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TURF CULTURE

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EXPERIMENTS WITH FERTILIZERS ON BLUEGRASS TURF

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One of the most common causes of poor turf is starvation. If grass is starved or if nutrients are applied in the wrong proportion or at the wrong time, weeds may overpower or even kill the grass. On the other hand, if grass is properly fed it usually will crowd out most turf weeds and will do surprisingly well on unpromising soil. The question of whether grass or some other plant shall occupy a given area is largely one of competition between plant species. Survival in this competitive struggle depends largely upon food supply, other conditions being equal.

While no exact figures are available it is safe to say that millions of pounds of fertilizers are used every year on the turf of fairways, parks, cemeteries and lawns. Much of this is effective, some is harmful and too large a proportion of it is just wasted. The kind and quantities of fertilizer to use as well as the best time of application, therefore, become matters of great importance in turf maintenance.

Since Kentucky bluegrass is the most common grass used for turf purposes in this country, the majority of the Green Sec-

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tion's experiments with fertilizers have been conducted on turf in which Kentucky bluegrass predominated. The results from various series of fertilizer experiments conducted in other sections of the country as well as numerous field observations indicate that the response of different turf grasses such as other species of bluegrass, the fescues, Bermuda grass and carpet grass is comparable to that of Kentucky bluegrass.

Needs of Grass and Cultivated Crops Differ

Grass for turf differs from the cultivated farm crops in its fertilizer requirements chiefly because of the special need on the part of the growing grass for an abundant and readily available supply of nitrogen for the rapid production of leaves. As compared with many crop plants, the much more shallow root system of most closely cut grasses makes it impossible for them to forage deep for nutrients.

In growing cultivated crops the soil is plowed and worked. Fertilizers are frequently worked or drilled into the soil. Under turf conditions the soil cannot be worked, so the applications of fertilizer are necessarily made at the surface.

A similar problem has been met in the case of grass on permanent pastures. The problems of pastures and turf differ, however, in certain ways. On a good pasture the flush of growth is in the early spring. Growth and production later decline, and during the heat of summer the grass is nearly or quite dormant. During that period livestock may be maintained on emergency pastures or be given additional grain feed. Grass for turf, however, must be kept in as good a condition as possible throughout the entire season.

The expense of feeding pasture grasses with large amounts of nitrogen would in most cases be prohibitive, and recourse is had to encouraging an abundance of white clover (*Trifolium repens*). Clover is itself a valuable pasture plant, being high in protein and mineral content. Moreover, like other leguminous plants, it is able to use nitrogen from the air because of the bacteria in the root nodules which fix atmospheric nitrogen in a form available to plants. When roots or tops of clover or both are decayed in the ground they enrich the soil in nitrogen and thereby stimulate the growth of grass and other pasture plants.

In fertilizing pastures, therefore, much of the supply of nitrogen usually is furnished by encouraging white clover, and the fertilizing program usually is planned so as to maintain a good stand of this legume. Where this plant is not objectionable in turf, such as in some lawns and parks, white clover may well be encouraged. However, in most turf used for recreational purposes, as well as in many lawn and park areas, white clover is decidedly objectionable. In these cases a liberal use of nitrogen will usually discourage clover and produce the desired quality of turf.

Soil and Turf Under Test

The experiments, results of which are summarized in this article, were conducted at the Arlington Experiment Farm (across the Potomac River from Washington) and on the fairways of the Capital Golf and Country Club (formerly Bannockburn), Glen Echo, Md. The soil at the Capital course is a poor clay loam of the Louisa series; that at Arlington Farm is a silt loam. The soil at the Capital course was approximately neutral in reaction, having been limed some years before the experiments were started; that at the Arlington Farm was distinctly acid. Both soils were deficient in available phosphoric acid, tests showing from 5 to 10 parts per million (p.p.m.) at the Capital course and 10 to 15 p.p.m. at the Arlington Farm, by the LaMotte-Truog method, as compared with the 40 to 50 p.p.m. usually considered sufficient on these types of soil. They were, therefore, of neutral or acid reaction and of low fertility. The topography of the areas at the Capital course varied from nearly level to rolling, with some steep slopes; that at the Arlington Farm was nearly level.

On such soils the turf was naturally thin. It had not been fertilized for many years and consisted of a sprinkling of Kentucky bluegrass, a little redtop and white clover, with a large amount of buckhorn plantain (*Plantago lanceolata*), crabgrass (*Digitaria ischaemum* and *D. sanguinalis*), some dandelions (*Taraxacum officinale*) and other weeds. At the Capital course much red fescue and some bent grass was scattered in the turf.

Kind of Fertilizer Used

The three fertilizer elements, nitrogen, phosphorus and potassium, were applied alone and in various combinations with and without lime. Several different materials supplying nitrogen and phosphorus were used. The complete fertilizers were made up in several different formulas.

Nitrogen is the nutrient most frequently deficient and the one needed in greatest abundance for the vigorous growth of grass for turf. Therefore, the rates of application of the complete fertilizers were based on the amounts of nitrogen applied.

In order to simplify the comparison of the results with different rates of application, the fertilizers are described on the basis of the pounds of nitrogen applied to 1,000 square feet. Ten pounds of a 10-6-4, or 8 1/3 pounds of a 12-6-4, or 16 2/3 pounds of a 6-12-4 are required to give a rate of 1 pound of nitrogen to 1,000 square feet.

All fertilizers were broadcast and were not watered in. The turf was not watered during the experiments. The plots differed in area and arrangement, but in all cases an unfertilized check plot adjoined every fertilized plot.

Response to Fertilizers

The response of the thin turf to fertilizers was striking. On one series at the Capital course to which complete fertilizer had been applied at different rates, a poor thin turf was transformed in 2 years into a good turf without the use of seed, watering or mechanical working. With an adequate quantity of fertilizer on these plots the number of Kentucky bluegrass shoots to a square foot increased about 1,000 per cent over the number on the unfertilized check plots.

Similar results with a complete fertilizer were secured on a series of plots at Arlington Farm. Careful estimates of the percentage of grass 5 years after the first application showed that on the fertilized plots there was over four times as much grass as on the checks. Not only did the application of fertilizers thicken the turf but it also helped in weed control.

It is well known that nitrogen stimulates growth, produces a dark color and is generally favorable to vegetative activity. An excess of nitrogen may delay flowering and fruiting. Phosphorus also stimulates growth, tends to make a sturdier plant and encourages such maturation processes as seed production. Potassium is less specific in its function, serving in a general way to accelerate such vital processes as respiration and the manufacture of carbohydrates in the leaves.

On some plots in these experiments, fertilizers containing

General view of fairway fertilizer plots at the Capital Golf and Country Club 4 months after the first application was made in October, 1931. The light strips received no fertilizer; the dark strips from left to right received one application of complete fertilizer at rates of 1, 2, 4 and 8 pounds of nitrogen to 1,000 square feet, respectively. The left half of each dark strip received inorganic fertilizer and the right half, organic fertilizer at the same rate and time. The dark color indicates turf with good color and density.

only one of each of the important plant nutrients were applied. Therefore it is possible from this series of experiments to compare the results obtained from the use of any one element alone with those secured when that element was applied in combination with any one or all of the other elements.

Figures for the percentage of turf grasses, crabgrass and clover present in 1939 on some of the plots in this series at Arlington are given in the table on page 159. Except for insignificant variations, these figures are typical of the conditions during the past 3 years. Weeds such as selfheal (*Prunella vulgaris*), dandelion, buckhorn plantain and chickweed (*Stellaria* spp.) were present in varying amounts, but the percentages of

Soil Acidity, Percentage of Major Species Present and Per Cent Density of Total Vegetation on Some of the Kentucky Bluegrass Plots at Arlington Farm Which Have Received Various Combinations of Nitrogen (N), Phosphorus (P), Potassium (K), and Lime (L) from 1934 to 1939. The Results Given are Taken from Ratings Recorded in October, 1939. Inorganic Fertilizers Were Used Except in the One Case Indicated. The Annual Applications Were 2.5 Pounds of Nitrogen, 2.5 Pounds of Phosphoric Acid, 1.1 Pounds of Potash and 23 Pounds of Ground Limestone to 1,000 Square Feet.

Materials applied	Acidity in pH	Percentage of major species present: Turf grasses	Crabgrass	Clover	Percent density of total vegetation
NP	4.2	70	27	Trace	80
NPL	5.2	67	1	32	95
NPKL	5.3	65	2	33	95
NPK Organic	4.9	31	3	61	80
N	4.2	29	64	Trace	70
NPK	4.3	25	65	Trace	80
NKL	5.2	24	38	32	85
NK	4.3	20	73	Trace	75
NL	5.9	14	10	71	85
None	5.0	15	25	35	60

each are not included. The density of the total vegetation is given in percent, 100 percent representing the density of ideal Kentucky bluegrass turf.

Nitrogen

In past experiments several kinds of inorganic and organic fertilizers containing nitrogen only were used. In general there was little apparent difference in the response of Kentucky bluegrass to nitrogen in these various forms. In the experiments reported here, sulfate of ammonia, cyanamide and a mixture of sulfate of ammonia and nitrate of soda were used. The annual rates of application were 0.5, 1, 2, 2.5, 4, 8 and 9 pounds of nitrogen to 1,000 square feet.

The tests on the Capital course have been more extensive than those at Arlington Farm. On these fairways the lighter rates of application increased the vigor of the crabgrass, but produced only a slightly darker color in the turf grasses without increasing the stand materially. The 8- and 9-pound applications were made only once. At the end of a 2-year period they had caused a decided reduction in buckhorn plantain. However, while there was no increase in turf grasses, there was a great increase in the amount of crabgrass. On this neutral soil similar results were obtained with sulfate of ammonia, cyanamide, a mixture of sulfate of ammonia and nitrate of soda, and sulfate of ammonia and ground limestone. In the case of this last combination, an interval of at least 3 weeks elapsed between the applications of the two materials. The turf produced by fertilizers containing nitrogen alone was decidedly inferior to that produced by fertilizers containing nitrogen, phosphorus and potassium.

At Arlington Farm the use of nitrogen at the annual rate of 2.5 pounds to 1,000 square feet in two applications has greatly reduced the number of plants of buckhorn plantain and self-heal. The condition of the turf, however, has been erratic from year to year, but usually it has been partially infested with crabgrass each summer. Frequently these plots receiving nitrogen alone have been as good as, or even better than, the plots receiving complete fertilizer containing nitrogen, phosphorus and potassium. However, the plots receiving nitrogen alone have had a far more open turf and more crabgrass than the plots receiving a complete fertilizer plus lime. These results are listed in the table on page 159.

Nitrogen plus calcium, applied as ground limestone at the annual rate of 1,000 pounds to the acre, produced little effect the first year, as can be seen in the table on page 165. Since that time the condition of the turf has been erratic. Some years the turf on plots receiving nitrogen plus lime was superior to that on the nitrogen plots, but other years the nitrogen alone has produced the better turf.

Potassium

The application of potassium as muriate of potash alone or combined with calcium as ground limestone has produced no improvement in the composition of the turf. It should be stated, however, that these soils have had a sufficient reserve of potassium. This is also true of many other soils where turf is grown.

Nitrogen and Potassium

The plots supplied with both nitrogen and potassium received muriate of potash at the annual rate of 1.1 pound of K_2O to 1,000 square feet. The addition of the potassium did not improve the turf the first year, but since that time and until 1939 there has been a slight improvement over the plots receiving nitrogen alone. However, the data for the past season has shown the plots receiving nitrogen alone to be somewhat superior. The nitrogen-potassium plots have usually been overrun with crabgrass each summer, and half of the time they have had an even higher percentage of crabgrass than the plots receiving nitrogen alone.

During the first few years the plots receiving nitrogen and potassium plus ground limestone at the annual rate of 1,000 pounds to the acre were superior to those receiving the nitrogen and potassium alone. Since that time the effects have been reversed, so that now the nitrogen-potassium plots are somewhat superior to the plots receiving these two elements plus calcium, in that they have nearly as much turf grass and far less clover. The nitrogen-potassium-calcium plots were superior at the end of the first year to the plots which had received nitrogen alone, but this effect has been lost gradually. Although the total vegetation was denser on the plots receiving nitrogen, potassium and calcium during 1939, they had less turf grass and more weeds than the plots receiving nitrogen alone.

