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Contents

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Soil Acidity and Lime for Bent Turf

By John Monteith, Jr.

Many years ago it was observed that in a general way the bent grasses thrived best on acid soils. It was found that sulphate of ammonia and certain other nitrogen fertilizers which tended to make soils more acid resulted in a great increase in vigor of the grass and a reduction in weeds. On the other hand, fertilizers such as nitrate of soda, which tended to make soils less acid, were found to encourage weeds and to be far less beneficial to turf. Experiments at the Rothamsted Experiment Station in England and at the Rhode Island Agricultural Experiment Station indicated that turf was decidedly improved when repeatedly fertilized with sulphate of ammonia, which tends to make soils more acid. Experiments at the Arlington turf garden initiated somewhat later showed very favorable results with ammonium phosphate as well as with sulphate of ammonia. The ammonium phosphate, which also tends to make the soil acid, had a somewhat better effect than the sulphate of ammonia, supposedly because the phosphate residue left in the soil after the ammonia was taken up had a better effect in the soil than the sulphate residue left from sulphate of ammonia. These observations and experiments led to the belief that bent grasses needed decidedly acid soils and that the common weeds of turf were discouraged by an acid condition of the soil. As a consequence the so-called "acid theory" was developed and widely endorsed by those who were the closest followers of turf-culture studies. There were case after case added to the records of poor, weed-infested turf being almost miraculously improved by repeated and heavy applications of sulphate of ammonia. It was only natural that the large amount of evidence that accumulated should win many enthusiastic converts to the acid theory. The beneficial effects of the acid-reacting fertilizers were attributed primarily to their changing the acidity of the soil. Failures to obtain desired results were attributed to insufficient change of the acidity of the soils in question, and heavier rates of application were recommended for these cases.

The acid theory was subject to two serious handicaps. In the first place, its increasing host of enthusiastic supporters, like the enthusiastic friends of any new principle that has shown some definite results, extended the claims far beyond the limits that were acknowledged for it by those who first sponsored it. In the second place, the theory was based on the overemphasis of a single factor. Even though there was an abundance of evidence which seemed to clearly indicate a direct correlation between the improvement of turf and the increased acidity of the soil, there had been no direct proof that the change in acidity was the only important factor in accomplishing this improvement.

It is interesting to note that the acid theory came into general application in turf culture at a time when lime was generally used in great excess on grass for both lawns and golf course turf. Lime was used as a fertilizer, and in many cases nothing else was applied to turf. As a result the soil soon became greatly depleted of nitrogen. Then clovers or other legumes which could obtain nitrogen from the air were able to compete successfully with grass and in many cases soon dominated the turf. Under those conditions any fertilizer that provided nitrogen in a suitable form was almost certain to produce startling results. Sulphate of ammonia and ammonium phosphate provided nitrogen in this form and proved to be of unusual value to turf which had little nitrogen available in the soil. Much of the popular conception of unparalleled benefits of sulphate of ammonia was based on a comparison of its effectiveness as compared with lime rather than on a comparison with other fertilizers containing an equal amount of nitrogen in readily available form.

It had been noted that on some putting greens where sulphate of ammonia had been used in large quantities there had been no noticeable change in soil acidity. This was due to various causes, among which were the large reserves of some form of lime in the soil, the use of sand with a high lime content in the preparation of topdressing material, and the sprinkling of greens with hard water that contained large quantities of lime. In such cases even without any change in soil acidity the heavy applications of sulphate of ammonia in many instances accomplished the desired result of improving the bent turf and reducing the weed content. In other instances, even though the soil was made decidedly acid it was found that the results obtained from the use of heavy quantities of sulphate of ammonia did not come quite up to expectations. Such observations naturally raised questions as to how widely applicable was the acid theory.

