EXPERIMENTS WITH FERTILIZERS ON BENT TURF

JOHN W. BENGTSON AND F. F. DAVIS *

Early in the development of bents in this country it became evident that their nutritional demands differed from those of Kentucky bluegrass. Apparently, by applying certain fertilizers, notably sulfate of ammonia, it was possible to check clover, dandelions and other weeds on the plots and at the same time improve the condition of the grass.

EARLY FERTILIZER EXPERIMENTS

The Green Section established its first series of fertilized plots on the Turf Garden at the Arlington Experiment Farm in 1921. In that year, thirty 8 by 8-foot plots were sown to Colonial bent and the first fertilizers were applied in April, 1922, and at regular intervals thereafter. In this series of experiments, 12 different fertilizers or fertilizer combinations were applied on duplicate plots. Sulfate of ammonia, ammonium phosphate and nitrate of soda were the sources of inorganic nitrogen. The organic sources were cottonseed meal, soybean meal, stable manure, bonemeal and calcium cyanamide.

The condition of the grass and the distributon of the weeds were noted each year. The plots were never weeded, so that after a period of years it was possible to obtain evidence regarding the effect of the fertilizers on the weeds as well as on the grass. In November, 1925, after fertilizers had been applied for 4 years the soil acidity was determined and weed counts were made. Weeds made up 45 percent of the turf on the unfertilized or check plots.

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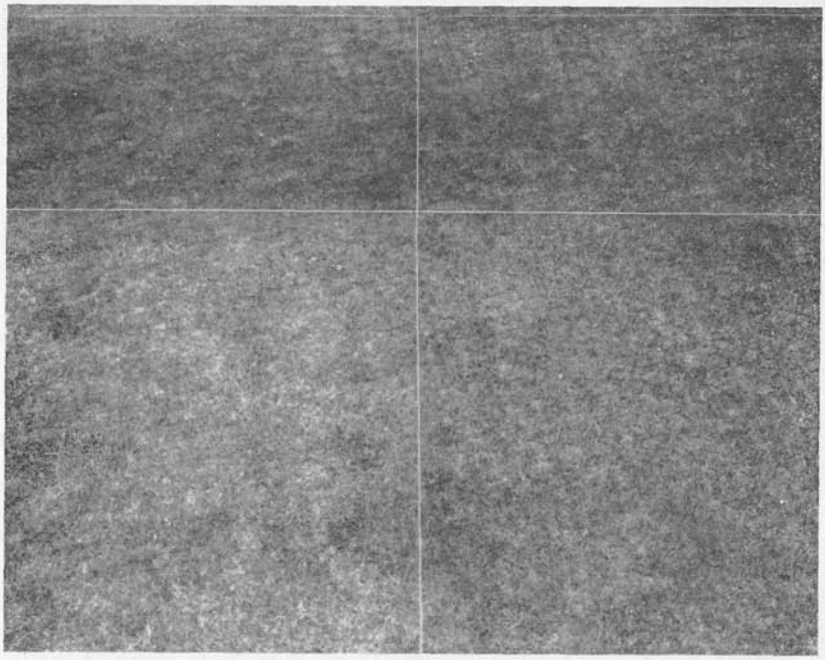
* Agronomist and Botanist, respectively, of the United States Golf Association Green Section.



Varying response of mixed bent turf to different fertilizers evident in June, 1939. The fertilizers have been applied to these four plots since 1921. Since 1930 all plots have received nitrogen at the annual rate of 6 pounds to 1,000 square feet. The dark color indicates the best turf, both in color and density. Upper left plot received sulfate of ammonia, bonemeal and muriate of potash; upper right, sulfate of ammonia and bonemeal; lower left, ammonium phosphate; and lower right, sulfate of ammonia. The upper right plot was on the average the best one in the entire series during 1939 after having received no fertilizers other than this combination for 18 years. The lower left plot was the poorest in the entire series.

A report published in December, 1925, summarized the results in the following statements: "Sulfate of ammonia alone or in combination with other fertilizers in every case increased the acidity, improved the bent grass and thereby held the weeds in check. Sulfate of ammonia alone has accomplished more along these three lines than it has in any mixture. Plots treated with ammonium phosphate are fully as good as plots treated with sulfate of ammonia in spite of the fact that they are

appreciably less acid. Nitrate of soda reduced the acidity and thereby rendered conditions more favorable for the weeds which flourished at the expense of the bent grass. . . . Bonemeal, cottonseed meal and soybean meal did not change the acidity of the soil appreciably or the relative proportions of grass and weeds, as compared with the check, although both grass and weeds were more vigorous where fertilizers were used."