Phosphorus

On the experimental areas at both the Arlington Farm and the Capital course the available phosphoric acid was low. Unfertilized soil at Arlington gave readings of phosphoric acid of 10 to 20 p.p.m. when the surface inch samples were tested by the LaMotte-Truog method. Similar samples of unfertilized soils taken from the fairways on the Capital course gave readings of 5 to 10 p.p.m.

Where phosphorus was applied as superphosphate to either area, the turf has shown little response. There has been a slight increase in the growth of white clover, black medic (*Medicago lupulina*) and lespedeza (*Lespedeza striata*), but little immediate improvement in the grass. When lime was added in combination with phosphate there has been a decided increase in the growth of white clover, which in turn has slowly resulted in an increase in the growth of grass.

Phosphorus and Potassium

Where potassium was added with the phosphorus there has been a somewhat greater stimulation of white clover, lespedeza and black medic than when either element was applied alone. There has been practically no immediate response from the

The response of Kentucky bluegrass turf to one application of complete fertilizer at the rate of 4 pounds of nitrogen to 1,000 square feet. The light areas represent unfertilized turf. The dark area in the center represents good turf on the fertilized area. Left half of dark area was fertilized with organic and right half with inorganic fertilizer. The picture was taken 4 months after the fertilizer was applied in October, 1931.

grass but in the course of 2 or 3 years there has been a little stimulation of the turf grasses possibly caused by the nitrogen which was added by the legumes. The addition of lime to the combination of phosphorus and potassium has further increased the growth of clover and other legumes which in turn has slowly resulted in an increase in the growth of the turf grass.

Nitrogen and Phosphorus

In these experiments phosphorus was supplied in several different materials; bonemeal, superphosphate, Ammophos, and activated sewage sludge. Since a definite amount of nitrogen as well as phosphorus was specified for each plot in this series and since some of the sources of phosphorus also carried nitroen it was not always possible to apply the desired amount of phosphoric acid by the use of a single material without interfering with the prescribed rate of nitrogen. In such cases the chief material was supplemented by small amounts of other materials. The annual rates of application of phosphoric acid varied from 0.5 to 2.5 pounds to 1,000 square feet.

Only a moderate response from bluegrass has been noted when nitrogen was applied at the lower rate of application. However a decided improvement has been observed when phosphorus was included. Plots at Arlington which received both nitrogen and phosphoric acid at the annual rate of 2.5 pounds of each to 1,000 square feet have had a denser turf, greater abundance of bluegrass, less crabgrass and other weeds than plots receiving nitrogen alone, nitrogen-calcium, nitrogen-potassium, or nitrogen-potassium-calcium. The nitrogen-phosphorus plots have been far superior to the plots receiving complete inorganic fertilizers, showing a greater abundance of turf grasses and less crabgrass. They have had more crabgrass, however, than have the plots receiving complete organic fertilizer.

The addition of calcium together with nitrogen and phosphorus produced a much denser turf with less crabgrass than when nitrogen and phosphorus only were applied. There has been a great increase in white clover, but in spite of this increase there actually has been more grass and a denser turf. For the first few years these plots were about on a par with those receiving complete inorganic fertilizer plus lime, but since then they have been superior, having less clover and crabgrass.

Abundance of Turf Grasses on Some of the Kentucky Bluegrass Plots at Arlington Farm to Which Various Combinations of Nitrogen (N), Phosphorus (P), Potassium (K), and Lime (L), Were Applied. Figures Are Given for October, 1934, at the End of the First Season, and for October, 1939, at the End of the Fifth Season. Inorganic Fertilizers Were Used Except in the One Case Indicated. The Annual Applications Were 2.5 Pounds of Nitrogen, 2.5 Pounds of Phosphoric Acid, 1.1 Pounds of Potash and 23 Pounds of Ground Limestone to 1,000 Square Feet.

Materials applied	Percentage of turf grasses	
	October, 1934	October, 1939
NP	25	70
NPL	45	67
NPKL	55	65
NPK (organic)	20	31
N	20	29
NPK	17	25
NKL	40	24
NK	15	20
NL	20	14
None	15	15

From the results given in the table on page 159 it is apparent that on this soil nitrogen and phosphorus have produced a turf which has been more free from crabgrass and which has a much greater abundance of turf grasses than when potassium was included. This has been true whether or not calcium was supplied, although the addition of calcium has greatly decreased this difference. Evidently the calcium has overcome some of the apparently detrimental effects of the potassium.

The table on this page gives the percentage of turf grass at the end of the first year and at the end of a 5-year period in a series of plots at Arlington Farm. It will be noted that the check plots remained in about the same condition, having the same percentage of grass at the end of the 5-year period as at the end of the first year. The plots receiving lime showed the greatest increase in turf grasses at the end of one year. This improvement, however, continued only on the plots receiving both nitrogen and phosphorus in addition to lime. At the end of the 5-year period the plots showing most marked improvement had received both nitrogen and phosphorus.

Nitrogen, Phosphorus and Potassium

In the production of most farm crops a complete fertilizer containing nitrogen, phosphorus and potassium generally has been used. These three elements are among those essential for normal plant development from germination through seed production. Grass maintained in turf is grown by highly artificial means to prolong the vegetative condition and so does not necessarily need all of these nutrients in the same proportions as do plants grown to maturity under normal conditions. In spite of the difference in nutrient requirements of crop and turf plants, many individuals have recommended the same type of fertilizers for both.

Observations on many golf courses in the past few years have indicated that where a sufficient supply of any one of the essential nutrients is available for the vigorous growth of plants further additions may not only be wasteful but actually detrimental to the turf. The results on the experimental plots at the Capital course and at Arlington have given further support to these observations.

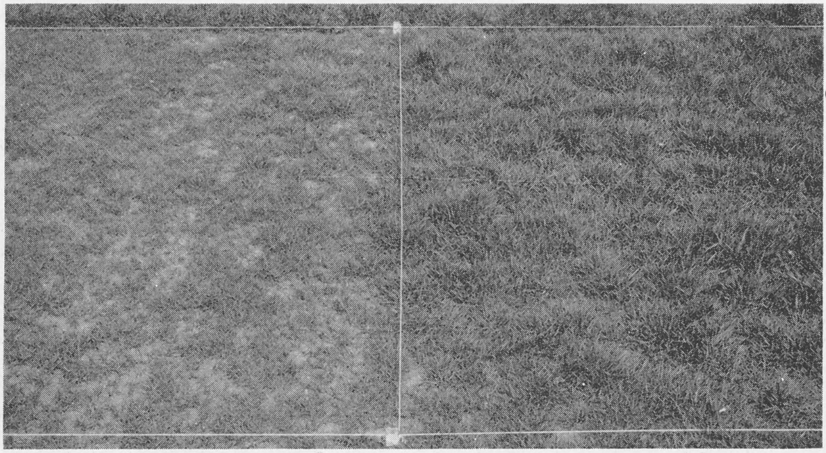
Complete fertilizers of such diverse formulas as 12-6-4, 6-12-4, 4-12-4, 9-9-4, 6-3-2, and 6-24-2 have been used. The 6-24-2 was used in the inorganic form only, while the others were used in both the inorganic and organic forms.

At the Capital course the turf on the plots receiving complete fertilizers has been far superior to that on the plots where nitrogen alone was used. The turf has not only been denser but there has been a greater increase in turf grasses and a corresponding reduction in crabgrass and weeds on the former than on the latter plots. There has been little apparent difference between the plots receiving the same amounts of nitrogen in the various complete fertilizers, except that the high phosphate mixtures have tended to produce more white clover.

At Arlington, where the soil was more acid, a marked response has resulted during the first 2 years from applications of complete fertilizers. Since that time, however, some of the plots receiving complete fertilizer have become badly overrun with crabgrass and during 1939 they were inferior to the plots receiving nitrogen only as well as to those receiving nitrogen and phosphorus. The plots receiving complete inorganic fertilizers have been superior to those receiving complete organic fertilizers but here the striking difference has been in the greater reduction in clover and chickweed following the application of the inorganic fertilizers. The complete fertilizer which contained phosphoric acid in amounts several times greater than the nitrogen has tended to produce some yellowing of the Kentucky bluegrass.

Where calcium was applied in addition to the complete inorganic fertilizer at Arlington there has been a striking increase in the density of the turf, an increase in clover and a reduction in crabgrass and other weeds. Even in cases where clover is objectionable, the increase in density and abundance of turf grasses and reduction of crabgrass has more than compensated for the increase in clover and has made the turf on these plots far superior to that on plots receiving complete fertilizers without lime. This turf has also been superior to that on plots receiving nitrogen-phosphorus in that it has been much denser and has had less crabgrass.

The plots receiving inorganic complete fertilizers plus lime have had about as much crabgrass in 1939 as the plots receiving organic complete fertilizers without lime but have had decidedly less clover and chickweed. Most of the phosphorus on



Results obtained from the application of fertilizer before seeding. Plot on left not fertilized; plot on right fertilized with bonemeal previous to seeding to Kentucky bluegrass and redtop. This picture, taken in April following seeding the fall before, shows the quicker production of good turf on the plot which was fertilized before seeding.

the organic fertilizer plots was supplied in the form of bonemeal. The bonemeal contained enough calcium to prevent any appreciable change in soil acidity. The organic fertilizer plots were slightly more acid than the limed inorganic fertilizer plots yet had much more clover than any of the inorganic plots with comparable acidity.

The results from applications of the various complete fertilizers of different formulas were compared when applied at comparable rates of nitrogen. Naturally some mixtures supplied more phosphoric acid than did others. As these soils were extremely low in available phosphoric acid, the fertilizers that supplied a much greater quantity of phosphoric acid produced the best turf the first year. However there was little difference in the quality of turf afterward. After several years the plots which received the most phosphorus had somewhat more clover.

The fertilizers with the higher proportions of nitrogen, such as a 12-6-4, produced the same quality of turf with smaller amounts of fertilizer than did those like the 6-12-4, which contained lower proportions of nitrogen. When the fertilizers were applied on a nitrogen basis the additional phosphoric acid and potash supplied by such grades as the 4-12-4 or the 6-12-4 were apparently of little value and not worth the extra cost.

The inorganic fertilizers with the highest percentage of nitrogen had a greater tendency to burn than did those with less nitrogen.

Lime

The figures in the table on page 165 indicate that on the acid soil at Arlington the use of lime at the rate of 1,000 pounds to an acre in addition to the application of any of the fertilizer combinations except that of nitrogen alone had produced by the end of the first year a striking increase in the abundance of turf grasses over the amount present on the plots receiving the respective combinations without lime. The figures in the table show that continued use of lime in combination with inorganic complete fertilizers or with the nitrogen-phosphorus mixtures has further increased the abundance of turf grasses during the 5 succeeding years. The original stand of clover has been maintained on these plots but the density of the total vegetation has been greatly increased.

Where lime was not applied to the plots receiving complete inorganic fertilizers the clover has been eliminated but the crabgrass has been increased decidedly at the expense of the turf grasses. These results together with those on plots receiving lime in addition to the nitrogen-potassium mixture indicate that the presence of lime may have overcome in part the apparently detrimental effect of the potassium.

Likewise where lime was not applied to the plots which had received the nitrogen-phosphorus mixture, the clover has been eliminated. However, the density of the total vegetation has not been increased nor the crabgrass reduced so markedly as when lime was present in addition to nitrogen and phosphorus.

The continued use of lime on plots which had not received phosphorus has been accompanied by a gradual increase either in the amount of clover or of crabgrass at the expense of the turf grasses, so that, at the end of 5 years, there is now a smaller percentage of turf grasses on these plots than at the end of the first year.