At the Arlington turf garden it was found that the acidity of the soil had been decidedly increased in plots which had received sulphate of ammonia or ammonium phosphate for a period of years. As early as 1922, however, it was noticed that the colonial bent grass on these plots, although producing good turf throughout most of the season, showed a tendency to become easily injured in periods of extreme heat during the months of July and August. This periodic injury seemed increased from year to year, and excessive acidity was suspected as one of the contributing causes. In 1926 some experiments were started at the Arlington turf garden to determine the effect of lime on such injured areas. The response was favorable and further tests were started. The investigation of turf diseases about this time had also led to the observation that plots which had been fertilized excessively with sulphate of ammonia were more susceptible to the dollarspot and brownpatch diseases and to nonparasitic injury commonly designated as scald. A number of tests at the Arlington turf garden showed that these injuries on plots which had been fertilized excessively for a long period with this acid-reacting fertilizer could be decidedly reduced by an application of lime. These observations were published in the May, 1929, Bulletin. The publication of this Bulletin was heralded by many as marking the end of the acid theory in bent culture. This, however, was not the case. It merely served as a warning against the extreme application of this theory. It indicated that the use of certain of these acid-reacting fertilizers could be overdone and that the previous extreme position which led to the tabooing of lime on golf courses was erroneous. A few extremists unfortunately took the cue from the May, 1929, Bulletin to again use lime recklessly on golf course turf. The Green Section work reported in the May, 1929, Bulletin gave no indication of definite pH limits, and consequently no recommendations were made. As observations were continued at the Arlington turf garden and the Mid-West turf garden, further evidence was obtained indicating that other factors were involved and that the question could not be resolved into a simple matter of prescribing any definite degrees of soil acidity. All of the contentions on which this question of soil acidity had been argued were based on general observations or experimental work in which there was a conflict of various factors, and no definite work had been performed in which these various factors could be considered separately. The conflict of evidence clearly indicated that such work was desirable, and the Green Section therefore undertook the task of determining more definitely the influence of soil acidity on the growth of bent. Some of the results of this work are presented in this number of the Bulletin.

The experiments indicate in general that bent grasses can tolerate a wider range on the acid than on the alkaline side. They have also shown that with one type of soil, Metropolitan bent grew best when the soil reaction was decidedly acid, pH 4.5, whereas with another type of soil its best growth occurred when the soil was decidedly alkaline, pH 8.3. These wide limits indicate the folly of prescribing definite acidity limits for all soils. Although one of the soils used in the experimental work gave the best growth when alkaline, it is probable that most soils used on golf courses give best growth of bent grasses when they are somewhat acid. The experiments showed that the kind of acid in the soil was an important factor. The chemical effect of acids or lime on plant-food materials in the soil also appears to be an important and at times a determining factor. There are many other interrelated factors that exert important influences on turf production whenever there is a change in soil acidity. All of these results clearly explain why there has been so much conflicting evidence injected into the discussion of the question as to how acid soil should be for bent turf. They explain why the Green Section prescribes no definite limits as to degree of soil acidity. They further indicate the importance of certain factors that have been given little consideration in the past, and clearly show the need for further experimental work to determine more accurately many of the factors that influence turf production, to the end that course maintenance be based on knowledge rather than on mere argumentation and speculation.

Individuals in charge of a golf course naturally will ask how this information can be applied to turf culture. The Green Section has been asked to define its policies on soil acidity and the use of lime based on present information. Its position on these questions is briefly defined below.

The bent grasses seem to thrive best on most soils if they are slightly acid. Therefore fertilizers which tend to make soils more acid or have a neutral effect are to be preferred to the common fertilizers which make soils less acid or alkaline.

Any extreme change in acidity should be avoided unless carefully conducted experiments indicate that such a change is desirable.

Juggling of soils to bring them within certain prescribed limits of acidity as expressed in terms of pH is not justified in the light of present knowledge.

The use of sulphur or other materials chiefly to increase soil acidity is considered unwise.

Tests of soil acidity by means of the various devices for determining degrees of acidity expressed in pH or in "lime-requirement" should be regarded simply as useful indicators and not as final proof that a soil needs some change in its degree of acidity or alkalinity.

Lime should be used as needed to correct excessive soil acidity or to correct the harmful effect of excessive use of certain fertilizers, such as sulphate of ammonia or ammonium phosphate, even though they may not have made the soil acid.

Excessive use of lime should be avoided on golf course turf just as excessive use of any other chemical should be avoided.

The need for lime by turf is expressed in various ways. One of the most common symptoms in bent grasses is a yellowing and generally unthrifty appearance especially during the heat of midsummer. Yellowing may be due to excessive watering, shortage of nitrogen, or other unfavorable conditions. However, if the soil and moisture conditions are favorable and turf does not promptly respond to an application of a fertilizer containing nitrogen in readily available form, as sulphate of ammonia, it indicates that lime may be needed. If brownpatch and dollarspot are extremely active and they are not easily controlled by the customary mercurial fungicides this also may be regarded as an indication of lime shortage. If irregular patches of turf turn brown as though scalded and the soil in these patches dries and becomes almost impervious to water there is a possibility of lime deficiency. Any of the symptoms of lime deficiency may be produced by other causes and may therefore be misleading. However, if considered collectively, they are of great importance in pointing to the need for lime. If tests with one of the acid testing kits show that the soil is decidedly acid it may safely be assumed that if the above symptoms appear the soil will be benefited by an application of lime.