According to notes taken on these same plots 3½ years later the story was somewhat reversed. In March, 1929, the grass on the plots receiving sulfate of ammonia, ammonium phosphate and bonemeal was poorer, although in the case of the first two plots more weed free, than was that on plots treated over the same period of 7 years with cottonseed meal, soybean meal and mixtures of sulfate of ammonia, bonemeal and muriate of potash or nitrate of soda, superphosphate and muriate of potash. It will be seen that these results are in line with recent data taken from plots established in 1930.

Some of these plots have been continued in the present series and are indicated in the table on page 200 by (1).

Fertilizers on Creeping Bent

In the fall of 1924 a more extensive series of fertilizer experiments was inaugurated on the Turf Garden. At that time one strip each of Washington and Metropolitan strains of creeping bent was planted vegetatively, each strip being 16 feet wide and 128 feet long. The following spring each strip was divided into 32 plots, 8 feet square for experiments with fertilizers. The first applications were made on April 24, 1925, and were repeated monthly from April to September, inclusive, each year.

In this series, 30 combinations of fertilizers were tried on one plot each of Washington and Metropolitan bents. The plan was to have all the plots which received nitrogen in any form receive it at the annual rate of 3 pounds to 1,000 square feet. The main object of this experiment was to compare the effect of the various fertilizer combinations on the turf and on the amount and character of the weed growth. Notes were taken regarding the condition of the grass at intervals throughout each growing season. Every fall, after the last fertilizer application had been made and before the weeds had been killed by frost, the weeds were picked by hand and those from each plot were weighed separately. The weeds were not picked, however, until after they had shed their seed.

At the end of the third year it was evident that the grass on the ammonium phosphate plot was less vigorous than was that on the sulfate of ammonia plot. The most vigorous grass in the entire series was that on the cottonseed meal and soybean meal plots. Also the weed control on those plots during the third season was second only to that on the sulfate of ammonia and ammonium phosphate plots. Through an error, however, these plots for the first 3 years had received over twice as much nitrogen as did the other fertilized plots in this series. It was believed, therefore, that the decided superiority of these plots was probably due to the fact that they had been receiving twice as much nitrogen as had the other plots.

Present Series of Fertilizer Plots

The Turf Garden was reorganized and regraded in 1929. This change made it necessary to regrade the fertilizer plots, so the entire series of 64 plots was rearranged. The turf to a depth of 4 inches was carefully lifted and removed. In this

way the accumulation of chemical residues at the surface was not disturbed. After the area was regraded the turf with its 4 inches of surface soil was put in its new position. Immediately afterward the plots were topdressed with some of the regular Arlington topsoil. Just enough soil was used to true the surface. Except on this occasion and immediately after the original planting in 1924 no topdressing of soil or compost has been made other than on the two plots designated to receive compost and the combination of compost and sulfate of ammonia.

Some of the old plots were discarded and new ones were started at the time of the above reorganization. The old plots of the 1924 series are indicated in the table on page 200 by (2) and the new plots by (3). In all, 27 combinations of materials have been used in this series. Unfertilized plots were left as checks for purposes of comparison. There were eight of these check plots distributed over the area.

The annual rate of application of fertilizers was increased to 6 pounds of nitrogen to 1,000 square feet, in order to bring out greater contrast between the results with the various fertilizer combinations. Seven applications were made each year at monthly intervals from April to October inclusive. During July and August, however, the fertilizers were applied at one-half the rate used during the other 5 months of the growing season. The full unit application was made, therefore, at the rate of 1 pound of nitrogen to 1,000 square feet. The quantities of phosphoric acid and potash applied annually with each of the combinations of materials are given in the table on page 200. Except where indicated in this table with an asterisk all plots received nitrogen. Where magnesium and potassium carbonates were used they were applied at a rate to supply the

plots with the same amount of carbonates (CO_3) as was supplied by ground limestone at the rate of 23 pounds to 1,000 square feet. Since all plots which received nitrogen or carbonates received them at the same rate, the amounts supplied by each are not included in the table.

