been conducted, and the observations which have been made indicate harmful effects as a result of acidification. Further experiments should be conducted using somewhat less acid. The results at present suggest that seedlings in the clay soil may be less tolerant of high soil acidity than young plants which have grown from stolons.

In silt loam having a natural reaction of pH 7.8.—Different lots of this silt loam soil had sulphuric acid added in varying quantities. Some were left untreated as checks. The soil contained such large quantities of carbonates that adding as much as 72 cc. of sulphuric acid to 10 pounds of soil produced no change in reaction. A favorable response to the acid treatment was noted from the time the grass appeared above the surface of the soil, regardless of whether or not the soil reaction had been altered. The grass in the untreated soil grew very slowly at first, but it improved gradually as the experiment progressed. This grass was much paler in color and had a somewhat bleached appearance. The softness of the grass and the poor color were symptoms suggestive of magnesium or potash deficiency, or possibly of both. The grass in the most highly acidified soil (pH. 4.0) also did not grow well. The increased rate of growth of the other cultures due to the acid treatment finally resulted in a lack of available nitrogen, as shown by the fact that some of the cultures which had grown very rapidly during the first few weeks of the experiment and later became somewhat retarded, grew rapidly after an application of urea.

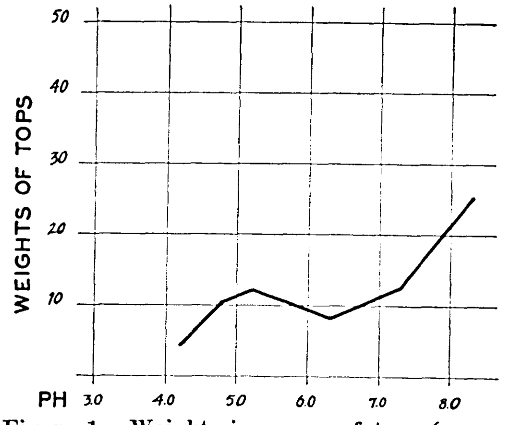

Figure 1.—Weights in grams of tops (green weights) of Metropolitan creeping bent grown in clay soil adjusted to different pH values.

The response due to treatment of this soil with sulphuric acid was of greater magnitude than that found in any of the other experiments with any kind of acid, alkali, or fertilizer treatment. The results of this experiment afford a striking illustration of differences in growth that may result from acid treatment of the soil without any resulting change in reaction. They strongly suggest that different growth effects observed in connection with an accumulation of acids in soils either with or without resulting changes in soil reaction, may in the former case and must in the latter be due to some other cause than changes in reaction itself.

V. EFFECTS OF SOIL FERTILITY

It was found in one experiment that the growth of Metropolitan bent (of the reactions tested) was the most rapid in clay soil at a pH value of 8.3 and in a compost mixture at a pH value of 4.5. The experiments were performed simultaneously, and all other conditions affecting growth, such as temperature, light, humidity of atmosphere, and soil moisture, were the same. The character of the soil was the only variable. In the light of such results it would be difficult to specify any particular soil reaction as the best for Metropolitan bent, especially since the optimum reaction in any given soil may vary with seasonal conditions and with the nature of the alkalizing and acidifying agents used. An insight into the causes governing these responses under different conditions of growth might furnish information that would be of some value in interpreting turf problems. Evidence has been presented that the response in many and probably most instances can not possibly be due to a requirement by the plant of a specific soil reaction. It more probably is caused by secondary effects of soil reaction rather than by the direct effect of a particular soil reaction upon the plant. It seemed probable that differences in response at different soil reactions, within the range at which growth could occur, might be due to differences in availability of plant nutrients.