The amount of lime used on the fertilizer plots has had little effect on the reaction of the soil. No plot in this series was made more alkaline than the pH 5.9 of the nitrogen-lime plot. While both the nitrogen-phosphorus-lime plot and the complete fertilizer-lime plot produced excellent turf, the best in the series, the soil was made only slightly less acid than the checks and was far below the neutral point of pH 7.0. Thus it appears that a neutral soil is not necessary for a good bluegrass turf, but that a satisfactory turf can be produced on an acid soil with proper fertilization. This is of particular interest to those who desire a good turf with a minimum of clover,

CONDITION OF THE TURF ON THE FERTILIZED PLOTS AT THE CAPITAL COURSE IN OCTOBER AND DECEMBER, 1932 AND OCTOBER, 1933, FOLLOWING APPLICATIONS MADE IN THE FALL OF 1931, THE FALL OF 1932 AND THE SPRING OF 1933. THE PERCENTAGE OF IMPROVEMENT OVER THE CHECK AND THE PERCENTAGE OF TURF GRASS ON EACH OF THE PLOTS IS GIVEN. THE CHECK PLOTS WERE CONSISTENTLY RATED AT 2 ON THE BASIS OF 10 AS REPRESENTING IDEAL BLUEGRASS TURF. THE RATE OF APPLICATION OF FERTILIZER IS GIVEN IN POUNDS OF NITROGEN TO 1,000 SQUARE FEET.

Kind of Fertilizer	Rate of application (Pounds of N to 1,000 square feet)	Percentage of improvement over unfertilized plots			Percentage of grass cover	
		October, 1932	December, 1932	October, 1933	December, 1932	October, 1933
Checks	0	—	—	—	60	50
Inorganic	1	150	250	300	82	86
Organic	1	0	200	300	80	86
Inorganic	2	200	400	300	94	85
Organic	2	150	200	300	80	88
Inorganic	4	300	400	0	95	50
Organic	4	300	400	−50	93	35
Inorganic	8	150	200	—	80	0
Organic	8	300	400	—	91	0

for it will be noted in the table on page 159 that when inorganic fertilizers were used the less acid the soil the more clover was present in the turf.

EXPERIMENTS ON RATES OF APPLICATION

The purpose of some of the experiments at the Capital course was to find out how much fertilizer should be used on a thin turf to bring it quickly into good condition and to determine how heavy an application the bluegrass would tolerate. The complete 6-12-4 fertilizer was applied at different rates, 700, 1,400, 2,800, and 5,600 pounds to the acre. These applications supplied approximately 1, 2, 4 and 8 pounds of nitrogen and twice that amount of phosphoric acid to 1,000 square feet. The lowest rate, therefore, was equivalent in nitrogen content to a little less than 5 pounds of sulfate of ammonia to 1,000 square feet, the highest to the extremely heavy rate of about 38 pounds.

The fertilizer was applied both in organic and in inorganic forms at each rate. The first application was made October 21, 1931. A second application was made in the fall of 1932 and a third in the spring of 1933.

The excellence of the turf was rated on the basis of a possible maximum of 10 representing ideal bluegrass turf. The increase in rating of the fertilized plots over that on the unfertilized check plots has been expressed as percentage of improvement. This percentage of improvement over the check plots should not be confused with the percentage of turf grasses present on the plots.

One Pound of Nitrogen

On this extremely thin turf, applications of fertilizer at the rate of 1 pound of nitrogen to 1,000 square feet produced no improvement during the first winter. During the following summer, however, improvement became evident on the plots that had received inorganic fertilizer at this rate. From the figures in the table on page 171 it can be seen that in October, 1932, the turf on the inorganic plots showed an improvement of 150 percent over that on the checks. The fall application increased the improvement to 250 percent by December, 1932. By October, 1933, following one more application in the spring of 1933, the percentage of improvement had been increased to 300 percent.

The plots receiving one application of organic fertilizer in the fall of 1931 showed no apparent improvement in the turf by the end of the crabgrass season. By December, 1932, after the bluegrass had made its fall growth and recovered from the crabgrass invasion, the application in that fall had produced an improvement of 200 percent. The application in the spring of 1933 increased this improvement to 300 percent which was equal to that of the turf on the inorganic plots.

Two Pounds of Nitrogen

The application of 6-12-4 inorganic fertilizer at the rate of 2 pounds of nitrogen to 1,000 square feet caused some burn as would be expected since the nitrogen applied was equal to nearly 10 pounds of sulfate of ammonia to 1,000 square feet. The grass quickly recovered, however, and made marked improvement during the winter. By spring the turf was in good condition and made further improvement during the summer of 1932. A reduction in the percentage of clover was also noted. In December, 1932, after the fall application, the turf on these plots showed an improvement of 400 percent with 94 percent of the area covered with turf grasses. As may be seen in the table, the percentage of improvement due to inorganic fertilizers dropped during the following season so that by October, 1933, these same plots showed an improvement of 300 percent with a grass cover of 85 percent.

The turf on the plots that received organic fertilizer at this rate showed some improvement by the end of the summer of 1932 but no clover control. The application in the fall of 1932 increased this improvement by December, 1932, to 200 percent. This is just half the improvement which was shown at that time on the inorganic plots which had received fertilizer at the same rate. By October, 1933, however, after an additional application of fertilizer in the spring at the same rate the improvement on the organic plots had increased to 300 percent which was the same as that shown on the inorganic plots at that time. The percentage of grass cover on the organic plots had also increased from 80 in December, 1932, to 88 percent in October, 1933.

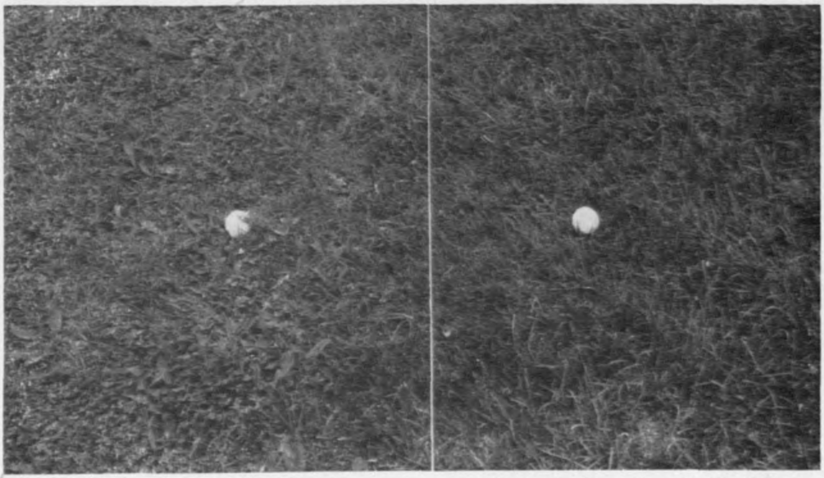
At the end of a year, after two applications, the turf on the plots fertilized at the 2-pound rate was superior to that which had received 1 pound of nitrogen. After the third application the turf on the two plots was in the same condition.

Four and Eight Pounds of Nitrogen

A 6-12-4 inorganic fertilizer used at the rate of approximately 4 pounds to 1,000 square feet, although put on in two equal applications, caused considerable burn but the grass recovered. The organic fertilizer did not burn. By March, 1932, the grass on the inorganic plots had recovered completely and was making vigorous growth. The organic fertilizer applied at this rate also stimulated the grass but not so much as did the inorganic. The inorganic plots also showed more clover and plantain control than did the organic plots.

The applications were repeated in the fall of 1932 and by December of that year the turf on both the inorganic and the organic plots was considered to be nearly perfect. As shown in the table on page 171, the improvement on both the inorganic and the organic plots was 400 percent, and the percentage of grass cover was estimated at 95 and 93 percent, respectively. As in the previous year, the inorganic plots showed better clover and plantain control than did the organic plots.

The application in the spring of 1933 resulted in a decided deterioration of the turf because of the heavy invasion of crabgrass during the following summer. The weather conditions during that summer were particularly favorable for the growth of crabgrass, so that after the crabgrass was dead in the late fall of 1933 the turf on the plots receiving inorganic fertilizer at the rate of 4 pounds of nitrogen to 1,000 square feet was



Reduction of weeds and increase in density of an established Kentucky bluegrass turf on a neutral soil, by the application of 6-12-4 inorganic fertilizer at the rate of 4 pounds of nitrogen to 1,000 square feet. Fertilizers were applied to the plot on the right in October, 1931; October, 1932; and March, 1933. The picture was taken in May, 1933. Note the abundance of buckhorn plantain and clover in the unfertilized plot on the left as compared with the dense, weed-free bluegrass turf on the fertilized plot on the right.

no better than that on the check plots. The turf on the organic plots was poorer than that on the unfertilized plots. These poor results in October, 1933, with both inorganic and organic fertilizers applied at the rate of 4 pounds of nitrogen may be compared to the 300 percent improvement shown on the plots which had been receiving the same fertilizers over the same period of time at the rate of 2 pounds of nitrogen.

Response of old established Kentucky bluegrass turf at the Capital Golf and Country Club to 12-6-4 inorganic fertilizer applied in October at the rate of 8 pounds of nitrogen to 1,000 square feet. Left, dense vigorous turf on fertilized area; right, thin, weedy turf on the unfertilized strip. The picture was taken 5½ months after the application of the fertilizer and before the first spring mowing of the fairway.

When applied at the rate of 8 pounds of nitrogen to 1,000 square feet, both the inorganic and the organic fertilizers were put on in two equal applications. Each application of the inorganic fertilizer at this rate burned the turf seriously. There was some recovery every year, but at the end of each season the turf was inferior to that which had received the same fertilizer at the 4-pound rate.

During the summer of 1933, after the final applications of fertilizer had been made, there was a very heavy infestation of crabgrass. This infestation was so severe that it entirely crowded out the bluegrass on the plots fertilized at the 8-pound rate.

During this favorable season for crabgrass the lower the fertilizer rate the less the bluegrass was injured by the crabgrass. This indicates that the excess fertility in the soil, over and above what the spring growth of bluegrass used, stimulated the excessive growth of crabgrass.

Two applications of inorganic fertilizer at the 4-pound rate of nitrogen produced no better results than the 2-pound rate. A third application at the 4-pound rate was harmful. Unlike the results with the inorganics, two applications of the organic fertilizer at the 4-pound rate of nitrogen did produce better results than the 2-pound rate. As was the case with inorganic fertilizer, a third application at the 4-pound rate was harmful. The use of 8 pounds of nitrogen in either inorganic or organic form resulted in a poorer stand of turf grasses and in a greater increase of crabgrass at the end of the first 2 years than did any of the other rates of application. The poorer condition of the turf grasses was apparently due to excessive stimulation of crabgrass.

Varying Rates of Application

In a later series of experiments the effects of a heavy initial application of fertilizer followed by smaller amounts annually were compared with those obtained from a light initial application followed by the same amount each year.

Where applications of a complete fertilizer containing 1 pound of inorganic nitrogen to 1,000 square feet were used for only 1 year the grass improved but the response was not sustained. The following year the turf reverted to its original condition. With a heavier initial fertilization at the rate of 4 pounds of organic or inorganic nitrogen to 1,000 square feet, response was much more marked. This improvement was maintained when this fertilization was followed by annual applications at the rate of 1 pound of nitrogen to 1,000 square feet. However, when the initial fertilization at the 1-pound rate was followed by annual applications at the same rate the turf produced after several years was as good as that on the plots to which fertilizer at the rate of 4 pounds of nitrogen were applied the first year, followed by annual applications at the 1-pound rate.

Light applications made year after year brought results but these were more quickly secured by a heavy initial fertilization followed by light applications to maintain the quality of the turf.

Rates of Application at Arlington

Similar results were obtained on some of the plots at the Arlington Farm. In some of the tests a 9-9-4 was used at the rate of 1,200 pounds to the acre, half being applied in the spring and half in the fall. This equals an annual application of nitrogen at the rate of 108 pounds to the acre, or nearly 2.5 pounds to 1,000 square feet.

The turf on plots treated with a mixture of organic and inorganic fertilizers at one-half the above rate was inferior to that where the full rate was used. The turf produced by this mixture applied at the full rate was not so good as that produced by inorganic fertilizers applied at the same rate.

Organic Compared with Inorganic Fertilizers

As already stated, at the Capital course the inorganic mixed fertilizers used at the rate of about 2 pounds of nitrogen to 1,000 square feet burned the grass; the organic fertilizers did not burn even when applied at the rate of nearly 4 pounds of nitrogen to 1,000 square feet in a single application. At the lower rates of application the results from organic fertilizers were inferior to those from inorganic fertilizers until the third application had been made. After three applications, however, the turf on the plots which had received organic fertilizers at the 1- and 2-pound rates was equal to that on the plots which had received inorganic fertilizer at the same rate. Even after 1 year the results obtained with the organic fertilizer at the 4-pound rate were equal to those obtained with the inorganic fertilizer at this rate.