Too much emphasis has been placed in certain districts on the determination of lime requirements of golf course soils by means of the test kits that determine acidity by chemical means. The Green Section fully recognizes the usefulness of such tests in scientific work or in rapid diagnosis of many soil difficulties. In greenkeeping they serve simply as useful instruments to provide supporting evidence in a diagnosis. They do not provide the definite and conclusive proof of lime requirement that some greenkeepers and green-committee members have been led to believe. The chemical tests sold for popular use are easily read, but are devised to show only one thing and are not intended to indicate anything about the complication of other factors that influence the growth of grass. Although not as easily read, the grass itself is a far better indicator of soil requirements than any chemical yet devised. The greenkeeper can accomplish far more by studying the responses and symptoms of grass than he can by learning how to operate the various test kits that are on the market. Tests for soil acidity should be used only as a guide, as is indicated in the following examples.

If soil is tested and found to be about pH 4.5 it is probably too acid for the best growth of bent. However, this is not necessarily so. If the grass has definitely shown some of the symptoms mentioned above, it would be well to apply lime. If on the other hand the grass continues thrifty there need be no alarm at this low pH reading and lime should not be applied without adequate testing.

In the case of an alkaline soil, such as that on which the Mid-West turf garden is located, repeated applications of sulphate of ammonia may only slightly change the degree of alkalinity. A pH reading in such cases may be 7.5, which would indicate no lime was needed. Nevertheless when the symptoms of the grass as mentioned above indicate lime deficiency, it has been found that where lime was added the result in the pH 7.5 soil was quite similar to that obtained on the pH 4.5 soil.

In most cases it will be found that the lime content of the soil is not sufficiently exhausted to cause the turf to exhibit the distinct symptoms of lime deficiency, except under severe climatic conditions. In such cases lime should not be applied indiscriminately, for there may already be more lime than is needed in the soil.

On many golf courses where no direct applications of lime have been made in recent years there have been large quantities unknowingly applied in hard water or in sand used for topdressing. In any case the development of lime deficiency is a gradual process; and if the turf is carefully watched any deficiency can be detected well before it produces disastrous effects.

The safest way to use lime on a golf course is to first try it on small definite areas. A 10-foot strip of lime across a putting green or a 20- to 50-foot strip across a fairway provides a simple test which, if closely watched, will give much more accurate information on the lime requirements of soil than will any other test now available. This method is somewhat slow; but it is seldom that any great speed is necessary in applying lime, except when the shortage is so marked that unmistakable evidence of such shortage is available. In making this test, lime should be applied at the rate of 25 pounds to 1,000 square feet of putting greens and 1 ton to the acre on fairways. For quick results, hydrated lime should be used. The test areas should be marked with string before the lime is scattered, and care should be taken to distribute it to the edge of the plot but not beyond it in order that there may be a clear distinction between the limed and unlimed areas. If throughout the season there is no sign of impoverishment in the turf that is limed as compared with the turf beside it that received no lime, it is obvious that liming is unnecessary. These tests are simple to perform and may avoid the cost of liming and the possibility of some danger to the turf. The custom of giving lime a trial by liming the entire course without some system of checking results previously is to be condemned, for it is a sign of guesswork greenkeeping.

Hydrated lime should not be put on turf within about 10 days after applying fertilizers containing ammonium salts. Neither should such fertilizers be applied for several days after hydrated lime has been spread on turf. Neglect of these precautions may result in severe burns, due to the release of ammonia gas.

The above-suggested rate of liming for trial plots is somewhat lower than that which yielded the best results in one of the soils used in the experiments described in the following article. This is chiefly because in the pot cultures the lime was mixed through the soil to a depth of over 6 inches, thus making application of the quantitative aspect of the results of value more particularly in connection with construction work. Under field conditions, when lime is applied to the surface it becomes effective in lowering the acidity first of the upper portion of the soil, later extending gradually to lower levels. Since in most turf the feeding roots are fairly near the surface, the effects even of light liming may soon be observed.