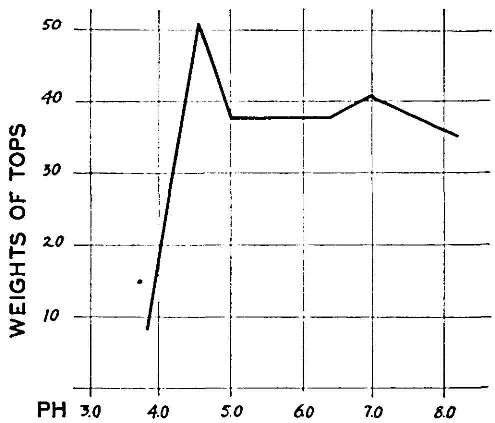

Figure 2.—Weights in grams of tops (green weights) of Metropolitan creeping bent grown in compost adjusted to different pH values. The graph shows the best growth at pH 4.6 with hydrochloric acid as the acidifying agent. Other cultures grown in compost acidified with sulphuric acid at pH 4.5 produced a still higher yield.

The stimulating effect of a pH value of 8.3 in the clay soil upon the growth of Metropolitan bent may be taken as an illustration of one of the outstanding responses to soil reaction. In tests in which a mixed fertilizer containing nitrogen, phosphorus, and potash was added to the clay soil at different reactions, there was a more uniform growth at the different reactions for a time, and then faster growth at pH 8.3 again became evident. Further addition of fertilizers produced a response similar to that which followed the first application, and was followed later by faster growth at pH 8.3.

That the improvement in growth at pH 8.3 was due chiefly to the greater availability of phosphates at that reaction is shown by the following facts:

The addition of nitrogen in the form of urea in some of the tests with plants grown out of doors in midsummer resulted in somewhat faster growth at all reactions, but growth was most rapid at pH 8.3. The more rapid growth and better color at this reaction persisted even when the extra nitrogen was supplied. The evidence strongly suggested that it could not have been caused by an increase in the available nitrogen resulting from heavy liming. It was stated previously that a probable increase in the supply of magnesium, which was doubtless present in the lime, may have been a minor factor in causing the betterment in growth at pH 8.3.

The addition of a phosphate fertilizer produced results which corresponded to those described above in which a complete fertilizer was used. The total growth at each reaction was, however, somewhat less. The growth of cultures at pH 5.2, 6.3, and 7.3 approximated that at 8.3, although those at the latter reaction again eventually took the lead. Further addition of phosphate produced a repetition of these responses. The question arises as to whether this response was due to the phosphate or to the other substances, potash and calcium, which were combined with it. The answer was obtained in other experiments in which phosphoric acid, which contains no potash or calcium, was added to the clay soil and the treated soil kept for several weeks before planting the grass. It was found that large quantities of this acid were necessary to produce acidifying effects in the clay soil. Grass grown in soil having a reaction indicated by pH 4.5 was markedly superior to that in the untreated soil or to that in the limed soil at pH 6.3, and also was somewhat better than that at pH 7.0. The plants grew at about the same rate as those in the limed soil at pH 7.8, and they had the same healthy appearance. The leaves had a better color and were wider, and the plants had much more proliferation than those in the untreated soil. Cultures were also prepared in soil acidified with phosphoric acid to produce a reaction indicated by pH 4.2. A good turf was formed at this reaction, but growth in length was much less than at the higher reactions. In these experiments Metropolitan bent did not endure a pH value of 4.2 in the clay soil acidified with either sulphuric or hydrochloric acid.

From these results it was concluded that the response of plants to heavy liming might occur as a result of an increase in available phosphorus. Through the courtesy of the Bureau of Chemistry and Soils of the United States Department of Agriculture an analysis was made of the clay soil at some of the reactions used in these experiments. The following results expressed in percent or parts per million of air-dried soil were obtained:

Table 1

	Limed	*Nothing added*	*Sulphuric acid*
Soil reaction (pH value)	7.8	4.8	4.5
Total phosphorus	0.04%	0.04%	0.05%
Water-soluble phosphorus	0.9 ppm.*	0.5 ppm.*	0.7 ppm.*
Total nitrogen	0.12%	0.12%	0.12%
Water-soluble nitrogen	0.004%	0.004%	0.16%

* Parts per million of air-dried soil.