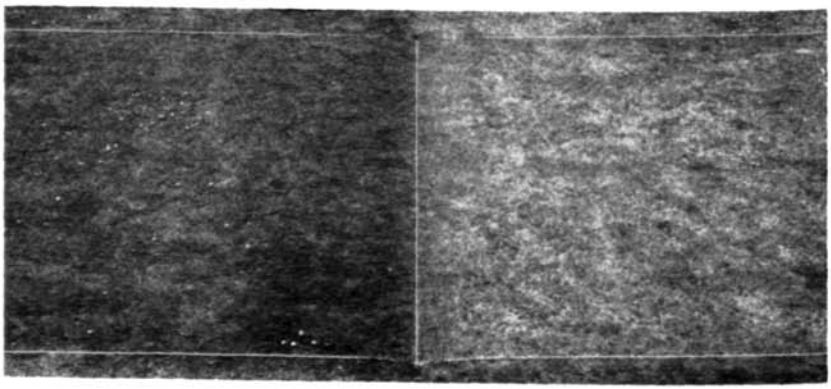
Because of the curtailment of funds for experimental work, no fertilizers were applied during 1934, 1935 and 1936. The plots were watered and mowed at sufficiently frequent intervals to keep the turf in reasonably good condition.

Metropolitan and Washington strains which received the same kind of fertilizers were planted adjacent to one another. Naturally some mixture of these grasses resulted due to differences in the aggressiveness of these strains at different seasons and the scattering of some clippings by the mowers. As these plots had become badly mixed by 1936 in the duplicate series, it was decided to replant with a mixture of bents. In addition to the cumulative effect of fertilizer on bent grass some information on the ability of the three types of bent to compete when fertilized with these different materials could be obtained.

After all of the vegetation on all of the plots had been destroyed by covering the plots with paper and boards, a mixture of 50 percent velvet bent, 45 percent Colonial bent and 5 percent creeping bent was sown. To avoid disturbing the soil the seed was sown and simply raked into the surface with an ordinary garden rake. A good stand was established even without preparation of the seed bed and the application of fertilizers was resumed in the spring of 1937.

The plots were rated at intervals throughout each growing season for color, density and texture of the grass and for the percentage of clover and weeds present. By 1939 the new seeding had been established long enough to show the cumula-

tive effects of the fertilizers, so the ratings for this year are used in the following discussion. The plots were rated on April 18, June 5, July 12, August 21, October 6 and November 13. The averages of these six ratings were calculated for each of the plots. Where two or more plots received the same combination of materials the average of their ratings was used. From these ratings the percentage of improvement of the turf



Effect of excessive phosphoric acid and soil acidity on mixed bent. The picture was taken in June, 1939, of plots which had received fertilizers since 1930 at the annual rate of 6 pounds of nitrogen to 1,000 square feet. Plot to the left received ammonium phosphate and urea. It had a resultant soil acidity of pH 4.8. Plot to the right received ammonium phosphate alone and had a resultant soil acidity of pH 4.2. The ammonium phosphate plot received four times as much phosphoric acid as the ammonium phosphate and urea plot. This large amount of phosphoric acid and the very acid condition in the soil has resulted in turf which has been poorer than that on the unfertilized plots through the 1939 season.

over that on the unfertilized or check plots was calculated for each of the 27 combinations of materials which were applied. The figures expressing percentage improvement over the average condition of the grass on the eight unfertilized plots, rather than the actual ratings, are given in the table on page 200. In a few cases the grass on the fertilized plots was poorer than on the check plots. This is indicated in the table by a minus sign

before the figure. In this table and in the ones on pages 204 and 207 the calculated figures for percentage of improvement are given to the first decimal place. This decimal is the result of the calculations and should not be considered significant.

Soil samples were taken from some of these plots in the early summer of 1939. They were tested for acidity by the Hellige-Truog method; for phosphoric acid by the LaMotte-Truog method; and for potash by the Indiana method. The samples were taken at 1, 2, 3 and 4-inch depths. The most significant changes in pH resulting from the application of fertilizers appeared to take place in the surface inch. In November, 1939, the acidity of the surface inch of soil was determined for each of the 64 plots and it is these figures which are used in this article.

Acidity Relations

As was indicated in the results from the early experiments with fertilizers at the Arlington Turf Garden, the question of the response of the bent grasses to fertilizers is intimately associated with the question of the acidity which they produce in the soil. Unfortunately the importance of soil acidity sometimes has been overemphasized due to the faulty reasoning that if some acidity is good, more must be better. The Green Section, however, in 1929 pointed out that turf suffered on soils which had become excessively acid and applications of lime were needed to correct this acidity. It was pointed out at that time that although lime was beneficial in correcting excessive acidity, its application in excessive amounts might likewise prove harmful to the turf.