The harmful effect on turf of excessive amounts of sulphate of ammonia is not to be interpreted as an objection to the use of the fertilizer on golf course turf, particularly of the bent grasses. It is harmful if used in excess; but in this respect it is simply like many of the other materials that are so useful in greenkeeping, including such things as water, lime, and fungicides. Sulphate of ammonia is still regarded as one of the best fertilizers for golf course use. The more recent observations and experiments have simply indicated that it is not the cure-all some enthusiasts once supposed it to be, and that regardless of acidity it must be properly balanced with other materials used for plant food in order to give best results in turf culture.

The "Herbae-Mira" Fraud

As early as January, 1924, the Bulletin issued a warning concerning the nefarious scheme of one Allan Ward Miller to defraud prospective purchasers of grass seed. Advertising leaflets, clever sales talk, and trays or samples of luxuriantly growing grass were used to entice greenkeepers, large property owners, and others to purchase a low grade seed at $2 a pound. Miller used the name "Herbae-Prati" for his seed mixture after originally using such names as "turfing fescue" and *"Festuca elatior,"* but these failed to catch the public eye and the name was changed to "Herbae-Prati." Most of this mixture was composed of common meadow fescue worth only about 10 cents a pound.

The Department of Agriculture and the Post Office Department made it so uncomfortable for Miller that he ceased operations for a while, later renewing his fraudulent activities and advertising the seed under the name "Herbae-Mira."

Miller was denied the use of the mails and fraudulent charges were filed against him. He was indicted several times during the past six years but avoided being brought to trial by creating complications in addresses and by changing the mixture of "Herbae-Mira." Miller operated through such agencies as "Forest Lawn Improvement Company" of Chicago; "Zenith Lawn Improvement Company of Kansas City; "Wilshire Lawn Improvement Company" of Dallas; and requested cash with orders. In some instances no office was maintained in the cities as advertised, and mail was forwarded to another destination from which point Miller directed his sales.

In February, 1930, Miller was arrested in Price, Utah, on a charge of petty larceny in connection with alleged misrepresentation of "Herbae-Mira" seed. He was fined $275, given a suspended jail sentence of six months, and ordered to repay $65 to the parties he defrauded. Again, in January, 1931, Miller was arrested, tried, and sentenced in the Circuit Court of Peoria County, Ill., to serve from one to ten years in the State Penitentiary at Joliet, Ill. He was charged with operating a confidence game and obtaining money under false pretenses.

Most value is obtained from manure when it is used in the compost pile. An excellent compost consists of one-fifth manure and four-fifths sandy-loam topsoil.

The ideal texture of soil or compost is such that after being compressed in the hand it will retain the form to which it is compressed but will fall readily apart when touched.

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.

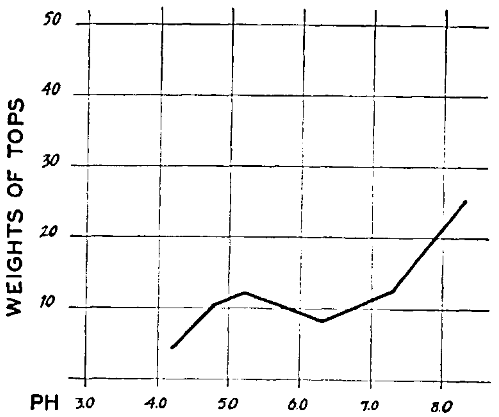

Figure 1.—Weights in grams of tops (green weights) of Metropolitan creeping bent grown in clay soil adjusted to different pH values.

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.

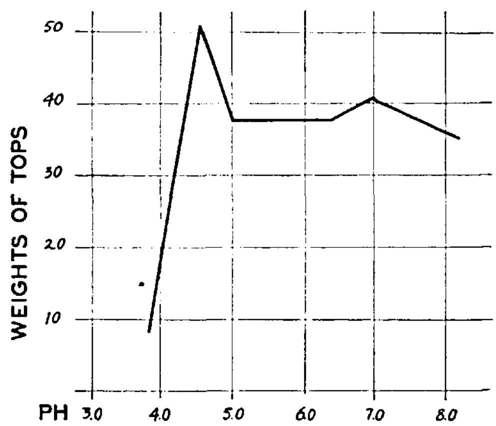

Figure 2.—Weights in grams of tops (green weights) of Metropolitan creeping bent grown in compost adjusted to different pH values. The graph shows the best growth at pH 4.6 with hydrochloric acid as the acidifying agent. Other cultures grown in compost acidified with sulphuric acid at pH 4.5 produced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