In control of clover and plantain, however, the organic fell behind the inorganic fertilizer when both were applied at the 1- and 2-pound rates. When applied at the 4- and 8-pound rates both fertilizers produced the same control.

In the Arlington Farm experiments the organic fertilizers produced a fair response after 2 years but weeds later invaded these plots much more than the plots which received inorganic fertilizers. In June, 1939, weeds were more than five times as abundant on the plots which received 9-9-4 organic as on those which received 9-9-4 inorganic plus lime.

Organic Fertilizers and Soil Organic Matter

The claim has been made that organic fertilizers are desirable because they increase the organic matter of the soil.

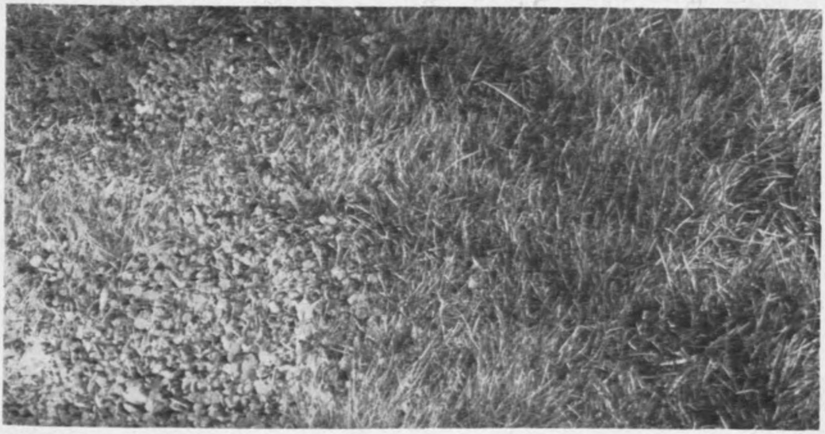
Bonemeal, which is an example of an organic fertilizer, contains approximately 75 percent of mineral compounds and 25 percent of organic matter. If bonemeal were applied at the rate of 1 ton to the acre it would, therefore, be supplying only 500 pounds of organic matter. It is estimated that an acre of soil to a depth of 6 inches weighs 2 million pounds, so an application of 1 ton of bonemeal to the acre would be equivalent to adding only one-half pound of organic matter to a ton of soil. Since the greater part of the organic matter is soon broken down and used by the plants or is leached out, this one-half pound of organic matter is reduced even further. The amount of organic matter added to the soil by a commercial organic fertilizer is too small to warrant consideration.

The most abundant source of organic matter in the soil is the vigorous root growth of well-fertilized grass. The use of any fertilizer that will stimulate root growth will result in an increase in the organic matter in the soil. This was confirmed by the experiments at the Capital course where both organic and inorganic fertilizers were used in large amounts. A study of the organic matter content of the plots made at the close of the experiment showed that on the plots receiving inorganic fertilizer the organic matter content had been increased by an average of 5.59 tons to the acre and on the plots receiving organic fertilizer by an average of 5.58 tons, almost exactly the same amount. The organic fertilizer did not of itself increase the organic matter in the soil but did so indirectly by stimulating root growth in exactly the same way and apparently to the same degree as was done by the inorganic fertilizer.

Lasting Effects of Fertilizers

The lasting effect of fertilizers can still be observed on the Capital course series of 1931. On these plots 6-12-4 fertilizers were applied at the annual rates of approximately 1, 2, 4 and 8 pounds of nitrogen to 1,000 square feet. Three applications were made, fall 1931 and 1932 and spring 1933. No fertilizers have been applied since.

The bluegrass on the areas which received fertilizer at the rate of 4 and 8 pounds of nitrogen was entirely killed by the heavy invasion of crabgrass during the 1933 season. These two areas were seeded to Kentucky bluegrass during the late



Comparison of response of Kentucky bluegrass turf to inorganic and organic fertilizers. This picture was taken 6 months after the first application of fertilizer was made in October, 1931, at the rate of 4 pounds of nitrogen to 1,000 square feet. The area on the left received organic fertilizer and that on the right, inorganic. The dense vigorous bluegrass on the right shows the quicker response obtained from the application of inorganic fertilizers than from the application of organic fertilizers at the same time and rate. Clover is conspicuous in the organic plot on the left and absent on the inorganic plot on the right.

winter of 1934. Only a fair stand was secured at that time but this rapidly improved and established a good turf.

Observations made in the fall of 1939 showed that the entire area still stands out from the surrounding poor unfertilized turf. Even where the lighter applications were made the grass is still better than the unfertilized turf after 6 years without additional fertilizer. The turf today is best on the areas which received the greatest quantities of fertilizer.

While buckhorn plantain is still the dominant plant on the surrounding area it is rare on the fertilized section. Contrary to what was true in December, 1933, crabgrass is not now so abundant on the more heavily fertilized areas as on those that received fertilizers at the rate of 2 pounds of nitrogen to 1,000 square feet. Apparently the good growth of bluegrass has helped to keep out the crabgrass.

All of the areas which received inorganic fertilizer are now somewhat better than those which received organic fertilizer. Contrary to general belief, the organic fertilizer in this case has not done better in the long run than the inorganic fertilizer.

Lines between the fertilized and check areas are no longer as sharp as shown in the illustration on page 158, for there is an irregular fringe of improved turf around each fertilized plot. When the fertilizers were applied, every precaution was taken to prevent any of the material from falling outside of the plots. Since the irregular border of improved turf is present on the up-hill side of the fertilized plots the improvement in this area must be due to clippings thrown up by the high-speed mowers, rather than to wash. This is further borne out by the fact that by far the most prominent borders extend in the same directions as the mowers are operated, while the borders in the opposite directions are negligible. It would seem, then, that at least part of the lasting effect of fertilizer is due to the release of nutrients during the decay of clippings returned to the soil.

Time to Apply Fertilizers

The time when fertilizers should be applied to bluegrass turf is of especial importance in sections where summer annual weeds, as crabgrass, are prevalent. If applied at the wrong time the fertilizer may merely stimulate the annual weeds and because of the severe competition they offer, the stand of Kentucky bluegrass may be seriously injured.

Where summer weeds are a problem, fertilizer should be applied when it will do the bluegrass the most good and the crabgrass the least. Bluegrass makes its best growth in fall and early spring and the need for nutrients is greatest at that time. The thickening of the turf resulting from fall applications of fertilizer is one of the best insurances against annual weeds invading the turf the following year. This has been shown in every experiment in which sufficient fertilizer was applied to stimulate the turf grasses without burning them seriously.

On the Capital course two fall applications of complete inorganic fertilizer at the rate of 1 pound of nitrogen to 1,000 square feet increased the percentage of grass cover from 63 on the check to 94; reduced the percentage of white clover from 8 on the check to 1, plantain from 11 to zero and the area of bare ground from 18 to 5.

When, however, spring applications were made on the same series a heavy infestation of crabgrass resulted. The competition from crabgrass was so severe on the heavily fertilized plots that the bluegrass was ruined. In a special test on this point one series of plots was fertilized in the fall of 1933. A similar application was made on May 1, 1934, on another series of plots. By July 3, 1934, the plots receiving inorganic fertilizer in fall had 82 percent bluegrass and 15 percent crabgrass, while those receiving the same fertilizer in late spring had 10 percent bluegrass and 90 percent crabgrass. Fall fertilizing produced a turf that kept out most of the crabgrass while with spring fertilizing the crabgrass quickly dominated.

These tests have shown that in the Washington district fertilizers should be applied in the fall. When spring applications of fertilizers have been made in this region best results have been obtained by very early applications rather than in late April or May. Spring applications at about one-half the rate of the fall applications have produced better results than the heavier rates.

It is likely that in sections where the winters are not too severe fertilizers may be applied at any time during the winter as the grass seems to have the ability to utilize fertilizers even where little or no active growth is being made. Farther north, however, where the ground is frozen for a long period during the winter, much of the fertilizer applied to the frozen ground might be lost in run-off.

Tests conducted by the Green Section several years ago indicated that late and heavy fertilizing with nitrogen should be avoided in regions where snow mold is troublesome. It has been shown that grass stimulated into late growth is more susceptible to snow mold than grass that has not been stimulated by late fertilizing.

Weed Control with Fertilizers

The improvement of the grass on plots receiving complete fertilizer was accompanied in every case by a reduction in all weeds except crabgrass. Crabgrass flourished on those plots which received extremely heavy applications of fertilizers, on those fertilized in the spring, and on the acid plots which received complete fertilizer but no lime. On acid soil the least crabgrass was on the plots receiving either complete fertilizer plus lime or on plots receiving nitrogen, phosphorus and lime. On the neutral soil similar results were secured with these fertilizers without the addition of lime.

Both at the Capital course and at the Arlington Farm one of the most abundant weeds was buckhorn plantain. This is still plentiful on the check plots and on the surrounding areas but has practically disappeared from most of the fertilized plots, especially from those receiving inorganic fertilizers.

A 6-12-4 inorganic fertilizer applied at the rates of 2 and 4 pounds of nitrogen to 1,000 square feet eliminated practically all perennial weeds and clover after two applications. When no further nitrogen was added, clover reinfested these plots after several years. Perennial weeds were also reduced but not wholly eliminated by the heavier applications of organic fertilizer, indicating that in this case elimination of the weeds was mainly due to increased competition from the grass.

On the Arlington Farm where the soil was acid, applications of the 9-9-4 inorganic fertilizer reduced the weed content of the turf excepting crabgrass, from 58 percent in 1934 to 14 percent in October, 1939, and wholly suppressed the clover. Every summer, however, the crabgrass on these plots was much more abundant than on the checks. When lime was applied annually in addition to the complete inorganic fertilizer, weeds excepting crabgrass and clover were reduced from 58 percent in 1934 to 1 percent in 1939. These annual applications of lime reduced the percentage of crabgrass during each summer from an average of 65 on the unlimed fertilized plots to about 2, and at the same time encouraged the clover until in 1939, although there was no clover on the unlimed plot, there was 33 percent on the limed plot. It should be noted that in these tests lime was applied annually, rather than every second or third year. Had the applications been made at the wider intervals the same benefits might have resulted without as much stimulation of clover.

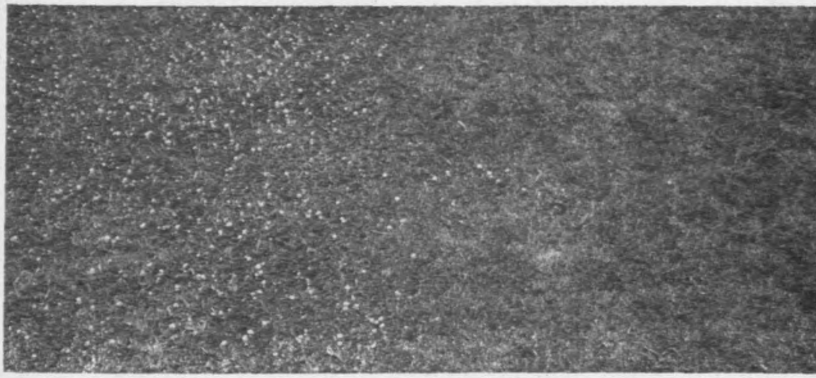
The 9-9-4 organic fertilizer on this series at Arlington reduced the weeds, excepting crabgrass and clover from 58 to 32 percent only. Crabgrass was reduced from 26 percent in 1934 to less than 3 percent in 1939. Clover was encouraged so that in 1939 it comprised 40 percent of the total vegetation.

Suppression of weeds was most marked in the case of buckhorn plantain which was nearly eliminated on all of the fertilized plots, while the average percentage on the check plots was 17. The elimination of the plantain was somewhat more complete on the inorganic than on the organic plots.