The results reported here confirm the statement made in 1929 that "although the finer turf grasses undoubtedly thrive

IMPROVEMENT IN THE CONDITION OF BENT TURF ON THE FERTILIZED PLOTS AT THE ARLINGTON TURF GARDEN OVER THAT OF THE TURF ON THE UNFERTILIZED PLOTS, AS NOTED IN 1939. THE EIGHT CHECK PLOTS HAD AN AVERAGE RATING OF 64.6 PERCENT IN DENSITY AND 63 PERCENT IN COLOR. PLOTS ARE ARRANGED IN THREE GROUPS: MOST ACID (BELOW pH 4.5), MODERATELY ACID (pH 4.5 TO 6.0), AND SLIGHTLY ACID OR ALKALINE (ABOVE pH 6.0) AND LISTED IN EACH GROUP ACCORDING TO IMPROVEMENT IN DENSITY. PLOTS WERE STARTED IN 1921, 1924 AND 1929, AS INDICATED RESPECTIVELY BY (1), (2), AND (3). FOR CONVENIENCE THE ANNUAL APPLICATIONS OF PHOSPHORIC ACID AND POTASH ARE GIVEN IN POUNDS TO 1,000 SQUARE FEET.

Fertilizer	pH of surface inch of soil Nov., 1939	Pounds of nutrients to 1,000 square feet P_2O_5	K_2O	Percentage of improvement over unfertilized plots Density	Color
Most acid plots (below pH 4.5)					
Sulfate of ammonia (1) (2) (3)	4.2	0	0	8.4	7.3
12-6-4 inorganic (3)	4.2	3.0	2.0	2.2	−3.2
Ammonium phosphate (1) (2)	4.2	25.6	0	−14.4	−14.3
Moderately acid plots (pH 4.5 to 6.0)					
Sulfate of ammonia and bonemeal (1)	5.7	16.2	0	34.7	42.9
Sulfate of ammonia, bonemeal and muriate of potash (1)	5.5	16.2	6.0	31.6	38.1
Ammonium phosphate and urea (2)	4.8	6.0	0	23.8	31.7
Sulfate of ammonia and compost (2)	4.6	1.5	3.0	23.8	27.0
Urea (2)	5.3	0	0	22.3	25.4
Cottonseed meal (1) (2)	5.4	2.1	1.7	21.8	22.7
Ammonium phosphate, urea and potassium nitrate (2)	5.5	6.0	6.0	21.5	30.2
Activated Sludge (3)	5.1	2.4	0.5	20.7	21.4
Ammonium nitrate (2)	5.2	0	0	18.4	21.4
Potassium nitrate and urea (2)	5.9	0	6.0	15.3	25.4
Poultry manure (3)	4.9	2.6	1.2	14.6	23.0
Compost (2)	5.6	3.0	6.0	8.4	4.0
*Potassium phosphate (KH_2PO_4) (2)	5.5	6.0	4.0	6.8	8.7
Check (1) (2) (3)	5.5	...	...	....	..

Slightly acid or alkaline plots (above pH 6.0)					
12-6-4 inorganic and lime (3)	6.6	3.0	2.0	20.7	23.8
Urea and lime (2)	7.3	0	0	20.7	19.0
Urea and magnesium carbonate (2)	7.5	0	0	16.9	23.8
Sulfate of ammonia and lime (3)	7.1	0	0	16.1	19.8
Bonemeal (2)	6.4	32.5	0	16.1	19.8
Nitrate of soda and muriate of potash (1)	6.3	0	6.0	14.6	23.8
Nitrate of soda (2)	6.8	0	0	13.0	16.7
*Magnesium carbonate (2)	7.5	0	0	10.7	7.9
*Lime (2)	7.2	0	0	9.1	8.7
*Potassium carbonate (2)	7.5	0	21.5	−6.3	−4.0
Urea and potassium carbonate (2)	7.3	0	21.5	−11.8	−3.2

* Plots receiving no nitrogen.

in an acid soil, it now appears that excessive acidity can not be tolerated." To show the correlation between the response of the bent grasses to various fertilizers and the acidity of the soil induced by these fertilizers, the plots have been grouped in the table on page 200 according to the acidity in the surface inch of the soil in November, 1939. The most acid group includes plots with a pH below 4.5, the moderately acid group includes plots ranging in soil acidity from pH 4.5 to 6.0, and the slightly acid or alkaline group includes those with a pH of above 6.0.