The data in table 1 show that the acid treatment has increased the supply of water-soluble phosphorus, but not so much so as has the heavy liming. Only the acid treatment of the soil has increased the water-soluble fraction of nitrogen. In later experiments a field equipment (Truog) for determining the available phosphorus has been used in testing the soils at all of the reactions used experimentally. Table 2 gives the results obtained in the clay soil used in the experiment performed during the summer of 1931.

Table 2

pH value of soil	*Amount of available phosphorus per acre*
7.8	50 pounds
7.0	25 "
6.3	10 "
4.8	10 "
4.5 H_3PO_4	50 "
4.5 H_2SO_4	10 "
4.5 HCl	10 "
4.2 H_3PO_4	50 "
3.7 H_2SO_4	10+ "
3.7 HCl	10+ "

In the experiments which have been described there has been an interesting parallelism between the growth of grass in the clay soil at different reactions and the results found with the soil tests for available phosphorus. Only at pH 7.8 and to a much less extent at pH 7.0 has there been a stimulation in growth except in cases in which phosphates were supplied. These are the only two reactions at which more than 10 pounds an acre of available phosphorus was found. The cultures grown in soils acidified with phosphoric acid were, of course, exceptions with respect to their available phosphorus content. The yield of grass from the phosphoric-acid-treated soil at pH 4.5 was the same as that from the limed soil at pH 7.8. It may be noted that the measurements for available phosphorus were also the same.

In some experiments with colonial bent grown in the clay soil, additional observations concerning the availability of phosphorus were made. If phosphates were added to this soil the available phosphorus as measured by the Truog test was somewhat higher in the acidified soils than in those not treated with acid, and also higher in the heavily limed soils than in those unlimed. It seems that the acid treatment may help to keep the phosphates available if there is a fair supply of them in the soil. If the supply is very deficient, however, heavy liming is the only treatment which has both had a beneficial effect upon the plants and which has shown a difference in the availability of phosphorus with the Truog test. Tests have shown that this clay soil has a very high phosphate-binding power. The addition of a phosphate fertilizer at the rate at which these substances are frequently applied to golf courses provides an increase in available phosphorus for only a short time. Also the addition of phosphates in the previously-described experiment produced a stimulation of growth for only a short time, because phosphates remained available for only a short time. The soil at a pH value of 7.8 continued to be the most productive, largely because there was a continuous supply of phosphates available to the plants.

The rôle of phosphates in this very acid soil is probably twofold. They supply an element needed for the growth of grass, and they may also act beneficially by binding otherwise soluble iron and aluminum compounds which may have a harmful effect upon the plants. There has been much discussion as to whether the injurious effects of low soil reactions are due directly to high acidity or to the presence of toxic concentrations of such compounds. It is known that above a pH value of approximately 4.7 there are only traces of these substances in true solution. As the acidity increases—that is, as the reaction becomes lower—the amounts in solution increase. Clay soils are apt to have a relatively high content of these compounds. Strongly acid reactions in such soils may consequently result in concentrations of the iron and aluminum compounds unfavorable to growth. Experiments with the bent grasses grown in clay soil tend to show that the plant can tolerate a more acid reaction if there is an abundance of phosphates present. This response may be partially related to their power to overcome toxic effects of iron and aluminum compounds. What is probably of greater significance, however, is that with appreciable quantities of iron and aluminum compounds present in the soil solution, the plant is likely to obtain too little phosphate.

The creeping bents grown in the greenhouse during the winter months have manifested a less definite stimulation of growth of tops in the clay soil at pH values of 7.8 to 8.3 than they have when grown in the open during the summer months. Growth of roots at this season was definitely less at this soil reaction than it was at lower reactions. Our recent experiments have suggested that the phosphorus requirements of plants grown in the open during midsummer may either be higher than or both quantitatively and qualitatively different from those of plants grown in the greenhouse in the winter months. At different soil reactions there may be a quantitative difference in the amount of phosphorus in combination with different bases, such as calcium, magnesium, and potash. Further work along these lines is in progress. Differences in phosphorus requirements such as those above indicated may afford a partial explanation of the seasonal differences in the response of grass plants to different soil reactions.