Disking or spiking fairways after they have received fertilizer.—We are planning to apply sewage sludge to our fairways. Our course is hilly and the soil clay. Would it be well to give the fairways a light disking or spiking after the sludge is applied in order to prevent its washing off the high places? (Michigan)

ANSWER.—It would be highly desirable to follow the fertilizing with disking or spiking, so that the fertilizer may work into the soil and not be washed away. Light disking can often be done by loading the carriage and by setting the disks straight. The straight-set, weighted disks will slice the sod but will not turn it to any extent. The disk furrows should be left open until the fairways are watered or until rain has fallen, provided the rain comes before the turf dries too much. The watering or rain will wash the fertilizer into the disk furrows. Before the disked turf dries to excess on account of being loosened from the soil, it is well to pass a roller over the area to put the turf back in contact with the soil.

Magnesia in limestone used for topdressing purposes.—We have received several samples of ground limestone. One contains 45 per cent carbonate of magnesia and only 40 per cent carbonate of calcium; another contains 10 per cent carbonate of magnesia and 65 per cent carbonate of calcium. Is not the sample with the higher percentage of lime the better? Is magnesia an impurity in lime? (Pennsylvania)

ANSWER.—Magnesia is not considered an impurity in lime. The value of carbonate of magnesia is equal to the value of carbonate of lime for agricultural purposes. Therefore the sample containing a total of 85 per cent carbonates of magnesia and lime is superior to the sample containinig only 75 per cent of these two carbonates. The same is true of the oxides of lime and magnesia.

Selecting a bent grass for putting greens.—We are contemplating the rebuilding of our putting greens. Have you any suggestions as to the best kind of bent grass to use? (Pennsylvania)

ANSWER.—Greens planted with stolons and those planted with seed both have their advantages, and the matter is principally one of personal choice. The first consideration should be the selection of a grass that does well in your section. The Metropolitan and Washington strains of creeping bent, which must be planted with stolons, make very good greens. The seaside strain of creeping bent is planted with seed, and also makes a desirable turf. Colonial bent, which is not a creeping bent, is planted with seed and has many advantages. Mixtures of velvet bent and colonial bent seed make very fine turf which has found much favor. A wide selection of turf grasses can be examined at the Arlington turf garden, near Washington, D. C.

Creeping bent on football fields.—What strain of creeping bent is recommended for use on football fields? After a stand of creeping bent is established on a football field will it be able to keep out quack grass? Is creeping bent likely to be injured by alkali? (Minnesota)

ANSWER.—Creeping bent is not generally recommended for use on football fields. It has been tried in a number of cases on football fields but the results have usually not been satisfactory. Since with football the playing season comes when the growing season is over for the grass, scars left in the turf do not heal. Moreover, the stolons of creeping bent are apt to be a nuisance when played on with cleated shoes. Creeping bent thrives best on a slightly acid soil and is not likely to withstand much injury from alkali. There appear to be no records of its being able to keep out quack grass satisfactorily.

Controlling snowmold.—November 25 our putting greens, which are a mixture of redtop, bluegrass, and Chewings fescue, were attacked by a disease resembling snowmold, although we had not had any snow. Almost overnight they developed a mottled appearance, spots appearing 3 to 6 or 8 inches in diameter. The mycelium was bluish and rather heavy. There were as many as 30 or 40 such spots on some of the greens, the grass in these spots presenting a scorched and dried appearance. The weather at that time had been very foggy but there had been little or no rain. We immediately had the greens sprayed with a solution of calomel at the rate of 3 ounces to 1,000 square feet. The mold thereupon seemed to lighten and gradually disappear. Is there any further treatment we should give the greens? (New York)

ANSWER.—From your description it appears that your greens were attacked with snowmold. Snow is not necessary for the development of this disease. We have had reports from various sections of the country of many snowmold attacks as early in the season as yours. The treatment you have given should hold the disease in check for the remainder of the season. You will find further information on snowmold in the August, 1932, Bulletin.

Treatment of turf subject to injury from salt water; late fall seeding.—Two of our greens have been ruined by salt water. Another we are reconstructing. Is it too late to reseed these after the middle of October? What grass would you recommend for putting greens under our conditions? (New Jersey)

ANSWER.—We would advise you not to replant the greens you refer to until likelihood of their further injury from salt water has been eliminated. Usually proper drainage will rid soil of salt. This may be accomplished by raising the elevation of the greens and putting in tile under-drainage if necessary. On account of its solubility salt is ordinarily readily washed out of well-drained soil. Late October is rather late in the season to sow seed, but it is nevertheless preferable to seed at that time rather than to wait until spring, provided the areas on which it is sown are not subject to surface erosion. In your locality the soil is seldom in condition to work until late spring, while seed sown in October may germinate and be growing early the following season. Under your conditions we would suggest that you use either seaside creeping bent seed or German mixed bent seed. In purchasing German mixed bent seed care should be taken to see that it does not contain a large percentage of redtop seed.