A series of plots laid out in the fall of 1936 received 6-3-2 organic and inorganic fertilizers at the annual rate of 2 pounds of nitrogen to 1,000 square feet. Observations made in June, 1938, showed that chickweed had greatly increased on the plot receiving the organic fertilizer. Both the organic and the inorganic fertilizer had reduced the clover and had slightly affected the buckhorn plantain.

Weed Control with Fertilizers and Arsenicals

Both arsenicals and complete fertilizers were applied on some plots. Arsenic acid was used at 1 pound and sodium arsenite at one-half pound to 1,000 square feet. Both were applied dry, mixed with sand, in April. While the fertilizers alone applied at the rate of 1 pound of nitrogen to 1,000 square feet reduced the clover and plantain to some extent but did not reduce the chickweed, the addition of arsenicals practically eliminated the chickweed and clover and further reduced the plantain. On the other hand, there was somewhat more crabgrass on the plots treated with arsenic acid and sodium arsenite than on those which received fertilizers only. This may have been due to the fact that the crabgrass was able to take over the areas vacated by the chickweed and clover more quickly than was the bluegrass. The plots treated with arsenic acid



The control of clover and buckhorn plantain in old established Kentucky bluegrass turf by the application of fertilizers. The weed-free plot on the right had received a 9-9-4 inorganic fertilizer every spring and fall from the spring of 1934 to the spring of 1938, inclusive, at the annual rate of 2.5 pounds of nitrogen to 1,000 square feet. The picture was taken in June, 1938. The plot on the left in which clover and plantain predominate had received no fertilizer during this time.

and fertilizers had a better stand of bluegrass than those to which fertilizers alone were applied.

Summary

The results of a number of experiments with fertilizers chiefly on old weedy turf composed largely of Kentucky bluegrass have been reported. These experiments were conducted in part at the Arlington Experiment Farm and in part on the grounds of the Capital Golf and Country Club near Washington.

In these experiments a thin weedy turf was transformed into a dense turf free of weeds in two years by moderate fertilization without the use of seed, water or mechanical working. The transformation was even more rapid with extremely heavy applications.

The best turf on the acid soil was produced with a combination of nitrogen-phosphorus plus calcium. However, the turf produced by applications of a complete fertilizer plus lime was almost as good.

The turf which received the nitrogen-phosphorus combination or the complete fertilizer was about equal on the neutral soil.

Nitrogen applied alone produced some improvement in the turf. However, a good turf resulted only when nitrogen was combined with certain other elements.

When nitrogen was combined with phosphorus there was a decided increase in turf grasses and a decrease in clover. There was no apparent difference in results on the neutral soil when potassium was added to this combination. However, on the acid soil the addition of potassium resulted in a pronounced decrease in turf grasses and a corresponding increase in crabgrass.

The addition of lime to the nitrogen-phosphorus combination on the acid soil effected a further reduction in turf weeds and crabgrass but clover was encouraged. When lime was added to the nitrogen-phosphorus-potassium combination turf grasses were likewise decidedly increased and crabgrass was again decreased. The lime seemed to have overcome the apparently detrimental effect of the potassium on the acid soil.

Nitrogen-potassium, nitrogen-potassium-calcium, and nitrogen-calcium produced no better results than nitrogen alone on these soils. The latter two combinations, however, effected an increase in the amount of clover which ultimately improved the turf to some extent.

The addition of phosphorus alone was not effective in improving the quality of the turf. Nevertheless it was necessary to include phosphorus in all of the combinations before good turf could be produced.

Phosphorus and potassium, phosphorus and calcium or a combination of these three elements were not much superior to phosphorus alone. These combinations, however, encouraged the growth of clover which eventually resulted in some increase in the amount of turf grasses.

Potassium was found to be of little value on these soils whether used alone or in combination with other nutrients. Its application on the acid soil checked the beneficial influence of other nutrients and produced a poorer turf with a greater increase in crabgrass than the same nutrients used without potassium. The addition of calcium, however, overcame some of the apparently detrimental effects of the potassium. On the neutral soils the depressing effect of potassium was not so plainly evident, the nitrogen-phosphorus-potassium combination producing turf about as good as the nitrogen-phosphorus combination. To obtain a high-quality turf on these types of soil it apparently was not necessary to include potassium in the fertilizer combination, and certainly not in such amounts as occur in most grades of fertilizers that are recommended.

The application of lime alone produced no immediate improvement in the turf. Clover was encouraged, however, and this in the end tended to stimulate the turf grasses. On the acid soil, when lime was added to any combination containing nitrogen it produced a striking increase in the amount of turf grasses the first year. Unless, however, phosphorus was included in such a combination the amount of turf grass at the end of the 5-year period was less than at the end of the first year. It was necessary to add lime on the acid soils before turf of high quality could be produced.

The use of 1,000 pounds of lime per acre annually on the inorganic fertilizer plots had little effect on the soil acidity.

When applied on an equal nitrogen basis all inorganic complete fertilizers of different formulas produced about the same results. The ones supplying the greatest quantity of phosphorus encouraged larger amounts of white clover. When these complete fertilizers were used, a good turf was obtained at the least expense with a formula supplying a high percentage of nitrogen, about half as much phosphoric acid as nitrogen and decidedly less potash than phosphoric acid.

Inorganic and organic fertilizers gave equally good results when repeatedly applied at heavy rates. Inorganic fertilizer produced a turf with fewer weeds and clover when light annual applications were continued over a period of years.

Inorganic fertilizers produced as great an increase in soil organic matter as did the organic. Both fertilizers increased the soil organic matter by approximately 5.5 tons to the acre. The increase was due to the vigorous growth of the grass roots and decay of other plant parts and not to the material added as fertilizer.

Of the various rates of application tested, the best turf maintained over a long period of time was that obtained by a heavy initial application of a complete fertilizer, followed by light annual applications. Equally good results were obtained by applications of a complete fertilizer every spring and fall at the rate of 1.25 pounds of nitrogen to 1,000 square feet, a total annual application of 2.5 pounds.

In single applications heavy rates resulted in the greatest improvement in the turf, although there was some burn. A mixed fertilizer, even when used at the extreme rate of 8 pounds of nitrogen to 1,000 square feet, improved the condition of the turf. However, repeated applications at such heavy rates resulted in a deterioration of the turf.

Although the best turf was obtained by continued applications of fertilizer, several heavy applications resulted in a turf which is still remarkably good even though several years have elapsed since the last application was made.

In the Washington district best results were obtained with fall applications of fertilizers. Spring applications, unless made very early, stimulated the crabgrass which then crowded out the bluegrass. When only spring applications were made the best results were obtained if they were made very early and at about half the rate of the fall applications.

The liberal use of fertilizers was effective in reducing the amount of weeds, especially plantains, chickweed, selfheal and clover. When applied at the lighter rates, the inorganic fertilizers were much more effective than the organic.

Arsenicals applied in addition to the fertilizers resulted in a quicker and greater reduction of turf weeds than did fertilizers.

"Be not the first by whom the new are tried
Nor yet the last to lay the old aside."

Pope referred to the use of words, but the idea conveyed is of wider application. The advice is good but does not mean that new ideas should be avoided. Try them out carefully but until the new method has been proved stick to methods that have been found successful. But don't stick to old ways long enough to fall behind the times. Changes of program should be made only with a clear view of the results that may be expected. There is no sense in trying anything and everything.

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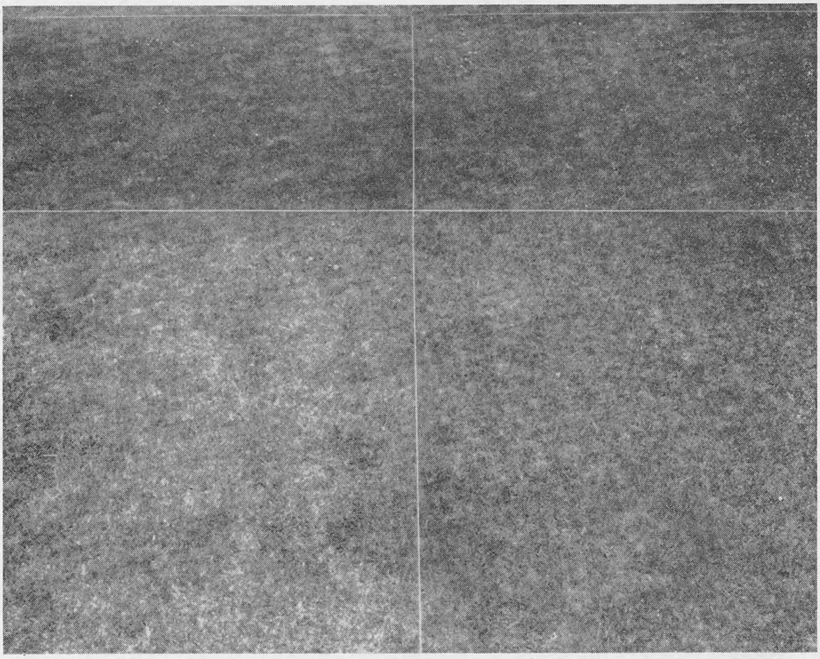
* Agronomist and Botanist, respectively, of the United States Golf Association Green Section.



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.

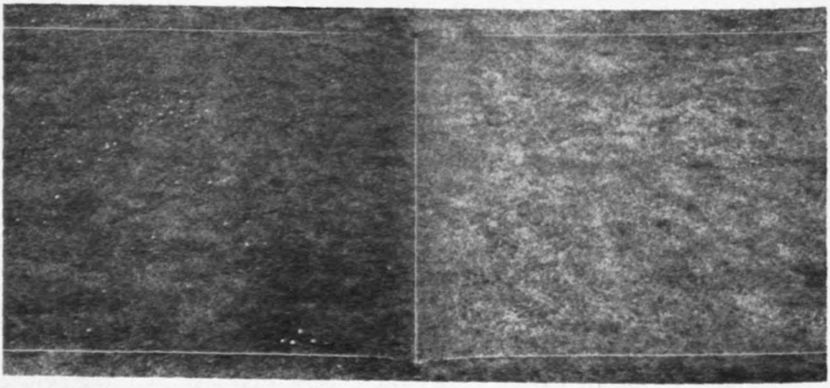
The annual rate of application of fertilizers was increased to 6 pounds of nitrogen to 1,000 square feet, in order to bring out greater contrast between the results with the various fertilizer combinations. Seven applications were made each year at monthly intervals from April to October inclusive. During 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 cumulative 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	Percentage of improvement over unfertilized plots: 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.

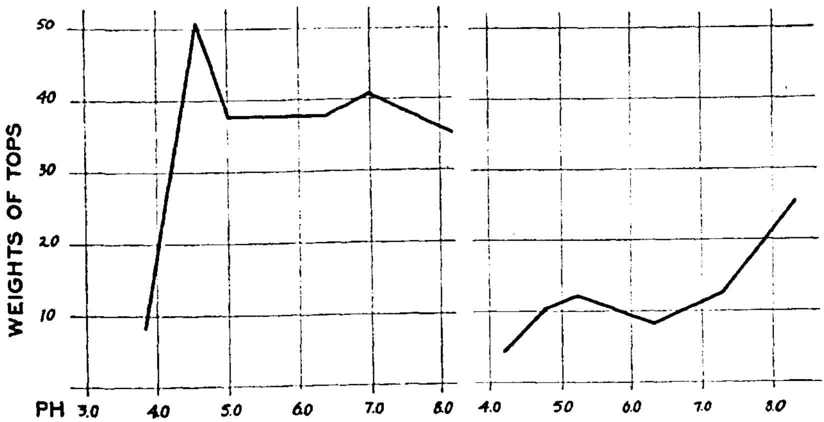
Response to Potash

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 potash annually, and has the favorable soil acidity of pH 5.5.

The greatest reduction in clover has been obtained on the most acid plots and the least on the slightly acid or alkaline plots.

When phosphoric acid was applied in addition to the 6 pounds of nitrogen in fertilizers which produced a moderate soil acidity, the improvement was somewhat greater than that resulting from the application of 6 pounds of nitrogen alone in the form of ammonium nitrate. When calcium was added as well as phosphoric acid and nitrogen the improvement was decidedly increased.