The figures for percentage of improvement in the density and color of the grass on those plots receiving nitrogen have been averaged for each level of soil acidity and are given in the table on page 204. Averages of the percentage of reduction of clover on the plots at each level are also included in this table. The eight unfertilized check plots, on the average, have a soil acidity of pH 5.5 and have been rated 64.6 percent in density and 63 percent in color.

From this table it is evident that on the Turf Garden at the Arlington Experiment Farm the bent grasses showed the most

improvement from fertilizers which produced a moderate soil acidity. The average acidity of the 24 moderately acid plots is pH 5.3. On the most acid plots, in which the fertilizers have produced a soil pH of 4.2, the clover has been more completely eradicated but the average density and color of the grass is poorer than that on the unfertilized plots and is much poorer than that of the grass on the moderately acid plots. As may be seen in the complete table on page 200 the condition of the grass on the ammonium phosphate plots, with a pH of 4.2, has been significantly poorer than that of the unfertilized grass on the check plots. The turf on the slightly acid or alkaline plots, in which the fertilizers have produced an average soil pH of 6.9, has been poorer in both density and color than has that on the moderately acid plots but has been decidedly better than that on the most acid plots. This may be associated with the fact that the change in acidity from pH 5.5 in the check plot to 4.5 is 10 times as great as the change from the check plot in the other direction to pH 6.5.

It is apparent from the figures in the table on page 204 that clover reduction is associated with the acidity of the soil produced by the fertilizer. Unquestionably the greatest reduction was exhibited on the most acid plots and the least on the slightly acid or alkaline plots. On the most acid plots, however, the reduction in clover has been associated with some of the poorest grass in the entire series. Unfortunately the turf on the plots showing the greatest reduction in clover was inferior to the turf on the moderately acid plots which contained some clover. Evidently this soil was too acid for the production of a high-quality turf.

It should be remembered that these responses were obtained entirely from turf grown on the silt loam at the Arlington

Farm. On other soils corresponding results may not necessarily be expected, as is shown by results of work published by the Green Section in the 1932 volume of the Bulletin of the United States Golf Association Green Section. At that time Metropolitan creeping bent had been grown in jars of clay soil adjusted to various acidities ranging from about 4.2 to 8.3 by the addition of acids or alkalies. The greatest growth occurred at pH 8.3. At the same time Metropolitan bent was grown also in jars of compost adjusted to various acidities and the greatest growth occurred at pH 4.6. These results are shown in the chart on page 211.

Response to Nitrogen

The discussion of acidity relations leads to a consideration of the effect of the nutrient elements on bent grasses as related to the acidity which they produce in the soil. In the table on page 200 the plots are grouped into the three levels of soil acidity—most acid, moderately acid, and slightly acid or alkaline plots. The rate of application of phosphoric acid and potash is given for each plot along with the percentage of improvement in the density and color of the grass.

When grass is grown for turf purposes the principal objective is the production of leaves and not flowers or seed. Throughout the plant kingdom nitrogen is the element in the soil most needed by plants for the development of vegetative or leafy structures. In a consideration of fertilizers for the best turf production, therefore, nitrogen is of primary importance. For this reason all of the plots in this final fertilizer series to which nitrogen was applied received it at the same rate; a total annual application of 6 pounds to 1,000 square feet.

As mentioned in the discussion of acidity relations the best grass was produced on the moderately acid plots. The addition of nitrogen alone, however, has produced some improvement in density and color of the grass regardless of the change

AVERAGE IMPROVEMENT OF TURF ON ARLINGTON FERTILIZER PLOTS WITH DIFFERENT SOIL ACIDITIES. CALCULATIONS ARE BASED ON SIX RATINGS TAKEN BETWEEN APRIL AND NOVEMBER, 1939. THE EIGHT CHECK PLOTS HAD AN AVERAGE RATING OF 64.6 PERCENT IN DENSITY AND 63 PERCENT IN COLOR. ONLY THOSE PLOTS WHICH RECEIVED NITROGEN ARE INCLUDED.