In addition to liming, another treatment of the clay and compost soils resulted in definite increases in growth, namely, the addition of small quantities of sulphuric or hydrochloric acid. It has been shown that the improvement in growth due to heavy liming of the clay soil is undoubtedly due to an increase in the available phosphates. The question arises as to what effect the increased productivity of the acid-treated soils is to be attributed. Chemical analysis of some of the clay soil treated with sulphuric acid (table 1) reveals that this treatment caused some increase in available phosphorus and a marked increase in available nitrogen. It is probable that it may also have caused an increase in the availability of potash, calcium, and magnesium. This, however, was not determined in the analyses. In the compost mixture, in which there was the best growth at pH 4.5, the supplies of available nitrogen and phosphorus were both apparently determining factors. There was no evidence that one deficiency was dominant over the other.

In general, there have been indications that the improvement in growth resulting from either liming or acidifying the soils used in these experiments has been a result of an increase in the available supply of important nutrients. The effects of similar treatment upon the growth of turf grasses in other types of soil would have to be determined.

Discussion

Phosphates.—In order to furnish a supply of available phosphates adequate for satisfactory growth of bent grasses in the acid clay soil employed in these experiments, it was found necessary to add very large quantities of phosphates or phosphoric acid. The amount of phosphorus thus supplied was larger than is usually applied to golf courses or than the experiments at the Arlington turf garden have indicated may be necessary. No reason for this difference in phosphorus requirements can at present be given except that the soil employed in these tests was much more deficient in phosphorus than soils ordinarily found on golf courses. The experimental results indicate that liming in addition to applications of phosphates may be effective in supplying an adequate quantity of available phosphorus in soils of this type. In the case of the compost mixture and the alkaline silt loam whose productivity was increased by the addition of sulphuric acid, liming was not beneficial in increasing the availability of phosphorus.

Nitrogen.—The greater tendency of grasses to show injury due to acid treatment of the soil in summer than in spring or fall is in agreement with similar seasonal responses to fertilization with sulphate of ammonia. This fertilizer, which acidifies the soil, if added in fairly large quantities in the spring encourages rapid growth, and the general effects at that time may appear to be entirely favorable. However, unless lime is eventually added to some soils, and particularly to those which are naturally acid, and which are located in sections having very high temperatures, unfavorable effects often develop during the summer, even without further addition of sulphate of ammonia. Furthermore, it has been found that a cumulative effect resulting from the addition of sulphate of ammonia during previous years may produce injury in summer. This is strikingly shown in tests conducted on some experimental plots at the Morris County Golf Club of New Jersey. Monthly applications of sulphate of ammonia had been made during the growing seasons of 1928 and 1929. Although none was added during 1930, there was marked injury in midsummer that year.

Since liming overcomes most of the detrimental effects resulting from fertilizing the soil with sulphate of ammonia, it is supposed that injury caused by the sulphate is due to accumulation of sulphate residues which form sulphuric acid. If there is lime in the soil it will combine with the acid as it is produced and form calcium sulphate, a substance relatively insoluble except in acid solutions. Even in soils which are neutral or alkaline, benefit to turf from liming is sometimes to be observed during the summer. The need for a larger supply of lime in the soil in summer than at other seasons is an indication that the tendency to injury is in some way connected with soil reaction. Whether or not a higher acidity occurs in summer than at other seasons in the soil areas immediately surrounding the roots, has not been definitely determined. However, there is some evidence from the work of other investigators that nitrogen may enter the plant more rapidly in the higher temperatures of the summer months than it does in cooler temperatures, such as prevail in spring and fall. If this behavior should be found to be characteristic of grasses also it would help to explain some of the differences in seasonal response to fertilization with sulphate of ammonia. If nitrogen does enter the plants more rapidly during the summer months, there would also be a more rapid accumulation of sulphate residues in the soil, and thus an increased acidity in the soil areas surrounding the roots. During a heavy rain some of these would be washed away from the roots, and the distribution close to and farther away from the roots would again become more nearly uniform. Favorable conditions for growth might thus be restored provided the leaching of the soil had not caused a deficiency of essential nutrients.