An excessive amount of phosphorus on the very acid ammonium phosphate plot has resulted in serious injury to the grass. As similar injurious effects are not evident on slightly acid plots which have received even more phosphorus the conclusion is drawn that the poor condition of the grass on the ammonium phosphate plots may have been due to the fact that phosphoric acid unites with the iron salts in the soil solution to form iron phosphate, which is practically insoluble in acid media. Thus the phosphoric acid may have been responsible for removing the iron from the soil solution, thereby making it unavailable to plants. An application of a solution of iron sulfate temporarily improved the grass.

Data are presented which demonstrate the fact that potash applied at the rate of 6 pounds or more to 1,000 square feet, has reduced somewhat the benefits derived from the addition of nitrogen and phosphoric acid. This apparently deleterious effect is more conspicuous in connection with the density than with the color of the turf. Also the presence of potash particularly in the moderately acid plots usually has been accompanied by a decided reduction in clover control.

FERTILIZER TRIALS ON DEMONSTRATION GARDENS

JOHN MONTEITH, JR., AND KENNETH WELTON*

It is generally recognized that the nutritional requirements of the bent grasses are not quite the same as those of the bluegrasses. It is also recognized that variations in the climatic and soil conditions under which turf may be growing prevent identical grasses from responding in the same way to any one fertilizer in all localities. Little information is available, however, regarding the extent of the variations in the responses of the several grasses to fertilizers, or the nature and relative importance of the climatic and soil factors involved. For this reason it was considered desirable to obtain evidence on the value of fertilizers for grass grown for turf purposes under as wide a range of soil and climatic conditions as practicable.

The Green Section, in 1928, with the cooperation of 15 golf clubs, established demonstration turf gardens in widely separated sections of the country. The primary object of the fertilizer sections of these demonstration gardens was to determine whether some fertilizers which had proved desirable or undesirable under conditions as they existed at Arlington Farm would produce correspondingly good or poor results under conditions as they are found in other sections of the country. The ability of the various clubs to undertake the expense associated with these demonstration gardens was naturally limited and consequently it was not possible to include as many fertilizers as might have been desirable.

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PLAN OF DEMONSTRATION GARDENS

The demonstration gardens were divided into plots 10 feet square. Fifteen of these plots were planted with mixed bent seed containing approximately 50 percent velvet bent, 48 percent Colonial bent and 2 percent creeping bent. In this series 11 different fertilizer combinations were applied at monthly intervals during the growing season. The bent plots were arranged with unfertilized check plots strategically placed for purposes of comparison, as is shown in the accompanying diagram.

PLAN OF FERTILIZER TRIALS ON MIXED BENT AT DEMONSTRATION GARDENS

Activated sludge.	Poultry manure tankage.	Check.	Sulfate of ammonia.	Compost and sulfate of ammonia.
Check.	Nitrate of soda.	Urea.	Ammonium phosphate.	Check.
Complete fertilizer 6-12-4	Complete fertilizer 12-6-4	Check.	Lime and sulfate of ammonia.	Bone meal.

A similar set of 10 plots was devoted to a study of the responses of Kentucky bluegrass to various fertilizer combinations. The plots were arranged as shown in the diagram on page 216. As in the mixed bent plots, each fertilized plot touched an unfertilized check plot on at least one side.

Other plots on the demonstration gardens were devoted to testing various grasses for putting green and fairway purposes, as well as to trying the effect of different heights of cut on these grasses. These plots are not related to the present subject and will not be discussed here.

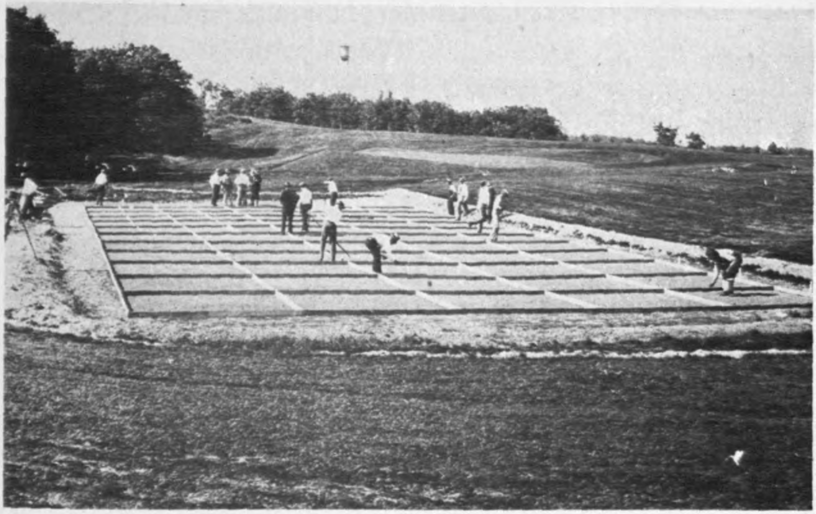
PLAN OF FERTILIZER TRIALS ON KENTUCKY BLUEGRASS AT DEMONSTRATION GARDENS

Bone meal.	Lime.	Check.	Sulfate of ammonia.	Activated sludge.
Check.	Manure.	Complete fertilizer 6-12-4	Complete fertilizer 12-6-4	Check.

Planting material and fertilizers for the demonstration gardens were furnished by the Green Section together with certain standard directions for the general care of the gardens. Details of maintenance were left to the individual greenkeepers at each of the cooperating clubs.

RECORD OF RESULTS

The plans for these gardens called for periodic reports to the Green Section on the condition of the turf on the plots. In these reports, which were submitted monthly from May to October, excellent turf was rated as 4, good turf as 3, fair as 2, and poor as 1. In determining the ratings, consideration was given to density, vigor, color, fineness, freedom from weeds, nap and any other factors which affected the quality of the grass for turf purposes. The value of each treatment was measured, therefore, in terms of the turf produced.



The planting of one of the Green Section's demonstration gardens in 1928. The view shows the strips of board in position between the plots. The strips were 3 or 4 inches wide and were set into the ground about 1 inch deep to prevent any possible washing of surface soil from one section to another. After the grass was well established the strips were removed.

As these tests were made on golf courses where white clover is objectionable in turf, any stimulation of clover by a fertilizer caused a lower rating for these plots. The ratings of the turf resulting from the use of some of the fertilizers are naturally quite different from those obtained from grassland experiments where white clover is valuable for forage. Likewise the ratings given here may not apply to some lawn and park areas, where white clover is not objectionable.

At the close of the 5-year period soil samples were taken at 1, 2, 3 and 4-inch depths from each of the fertilized and unfertilized plots on each of the nine demonstration gardens for which ratings over the 5-year period were available. These were tested by the Green Section staff for acidity by the Hellige-

Truog method and for available phosphoric acid (P_2O_5) by the LaMotte-Truog method. The conditions in the surface inch appeared to be more indicative of the responses of the soils to the various fertilizer applications than did those at the greater depths. Wherever reference is made to these determinations the values for the surface inch are given.

Cooperating Golf Clubs

Fifteen demonstration gardens were planted in 1928. Ten others were planted in 1929 and 1930. Some of the original gardens were soon discontinued for financial or other reasons and all were discontinued in 1933. Of the 25 gardens only 9 were kept up over the 5-year period from 1928 to 1933. In this summary of the data from the 5-year experiment, therefore, only the reports from these 9 gardens were used. They were distributed as follows:

Detroit District:	Detroit Golf Club Meadowbrook Country Club
Grand Rapids (Mich.) District:	Indian Trails Golf Course
Pittsburgh District:	Allegheny Country Club Oakmont Country Club
Boston District:	Charles River Country Club
New York District:	Century Country Club Upper Montclair Country Club Wheatley Hills Golf Club

Some of the 25 gardens were maintained for several more years and some additional observations have been made. Where results from the gardens not listed above have appeared significant they are included in the discussion.

Rates of Application of Fertilizers

Since nitrogen is of primary importance in the growth of leaves and the vegetative structure of plants, and since the object in growing grass for turf is to produce leaves rather than flowers or fruit, nitrogen assumes the position of ranking importance in the fertilizer requirements of turf grasses. On each type of grass, therefore, all of the fertilizers were applied at rates which gave the same amount of nitrogen for each fertilized plot.

Each 10 by 10-foot fertilized plot of mixed bent received one-tenth pound of nitrogen with each monthly application from May to October, inclusive, except during the months of July and August, when all applications were cut in half to reduce the danger from burning. Each plot of 100 square feet, therefore, received one-half pound of nitrogen in the 6 months. In other words, the nitrogen was applied at the annual rate of 5 pounds to 1,000 square feet. The quantities of phosphoric acid and potash applied varied with the composition of the fertilizer.

The quantities of mineral nutrients applied annually to each of the 11 plots are given in the table on page 220. For convenience the quantities are expressed in pounds to 1,000 square feet. The plot which was fertilized with a mixture of sulfate of ammonia and compost received half of its nitrogen from the sulfate of ammonia and half from the compost. The sulfate of ammonia was furnished by the Green Section but the compost was supplied by each club for its own garden. Each sample of compost was not analyzed but the amount that was prescribed was estimated on the basis of nitrogen determinations on average compost. Therefore the specific amounts of nitrogen, phosphoric acid and potash in the compost are not known, but the average should be very close to the figures given in the table.

ANNUAL RATES OF APPLICATION OF NUTRIENTS TO MIXED BENT PLOTS ON THE DEMONSTRATION GARDENS, IN POUNDS TO 1,000 SQUARE FEET. THE PLOTS ARE ARRANGED IN DECREASING ORDER OF TOTAL AMOUNTS OF PLANT NUTRIENTS APPLIED

Fertilizer	Pounds of nutrients to 1,000 square feet Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)
Bonemeal	5	28.00	0
Ammonium phosphate	5	21.84	0
6-12-4 Inorganic	5	10.00	3.33
12-6-4 Inorganic	5	2.50	1.67
Poultry manure tankage	5	2.50	1.30
Sulfate of ammonia and compost	5	1.25	2.50
Activated sludge	5	1.70	0.40
Urea	5	0	0
Sulfate of ammonia	5	0	0
Sulfate of ammonia and lime	5	0	0
Nitrate of soda	5	0	0
Checks	0	0	0

The bluegrass plots were seeded with a mixture of Kentucky bluegrass and redtop but the redtop was gradually crowded out. The materials tested were 6-12-4, 12-6-4, sulfate of ammonia, activated sludge, bonemeal, well-rotted stable manure and lime. As on the bent plots, all fertilizers were applied at rates to furnish equivalent quantities of nitrogen. Naturally the amounts of phosphoric acid and of potash varied with the composition of the fertilizers. The complete mixed fertilizers contained material of inorganic origin only.

In order to give the young grass a vigorous start the rates of application the first year were the same as those shown above for bent grasses. During the 4 following years the annual rates of application were one-half of those used on mixed bent. One-half of each annual application was made in early spring and the remainder in fall.

The annual applications of nutrients to 1,000 square feet during the 4 years are shown in the table on this page. For the first year these rates were doubled.

ANNUAL RATES OF APPLICATION OF NUTRIENTS TO KENTUCKY BLUEGRASS PLOTS ON THE DEMONSTRATION GARDENS, IN POUNDS TO 1,000 SQUARE FEET. THE PLOTS ARE ARRANGED IN DECREASING ORDER OF TOTAL AMOUNTS OF PLANT NUTRIENTS APPLIED

	Pounds of nutrients to 1,000 square feet		
Materials	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)
Bonemeal	2.5	14.00	0
6-12-4 Inorganic	2.5	5.00	1.67
Stable manure	2.5	1.65	1.65
12-6-4 Inorganic	2.5	1.25	0.83
Activated sludge	2.5	0.85	0.20
Sulfate of ammonia	2.5	0	0
Lime	0	0	0
Checks	0	0	0

The stable manure was furnished by the various clubs. The instructions were to apply a specified amount of a good grade of well-rotted manure. As it was not practical to analyze each lot of manure the amount that was prescribed was based on the average analysis of numerous samples of good grade manures. Undoubtedly there were variations in the composition of the manure that was used on the different gardens. However, it can be assumed that the average amount of nitrogen added in the various gardens was very close to the amount applied to the other fertilized plots, and that the other nutrients were added in the amounts shown in the table.