Fertilizer	No. of plots	Range in pH of plots	Percentage of improvement over unfertilized plots: Density	Color	Percentage of reduction in clover
Most acid plots					
Ammonium phosphate	4	4.2	−1.0	−2.5	84.0
Sulfate of ammonia	5				
12-6-4 inorganic	2				
Moderately acid plots					
Activated sludge	2	4.6 to 5.9	20.9	25.3	37.0
Ammonium nitrate	2				
Ammonium phosphate and urea	2				
Ammonium phosphate, urea, and potassium nitrate	2				
Compost	2				
Cottonseed meal	3				
Potassium nitrate and urea	2				
Poultry manure	2				
Sulfate of ammonia and bonemeal	1				
Sulfate of ammonia and compost	2				
Sulfate of ammonia, bonemeal and muriate of potash	2				
Urea	2				

Slightly acid or alkaline plots				
Bonemeal 2				
Nitrate of soda 2				
Nitrate of soda and muriate of potash 1				
Sulfate of ammonia and lime 2				
12-6-4 inorganic and lime 2	6.3 to 7.5	14.5	19.0	11.5
Urea and calcium carbonate 1				
Urea and magnesium carbonate 2				
Urea and potassium carbonate 1				

in soil acidity produced by the nitrogen carrier. In the table on page 200, this is shown in the sulfate of ammonia plot at pH 4.2, the ammonium nitrate and urea plots at about pH 5.3, and the sulfate of ammonia and lime, urea and lime, and nitrate of soda plots in the slightly acid and alkaline group. Moreover, the plots which received no nitrogen are among the poorest in the series. The potassium phosphate plot, for instance, which received annually 6 pounds of phosphoric acid and 4 pounds of potash but no nitrogen is decidedly the poorest of the fertilized plots at the moderately acid level and among the poorest the entire series.

According to a published report the early experiments at the Arlington Turf Garden indicated that ammonia nitrogen, particularly as it was supplied in sulfate of ammonia, resulted at first in the best grass and the greatest reduction in weeds and clover. After a few years, however, the grass on the plots fertilized with sulfate of ammonia became less vigorous. One of the possible explanations was that the soil had become too acid. On some of the plots in the final series, therefore, sulfate

of ammonia was applied in combination with other materials to reduce the resulting soil acidity.

When sulfate of ammonia was applied in combination with bonemeal the resulting soil acidity was pH 5.7 which placed the plot in the moderately acid group. This combination added 16.2 pounds of phosphoric acid to 1,000 square feet as well as 6 pounds of nitrogen and produced the best turf in the entire series. When lime was applied along with the sulfate of ammonia the soil reaction was changed to pH 7.1 or slight alkalinity. While in 1939 the turf on this plot was better than on the plot receiving sulfate of ammonia alone, it was not so good as on most of the moderately acid plots.

Response to Phosphorus

The tables on pages 200 and 204 show that at the Arlington Turf Garden a soil acidity between pH 4.5 and 6.0 has been associated on the average with the best bent grass, regardless of whether the plots received nitrogen alone or phosphoric acid and potash in addition to the nitrogen. To illustrate the response of the bents to phosphoric acid and potash at this acidity level the improvement on the plots fertilized with various inorganic and organic materials is compared in the table on page 207 with that on the plots fertilized with nitrogen alone in the form of ammonium nitrate. The ammonium nitrate plot is used as the standard of comparison since it is the only plot at the moderately acid level of soil acidity which has received inorganic nitrogen alone. In the last two columns the increase or decrease in improvement in density and color of the grass on the various plots over that on the ammonium nitrate plot is indicated. As all of the plots received nitrogen at the same rate, this increase or decrease in improvement

COMPARISON OF IMPROVEMENT OF GRASS ON MODERATELY ACID PLOTS WHICH RECEIVED PHOSPHORIC ACID AND POTASH IN ADDITION TO NITROGEN WITH THE IMPROVEMENT SHOWN ON PLOTS AT CORRESPONDING ACIDITIES WHICH RECEIVED NITROGEN ALONE FROM AMMONIUM NITRATE. THE ANNUAL RATES OF APPLICATION OF PHOSPHORIC ACID AND POTASH ARE INCLUDED. ALL PLOTS RECEIVED NITROGEN AT THE RATE OF 6 POUNDS TO 1,000 SQUARE FEET.