The conclusion should not be drawn from these statements that sulphate of ammonia should not be used as a fertilizer during midsummer. On the contrary, the use during midsummer of light applications of inorganic nitrogen fertilizers has been found to offer advantages over organic fertilizers. During the warmer months the latter may decompose rapidly and release nitrogen in such quantities that it produces soft grass and sometimes even toxic effects. The soft grass produced under these conditions may also be particularly susceptible to invasion by disease-producing organisms. If organic fertilizers are to be used, it has been found advantageous to apply them during spring or fall and to use the inorganic forms, as additional nitrogen is found to be necessary, during the summer months. The chief point to be emphasized here is that in using sulphate of ammonia care should be taken to have a supply of bases, such as calcium and magnesium, available in the soil so that as plants remove the ammonia harmful reactions will not develop and injure the roots and eventually also the turf itself.

Summary

Experiments were conducted to study the effects of soil reaction upon the growth of certain bent grasses commonly used on putting greens. Two different soils were used for most of the work, one a heavy clay loam relatively low in content of organic matter and plant nutrients, the other a rich compost mixture with a high content of these substances. Both soils were acid in reaction. Differences in pH value were obtained by the addition of acids or alkalies to produce a series ranging from pH 3.7 to 8.3. The following experimental results were obtained:

1. In experiments with fertile soils it was found that the creeping bents and colonial bent can grow well between reactions of pH 4.5 and 8.3. Velvet bent was somewhat less tolerant of the higher reactions. It is possible that if a greater variety of reactions and soils had been employed a still wider range of tolerance would have been found. The best growth of Metropolitan bent under certain climatic conditions occurred in one soil at pH 8.3 and in another at pH 4.5.

2. In a poor soil low in organic matter and plant nutrients, the bent grasses have, however, shown preferences for certain reactions. In this soil the creeping bents thrived best at reactions slightly above neutral to strongly alkaline, and velvet bent in reactions distinctly acid.

3. Growth of roots of Metropolitan bent was favored by an acid soil reaction under one set of environmental conditions and by a neutral or alkaline reaction under another set of conditions. Growth of roots of velvet bent was favored by the same somewhat acid reactions which under most environmental conditions promoted growth of the tops. Growth of roots of the bent grasses may be more unfa-

vorably affected than growth of the tops by very high acidity of the soil. Under the latter conditions there are few roots and they are very short and coarse.

4. The chief factor causing preferences for rather definite pH values in poor soils has been found to be a deficient supply of some nutrient or nutrients essential for growth. At certain reactions these needed substances may tend to become available to the plant in larger quantities and thus better growth will occur.

5. The supply of available phosphorus was found to be the chief factor causing variation in growth of Metropolitan bent in the clay soil at different reactions. If the phosphate deficiency is corrected a further improvement will result from adding nitrogen, but the latter causes relatively slight improvement unless phosphates are added. Another minor factor has been the supply of magnesium. The supplies of available nitrogen and phosphorus were both apparently determining factors in another soil, a compost mixture in which there was the best growth at pH 4.5. There was no evidence that one deficiency was dominant over the other. In other soils it is possible that still other nutritional factors may be influential in producing better growth at one reaction than at another. In general, it seems possible that if a soil tends to be markedly deficient in some mineral or minerals, that reaction which tends to release these elements so that they become available to the plants in quantities sufficient for growth, provided the reaction does not lie beyond the range which the grass will tolerate, will tend to be favorable to growth.