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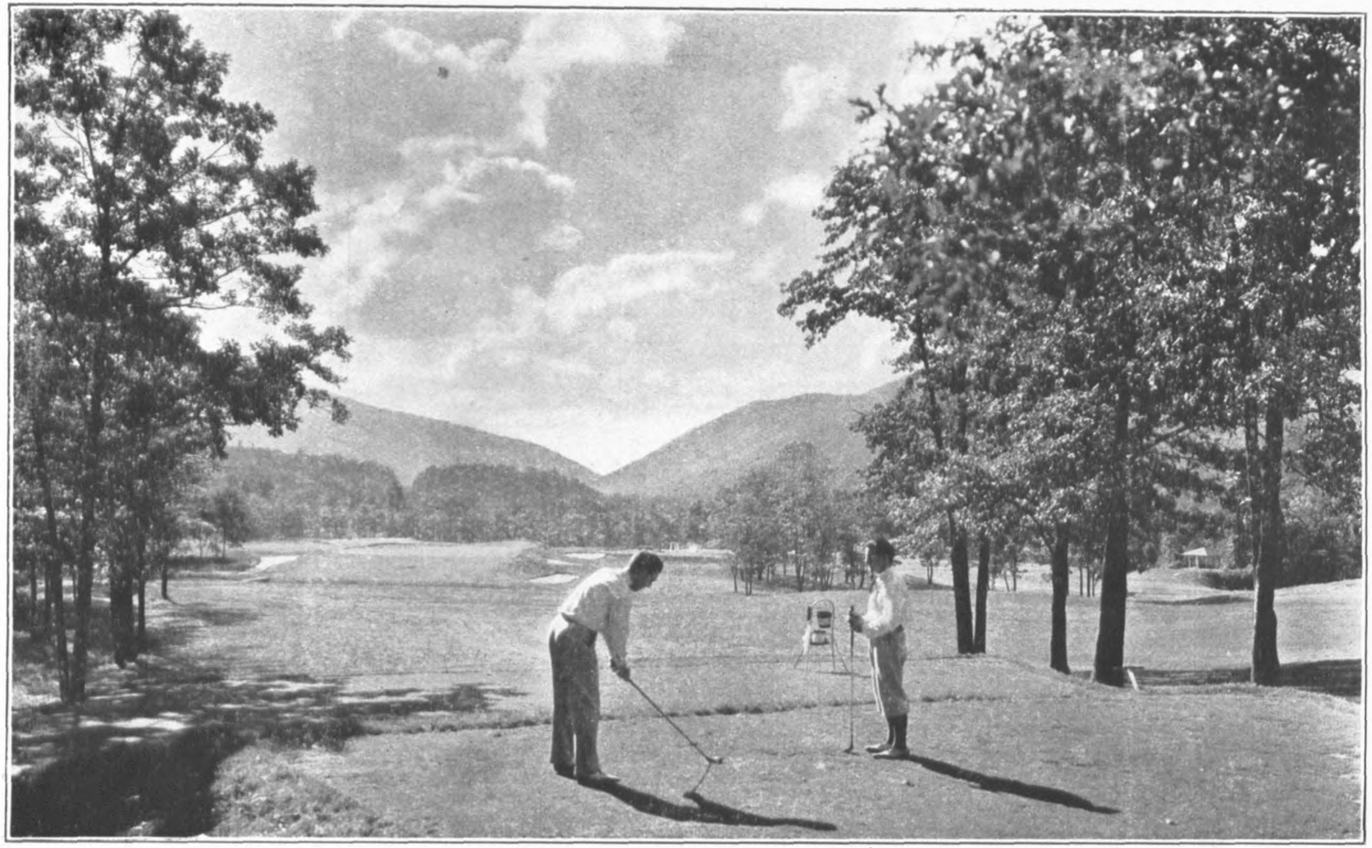

Tenth hole (236 yards), No. 3 course, White Sulphur Springs, W. Va.

Life consists of molting our illusions.

We form creeds today only to throw them away tomorrow.

The eagle molts a feather because he is growing a better one.

Elbert Hubbard