Fertilizer	Annual rates of application of nutrients in pounds to 1,000 square feet		Percentage of Improvement over unfertilized plots		Increase or decrease in improvement over that on ammonium nitrate plot	
	P_2O_5	K_2O	Density	Color	Density	Color
Ammonium nitrate	0	0	18.4	21.4	....	....
Sulfate of ammonia and bonemeal	16.2	0	34.7	42.9	16.3	21.5
Sulfate of ammonia, bonemeal and muriate of potash	16.2	6.0	31.6	38.1	13.2	16.7
Ammonium phosphate and urea	6.0	0	23.8	31.7	5.4	10.3
Ammonium phosphate, urea and potassium nitrate	6.0	6.0	21.5	30.2	3.1	8.8
Urea	0	0	22.3	25.4	3.9	4.0
Urea and potassium nitrate	0	6.0	15.3	25.4	−3.1	4.0
Cottonseed meal	2.1	1.7	21.8	22.7	3.4	1.3
Activated sludge	2.4	0.5	20.7	21.4	2.3	0
Poultry manure	2.6	1.2	14.6	23.0	−3.8	1.6

over that on the ammonium nitrate plot may be considered as being due in a large measure to the other nutrients added.

No separate readings have been made as yet on the relative amounts of the different bents on each plot. From general observations, however, it appears that velvet bent has been encouraged on the plot receiving the sulfate of ammonia and bonemeal mixture, and on the one receiving a similar mixture plus muriate of potash. The higher percentage of velvet bent

on these plots may account in part for their density ratings, the highest on the entire series.

The ammonium phosphate and urea plot received phosphoric acid in addition to nitrogen and showed a significant increase in improvement over that on the ammonium nitrate plot which received only inorganic nitrogen. The sulfate of ammonia and bonemeal plot received calcium as well as phosphoric acid and nitrogen and showed a striking increase in improvement of both density and color of the grass. During the summer of 1939 this was the best plot in the entire series. The figures given in the table on page 207 indicate that on plots which have received fertilizers producing moderate soil acidity the addition of phosphoric acid has resulted in some improvement. This improvement apparently has been increased when calcium also was added.

In the organic materials such as cottonseed meal, activated sludge and poultry manure, phosphoric acid was applied at rates varying from 2.1 to 2.6 pounds to 1,000 square feet. These plots were not so good as the urea plot, which received organic nitrogen alone. It will be noted in the table on page 200 that the activated sludge and poultry manure plots were not initiated until 1929.

The grass on the ammonium phosphate plot which received phosphoric acid at the annual rate of 25.6 pounds to 1,000 square feet was unquestionably poorer than that on any of the others, either fertilized or unfertilized. The soil on this plot was very acid but no more so than was the soil on the sulfate of ammonia plot; yet the grass on the sulfate of ammonia plot was somewhat better than that on the check plots and decidedlly better than that on the ammonium phosphate plot.

The injurious effect exhibited on the ammonium phosphate

plot may be associated with the fact that phosphoric acid in the soil solution unites with salts of calcium, iron, and aluminum to form more or less insoluble phosphates. The more alkaline the soil the less available is the calcium phosphate. On the other hand, the iron and aluminum phosphates are least soluble in the most acid soils. In acid soils, therefore, the phosphorus tends to remove from the soil solution the iron which would otherwise be soluble and available for use by the grass. Plants, like animals, must have small amounts of iron for normal development. Therefore the removal of the iron from the soil solution as insoluble iron phosphate may account at least in part for the yellowish color and otherwise poor condition of the grass on plots receiving excessive amounts of phosphorus from ammonium phosphate.

An application of a solution of iron sulfate to a portion of one of the ammonium phosphate plots temporarily improved the grass. This is evidence in favor of the view that the poor condition of the grass on the ammonium phosphate plot has been caused at least in part by the removal of iron from the soil solution.

Further evidence in favor of this view is found in the condition of the grass on the bonemeal plot. This plot had a soil acidity of pH 6.4 and received even more phosphoric acid each year than did the ammonium phosphate plot. In the table on page 201 it can be seen that the bonemeal showed the same percentage of improvement as was exhibited on the plot in the same soil acidity level which had received sulfate of ammonia and lime. Clover was encouraged, however, by the bonemeal. Apparently the application of phosphoric acid at annual rates as high as 32.5 pounds to 1,000 square feet is not associated with any particular injury to the grass when the

fertilizer results in a slightly acid or alkaline soil. In this slightly acid soil of pH 6.4 the iron would not have been removed from the soil solution since it is only in decidedly acid soils that the iron phosphate is practically insoluble.