AVERAGE 5-YEAR PERCENTAGE OF IMPROVEMENT OVER UNFERTILIZED PLOTS OF MIXED BENT TURF ON NINE DEMONSTRATION GARDENS. THE pH OF THE SURFACE INCH OF SOIL ON THE PLOTS AT THE CLOSE OF THE 5-YEAR PERIOD AND THE ANNUAL RATE OF APPLICATION OF PHOSPHORUS ARE INCLUDED

Fertilizer	Percentage of improvement over unfertilized plots	pH of surface inch of soil	Annual application of phosphorus (pounds P_2O_5 to 1,000 square feet)
6-12-4 Inorganic	126	5.2	10
12-6-4 Inorganic	125	5.3	2.5
Sulfate of ammonia	106	5.4	0
Ammonium phosphate	99	5.3	21.84
Activated sludge	92	6.3	1.7
Sulfate of ammonia and compost	88	5.6	1.25
Poultry manure tankage	87	6.1	2.5
Urea	76	6.3	0
Sulfate of ammonia and lime	71	6.7	0
Nitrate of soda	48	6.9	0
Bonemeal	47	6.9	28
Unfertilized plots	..	6.2	0

RESPONSE OF BENT TURF TO FERTILIZERS

As stated, the effect of each fertilizer was determined by the condition of the turf produced. In each case the rating of the grass on the fertilized plot was compared with that on the check plots and expressed as percentage of improvement over the average rating of the unfertilized check plots.

The average percentages of improvement of the bent grass over the 5-year period are shown in the table on this page. The annual rate of application of phosphorus and the resulting pH of the soil at the end of the 5-year period are given. The plots are arranged according to the percentage of improvement in the grass on the fertilized plots over that on the unfertilized check plots.

To measure the effect of phosphorus and potassium on the grass the improvement obtained by applications of inorganic fertilizers containing phosphoric acid and potash can be compared with the improvement resulting from the application of inorganic nitrogen alone. The 6-12-4 and 12-6-4 fertilizers both furnished nitrogen in the form of sulfate of ammonia and some ammonium phosphate.

In the table it can be seen that the improvement shown on the 6-12-4 and the 12-6-4 plots was significantly greater than that shown on the sulfate of ammonia plot. Since the nitrogen sources were ammonia compounds in the three plots and since the acidity of the soil was essentially the same on each of them, this increase in improvement may safely be credited to the presence of phosphoric acid or potash. The fact that on the average the grass on the plot fertilized with 6-12-4 was little better than that on the 12-6-4 plot, although it received 4 times as much phosphoric acid and twice as much potash, indicates that small proportions of phosphoric acid (application at one-half the rate at which nitrogen was used) and even smaller amounts of potash had improved the turf but that larger amounts had failed to appreciably increase this improvement.

Similar benefits from relatively small amounts of phosphoric acid and potash can be seen when the improvement in the turf on each of the plots receiving the organic fertilizers, activated sludge and poultry manure tankage, is compared with that on the plot receiving organic nitrogen alone in the form of urea, each receiving 5 pounds of nitrogen. The activated sludge and poultry manure tankage added phosphoric acid at annual rates of 1.7 and 2.5 pounds to 1,000 square feet, respectively, and small amounts of potash. In the table it can be seen that both the activated sludge and the poultry manure tankage produced better turf than did the urea. The figures indicate that the grass was generally poorer and that the soil was less acid on all of these plots than on those fertilized with 6-12-4, 12-6-4 and sulfate of ammonia. The urea plot, for instance, showed an average improvement of only 76 percent over the unfertilized plots, as compared with 106 percent improvement on the sulfate of ammonia plot.

The ammonium phosphate plot received phosphoric acid at the heavy rate of nearly 22 pounds to 1,000 square feet. The average improvement shown on this plot was slightly less than that shown on the sulfate of ammonia plot. The resulting soil acidity at the end of the 5-year period was about the same on the two plots.

When a large amount of phosphorus was added in the slowly available form of bonemeal there was an average improvement of only 47 percent during the course of the experiment as compared with 106 percent with sulfate of ammonia. It will be noted in the table that the pH of the soil on the bonemeal plot was much higher than that on the plots receiving sulfate of ammonia and other inorganic fertilizers. The fact that nitrate of soda which resulted in the same high pH likewise produced an improvement of only 48 percent over the checks would indicate that the practically neutral condition of the soil was significant on the bonemeal and nitrate of soda plots.

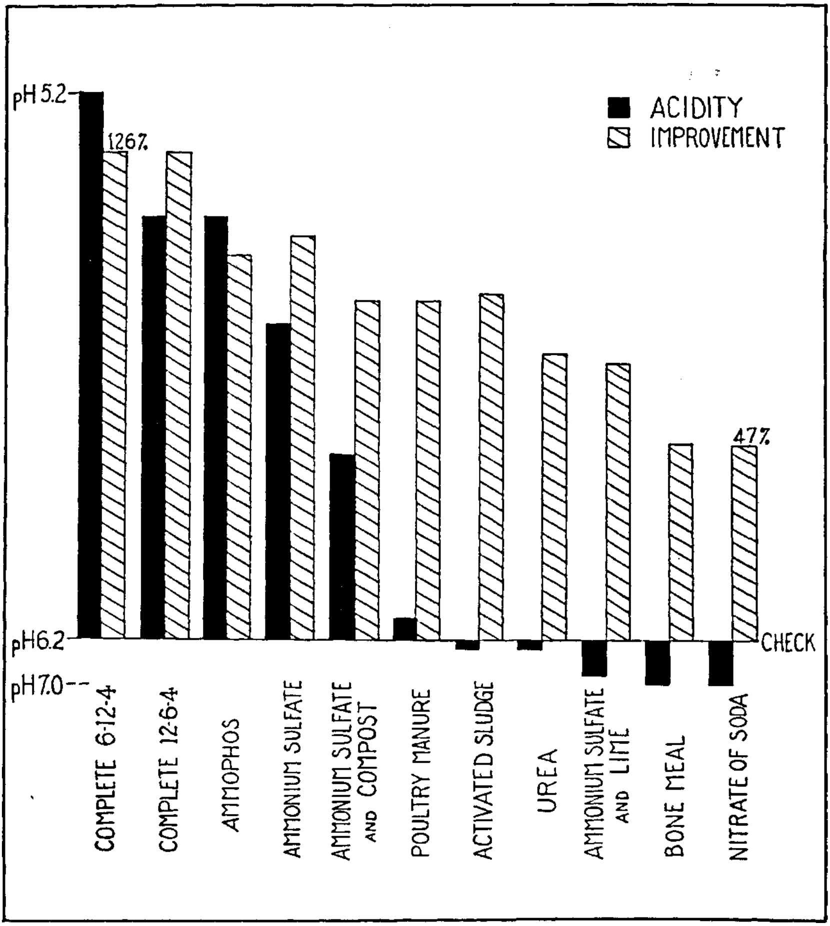
The plot receiving sulfate of ammonia and compost showed considerably less improvement than the plot receiving sulfate of ammonia alone. This was probably due to the fact that only one-half of the nitrogen was furnished by the sulfate. The other half came from compost in which the nitrogen is much more slowly available.

The grass on the plot receiving lime in addition to the sulfate of ammonia showed far less improvement than did that on the plot receiving sulfate of ammonia alone. It will be noted in the table that the acidity which was caused by sulfate of ammonia when applied alone was more than counteracted by the application of lime in addition to the sulfate of ammonia. On an average, sulfate of ammonia alone reduced the soil pH from 6.2 in the check plots to pH 5.4, whereas sulfate of ammonia and lime raised the soil pH from 6.2 in the check plots to 6.7.

The interpretation of the responses of the bents to the various fertilizer combinations used on the demonstration gardens will be discussed later in this article in the light of the results from other experiments carried on over a longer period of time.

Acidity Relations

The table on page 222 indicates that the question of acidity should be considered in any effort to interpret the results obtained from the fertilized plots of mixed bent on the demonstration gardens. The best plots were those with the most acid soils; that is, soils with readings of pH 5.2 to 5.4. In the ruled columns of the chart on page 226 the percentages of improvement are shown graphically. For purposes of comparison the actual acidity of each plot (hydrogen ion concentration) times 10 million is drawn to scale in the solid columns of the chart. The base line represents the average condition of the grass and the soil acidity (pH 6.2) of the check plots. It can easily be seen, therefore, which fertilizers produced the greatest improvement and whether they increased or decreased the acidity of the soil. The reader will notice the much greater



The average percentage of improvement in bent turf over check plots on the nine Demonstration Gardens with each of the fertilizer combinations, and the average soil acidity produced in the surface inch of soil by each of the fertilizers. The improvement is given in the ruled columns and the acidity (Hydrogen-ion concentration) times 10 million, in the solid columns. The base line represents the condition of turf and the soil acidity of the surface inch of soil on the unfertilized plots. The pH equivalent of the actual acidity is given at the left for the most acid plot, the check plot and the neutral plot. Also, the greatest and least percentages of improvement are given above their respective columns.

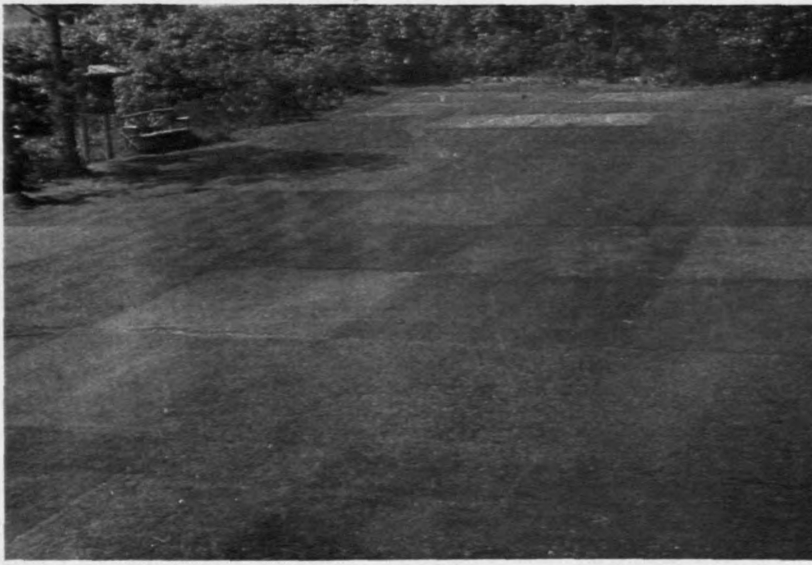
difference in acidity between pH 5.2 and 6.2 than between 6.2 and 7.0. The difference between the acidity of pH 5.0 and 6.0 is 10 times greater than that between pH 6.0 and 7.0. It is apparent that, with the exception of activated sludge, the more acid the plots (the lower the pH) the greater the improvement which is shown in the turf.

Soil Acidity and Response to Fertilizer

The acidity of the original soil as indicated by the pH of the check plots on the 9 different gardens varied from pH 4.7 at Wheatley Hills to pH 7.5 at Meadowbrook. A preliminary comparison of the ratings of the fertilizer plots at the individual gardens together with the results of the soil tests made on samples from each of these plots indicated that there was a significant difference between the response of the mixed bent to fertilizers on distinctly acid and on alkaline soils.

The gardens have been classified into three groups on the basis of the acidity of their untreated soil. On four gardens the soil was distinctly acid, with the soil pH below 6.0; on three the soil was slightly acid, with the pH between 6 and 7; and on two the soil was alkaline, with the pH above 7.0. The average response of the bent grasses to each of the 11 fertilizer combinations for each group of the demonstration gardens was calculated and plotted on the chart shown on page 232.

It appears significant that with each fertilizer treatment, with the single exception of that of nitrate of soda, the gardens with the distinctly acid soil showed most improvement in the turf, those with slightly acid soil showed less improvement, whereas those with alkaline soil gave decidedly the least response.



A view of one of the demonstration turf gardens planted by the Green Section showing some striking variations in the plots from different fertilizer applications.