6. The kind of acid or alkali present chiefly in the soil may influence the response of bent grasses to soil reaction. In the alkalization of the clay soil with lime or lime plus magnesium oxide, there was usually the best growth of Metropolitan bent at a pH value of 7.8 to 8.3; but in the case of alkalization with caustic potash there was the poorest growth at pH 7.6, the highest reaction obtained. In connection with acidification of the soil, the nature of the acid added was also highly important. There was usually excellent growth in this soil at pH values of 4.5 to 4.3 if phosphoric acid was the acidifying agent, but very poor growth if sulphuric or hydrochloric acid was used. The detrimental effects of hydrochloric acid were usually greater than those of sulphuric.

7. Unfavorably high concentrations of certain mineral substances such as iron and aluminum compounds may be the chief limiting factors to growth in some soils. In general, the more acid the reaction, the higher the concentration of these substances in the soil solution. In such soils, reactions which would tend to bind these toxic substances so that their concentration in the soil solution would be greatly reduced would tend to be favorable.

8. A combined effect of nutrient deficiency and toxicity factors may limit growth in some soils. For example, if an acid clay soil is deficient in phosphorus, the addition of phosphates may have a directly beneficial action upon growth. Without necessarily changing the reaction, they may also bind some of the otherwise soluble iron and aluminum compounds so that toxic concentrations no longer exist. There is a possibility, however, that the chief harmful effects of soluble iron and aluminum compounds may not be an effect of a directly toxic action but rather one of removal of phosphates from the soil solution. The plant consequently suffers more directly from

lack of phosphates than from a toxic action of the iron and aluminum compounds.

9. Liming raises the reaction of the soil so that less of the iron and aluminum compounds are in solution, and it may also increase the availability of phosphorus in acid clay soils of the type here used.

10. Lime overcomes the toxic effects of high sulphate concentrations in the soil. The action is largely one of neutralizing the acid to form relatively insoluble sulphates. This is of importance in counteracting the harmful effects of sulphate residues accumulated in the soil following the use of sulphate of ammonia as a nitrogen fertilizer.

11. Climatic factors may have an effect upon the response of bent grasses to soil reaction. The acid-tolerance of these grasses appears to be lower during midsummer than at other times of year. It has also been found that liming has a more beneficial action in summer than at other seasons. These responses are in agreement with the injury of turf in summer resulting from cumulative effects of fertilization with sulphate of ammonia at the Arlington turf garden.

12. The results of the experiments which have been described apply chiefly to two types of soil. In general, the results obtained indicate that, if the fertility of the soil is maintained it will not be necessary to establish narrow limits of reaction.

Questions and Answers

Use of sulphate of ammonia, superphosphate, muriate of potash, and bone meal as fertilizers.—Could a mixture of 2 pounds of sulphate of ammonia and 10 pounds of superphosphate be safely applied monthly to 1,000 square feet of putting green surface? Would an application in the spring of 200 pounds of sulphate of ammonia followed by an application of bone meal be satisfactory for fairways? (Pennsylvania)

ANSWER.—It would be quite safe to apply 2 pounds of sulphate of ammonia to 1,000 square feet of putting green surface and to apply also at the same time 10 pounds of superphosphate to the same area. There is seldom any burning with superphosphate, but occasionally muriate of potash burns, and the fact that it may burn should be considered when using it in a fertilizer mixture. Monthly applications of sulphate of ammonia are all right during the growing season, but superphosphate should not be applied monthly, since phosphorus is not used up as quickly as nitrogen, nor is it released from the soil as readily, and an excess of phosphorus in the soil might lead to difficulty from clover and weeds. One application of superphosphate, either in spring or fall, would be ample. On the fairways 200 pounds of sulphate of ammonia could be applied to an acre in the spring without danger of burning, but the bone meal should not be applied until after a good rain so that the sulphate may first be washed into the soil. The sulphate will give the grass a good start in the spring, and also will make the bone meal more readily available, thus producing good results from it as early as spring and the first part of summer. If bone meal is to be used without an application of sulphate of ammonia its fertilizing elements will become only slowly available, and in that case it should be applied early the preceding fall.