Response to Potash

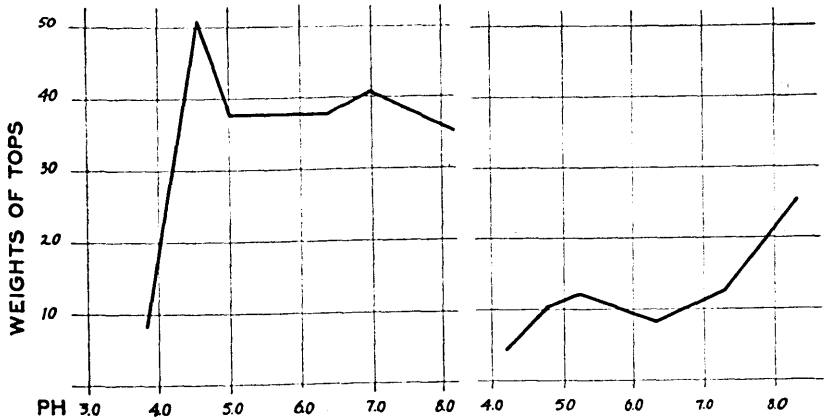
The effects of potash on the turf on the moderately acid plots are evidenced in the table on page 207. In this table there are three pairs of plots which indicate the effect of potash on the bents. The first pair of plots received sulfate of ammonia and bonemeal and one of them received muriate of potash as well. The plots received identical amounts of nitrogen and phosphoric acid and had essentially the same soil acidity; yet the plot which received the muriate of potash in amounts sufficient to supply 6 pounds of potash to 1,000 square feet has been slightly poorer in both density and color than the one which received no potash. In making this comparison it should be noted that these two plots belong to the oldest series. In the 18 years that these plots have been fertilized there has never been any potash added to the sulfate of ammonia and bonemeal plot and the clippings have been removed regularly. It should be noted also that, unlike most putting greens, these plots have received no topdressing of compost.

In a similar manner, the grass on the plot which received ammonium phosphate, urea and potassium nitrate has been poorer than the one which received ammonium phosphate and urea without the potash. The harmful effect of the potash has been more evident in the density of the grass than in the color.

Still another pair of plots can be compared. These are the urea plots which received no phosphorus. One plot received

urea alone and the other received potassium nitrate in addition to the urea. Here the apparently deleterious effect of the potash on the density has been evident although the color was equally good on both plots.

On the slightly acid or alkaline plots there is further evidence of the harmful effect of potash. In the table on page 201 the three urea plots in the slightly acid or alkaline group may be compared. All three plots received carbonates in



Weight in grams of tops (green weight) of Metropolitan creeping bent grown in soils adjusted to different pH values. Graph on left—grass grown in compost—showed most growth at pH 4.6; graph on right, grass grown in clay soil showed most growth at pH 8.3.

amounts equivalent to 23 pounds of calcium carbonate (lime) to 1,000 square feet. One received lime, a second magnesium carbonate, and a third, potassium carbonate in addition to urea. The soil pH produced on all three of the plots was between 7.3 and 7.5. By comparing the improvement over the check as shown in this table for each of these plots, it can be seen that the urea and lime and the urea and magnesium carbonate plots have been similar, the former showing slightly more improvement in density and the latter, slightly more in

color. On the contrary, the grass on the urea and potassium carbonate plot which received potash at the rate of 21.5 pounds to 1,000 square feet annually in addition to the 6-pound rate of nitrogen has been the poorest plot at this soil acidity level. It was 11.8 percent poorer than the check plot in density and 3.2 percent poorer in color.

The effect of potassium carbonate on the density and on the clover control may be associated with the fact that the applications of the potassium carbonate burn the bents. This burn, recurring every month, may not only have retarded the growth of the grass but have permitted the clover to come in.

Summary and Conclusions

Data presented in this article show that in any discussion on the response of the creeping bents to fertilizers the question of the change in acidity which they produce in the soil must be considered.

The grass has been in best condition on those plots ranging in soil acidity from pH 4.5 to 6.0. On the most acid plots with a soil acidity of about pH 4.2 the grass has been decidedly poorer than on those with an acidity of above pH 6.0, although on the most acid plots there has been best control of clover.

Regardless of the final soil acidity, the bents have responded favorably to fertilizers carrying nitrogen alone at an annual rate of 6 pounds to 1,000 square feet, but the best response has been exhibited when the nitrogen carrier has maintained the soil acidity at about pH 5.5. Moreover, those plots which have not received nitrogen have invariably been among the poorest plots at the soil acidity level in which they occur. This is true even of the potassium phosphate plot, in spite of the fact that it received 6 pounds of phosphoric acid and 4 pounds of