On the alkaline soils the fertilizers had least effect on the acidity of the soil. Apparently the soil on the alkaline gardens was well buffered against any change in soil acidity. In the table on page 229 it can be seen that the acidity of the fertilized plots on the gardens having naturally acid soils varied from pH 4.5 to 4.8 (on those plots fertilized with the inorganic complete mixtures) to pH 6.5 to 7.0 (on the bonemeal and nitrate of soda plots) a range of 2 full pH units. On the other hand, on the alkaline gardens the acidity of the plots varied within the very limited range of from pH 6.5 to 7.3 on the least acid plots, to 7.5 on the most alkaline plots—a range of only 0.2 to 1.0 pH unit.

Soil Acidity of Check Plots Expressed in pH and Range in Soil pH of the Fertilized Plots on the Nine Demonstration Gardens

Gardens	pH of soil on check plots	Range in soil pH of fertilized plots	
		Most acid plot	Least acid or alkaline plot
Most acid gardens			
Wheatley Hills	4.7	4.5	6.5
Oakmont	5.3	4.5	7.0
Charles River	5.7	4.5	6.8
Upper Montclair	5.8	4.8	7.0
Moderately acid gardens			
Century	6.3	4.5	7.2
Allegheny	6.6	4.8	6.8
Detroit	6.7	5.0	7.0
Alkaline gardens			
Indian Trails	7.2	6.5	7.5
Meadowbrook	7.5	7.3	7.5

Response of Kentucky Bluegrass Turf to Fertilizer

The method of recording the effect of fertilizers on the Kentucky bluegrass series was the same as that already described for the mixed bent plots. As the scoring was done by greenkeepers and others interested in golf courses the emphasis was placed on grass development. Stimulation of clover or other legumes and weeds lowered the score. These ratings are consequently not likely to be in accord with many obtained from fertilizer experiments on bluegrass where the objective is to produce a mixture of grass and clover for pasture or other purposes.

The fertilizers were applied on the basis of equal quantities of nitrogen with varying amounts of phosphoric acid and potash, as shown in the table on page 221. To hasten the establishment of the turf they were used at double the usual rate during the first year. Therefore the total quantities used in the 5-year period were six times the amounts shown in the table.

The average effects over the 5-year period of the several fertilizers and lime on Kentucky bluegrass turf are shown in the table on this page. On the opposite page are given the percentages of improvements over the unfertilized turf on the several plots for each year.

AVERAGE 5-YEAR PERCENTAGE OF IMPROVEMENT OVER UNFERTILIZED PLOTS OF KENTUCKY BLUEGRASS TURF, AVERAGE pH OF SURFACE INCH OF SOIL AT CLOSE OF 5-YEAR PERIOD, AND TOTAL PHOSPHORUS APPLIED IN 5 YEARS, ON NINE DEMONSTRATION GARDENS

Materials applied	Percentage of improvement over unfertilized plots	Average pH of surface inch of soil	Total phosphorus applied in 5 years (pounds P_2O_5 to 1,000 square feet)
6-12-4 Inorganic	69	5.2	30.0
Activated sludge	62	5.8	5.1
12-6-4 Inorganic	62	5.2	7.5
Bonemeal	56	6.3	84.0
Sulfate of ammonia	44	5.3	0
Lime	23	6.9	0
Stable manure	21	6.1	9.9
Check	..	6.2	0

Climatic variations naturally affect the condition of turf with or without fertilizer. The ratings of the unfertilized check plots, therefore, varied from year to year. By using figures that indicate improvement over the check plots this variation in the unfertilized turf due to seasonal differences is taken into consideration. It will be noted that in 1931 every fertilized plot showed the lowest percentage of improvement of any year. This was the year when the unfertilized turf was at its best, which in part accounts for the lower figures of improvement due to fertilizers. In the case of the organic fertilizers the lower ratings in 1931 were found to be due entirely to the higher ratings of the checks. On the other

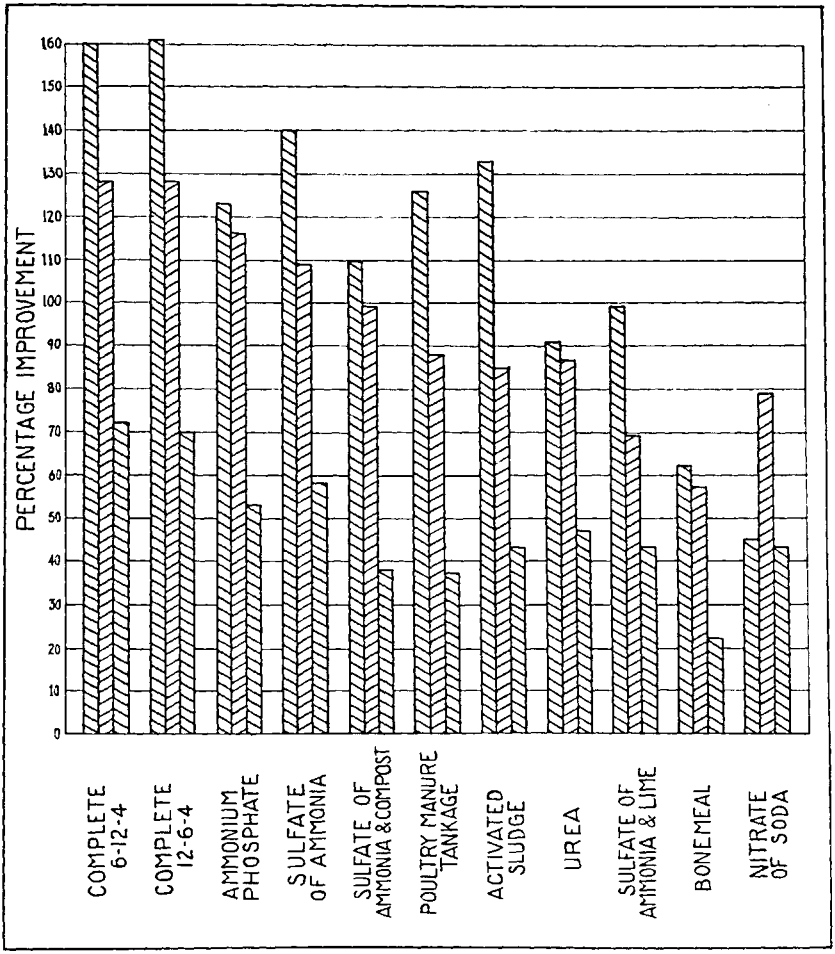
PERCENTAGES OF IMPROVEMENT OF KENTUCKY BLUEGRASS TURF OVER UNFERTILIZED PLOTS ON NINE DEMONSTRATION GARDENS FOR EACH OF 5 YEARS, 1929-1933. PLOTS ARE ARRANGED IN THE ORDER OF AVERAGE IMPROVEMENT OVER 5-YEAR PERIOD

Materials applied	1929	1930	1931	1932	1933
6-12-4 Inorganic	101	77	28	62	78
Activated sludge	57	59	42	64	89
12-6-4 Inorganic	88	65	32	58	67
Bonemeal	49	56	37	60	78
Sulfate of ammonia	67	44	13	39	56
Lime	12	19	10	32	41
Stable manure	26	18	14	16	33

hand the three inorganic fertilizers showed a decided falling off in ratings in the four gardens in the New York and Boston districts. In these two districts rainfall had been above normal, particularly following the fertilizer applications the previous fall. In the other districts there had been less than normal rainfall and the percentages of improvement were not lower than they were in other years. This difference in rainfall may have had some bearing on the response to the inorganic fertilizers due to excessive leaching of nitrogen from the soil.

The figures indicate that the turf was established most rapidly on the plots receiving the two complete inorganic fertilizers. They maintained this lead for 2 years but thereafter were equalled or surpassed by the activated sludge and the bonemeal.

The 6-12-4 plot showed the highest percentage of improvement over the 5-year period but, as shown below, the differ-



Response of the mixed bent grasses to fertilizers on soils of varying acidity. The results are expressed in percentage of improvement over the check plots. The three columns shown for each fertilizer, reading from left to right, represent the average percentage of improvement for four gardens with unfertilized soils with pH below 6.0, three gardens with pH between 6.0 and 7.0, and two gardens with pH above 7.0.

ence was unimportant. This lead over the activated sludge was due to the decided differences in the ratings of the first 2 years. In the ratings for the 5 years the 6-12-4 led the sludge on only four gardens but the percentages of improvement in these cases were sufficiently high to offset the figures from the five gardens where the sludge led the 6-12-4. In two of these five gardens the differences in ratings were very small.

The activated sludge led the 12-6-4 by a small fraction over the 5-year period in spite of the slower start. In this case also the sludge led in five gardens whereas on the other four gardens it was inferior to the 12-6-4.

The 12-6-4 fertilizer gave results superior to 6-12-4 on two gardens and tied it on two others. On two other gardens there were only trivial differences between the plots with these two fertilizers. On only three gardens did the 6-12-4 lead the 12-6-4 by a significant margin. This lead was maintained in 4 of the 5 years of the test. In order to apply the same quantities of nitrogen to these plots it was necessary to use twice as much 6-12-4 as 12-6-4. Consequently the plot receiving 6-12-4 had four times as much phosphoric acid and twice as much potash as the plot receiving 12-6-4.

It is interesting to compare results on the plot fertilized with sulfate of ammonia alone with those obtained on the plots fertilized with the two complete inorganic fertilizers in which most of the nitrogen was supplied in the form of sulfate of ammonia. During the first year the sulfate of ammonia was in third place but well below the complete inorganic fertilizers. It remained well below them throughout the test period, indicating the need for phosphoric acid or potash. By comparing the results on the different gardens it was found that the complete inorganic mixtures led the sulfate of ammonia on seven gardens. The sulfate of ammonia was superior to the two complete fertilizers on two gardens but in only one case was this difference large enough to be considered of any importance.

In the table showing the yearly ratings it will be noted that, with the exception of 1931, there was a steady betterment of the turf in the plots receiving the two organic fertilizers—activated sludge and bonemeal. Even in that year the proportionate drop in improvement was much less in these two plots than in the three plots receiving inorganic fertilizers. The percentage of improvement during the fifth year as compared with the first year was 32 higher for activated sludge and 29 higher for bonemeal.

RESPONSE OF MIXED BENTS AND KENTUCKY BLUEGRASS TO THE SAME FERTILIZERS. RESULTS ARE EXPRESSED IN PERCENTAGE OF IMPROVEMENT OVER RATINGS OF THE GRASSES ON UNFERTILIZED PLOTS. THE BLUEGRASS PLOTS RECEIVED 60 PERCENT OF THE AMOUNT OF FERTILIZER APPLIED TO THE BENTS IN 5 YEARS

Fertilizer	Percentage of improvement Mixed bents	Kentucky bluegrass
6-12-4 Inorganic	126	69
12-6-4 Inorganic	125	62
Sulfate of ammonia	106	44
Activated sludge	92	62
Bonemeal	47	56

The ratings of the plot receiving bonemeal put this fertilizer in fourth place in the total ratings. It led the 6-12-4 however in three gardens but in each case the margin was a narrow one. It likewise led the activated sludge on three gardens and the 12-6-4 on four gardens by comparatively narrow margins.

Although not classed as a fertilizer, lime produced an average improvement of bluegrass turf greater than that obtained with manure. It will be noted that the improvement in the first year was less than a third that of the last year. The relatively large increase in improvement the last year was mainly due to the great increase on one garden even though the unfertilized soil on this garden was nearly neutral.

The stable manure produced the least improvement of all the materials tested. In spite of the fact that the manure added more total plant food than was added by the 12-6-4 or the activated sludge it improved the turf only a third as much as these two fertilizers.

Kentucky Bluegrass and Soil Acidity

When the figures showing turf improvement in the table on page 230 are compared with those in the column of pH values it is apparent that there is no such uniform relationship between them as is the case in the bent series.

It is generally believed that Kentucky bluegrass grows best in soil that is nearly neutral. With this point of view in mind it is interesting to note that the three fertilizers at the top of the list had each made the soil more acid than in the unfertilized check plots.

Some interesting facts become apparent with a study of the average improvement produced by the various fertilizers on the individual gardens. The two highest rates of improvement occurred on the garden with an original soil pH of 5.3, next to the most acid of the series, and these high improvements were produced by the two fertilizers, the complete inorganics, with the strongest tendency to make the soil more acid. The next two highest rates of improvement were produced with the same fertilizers on a slightly acid soil with a pH of 6.7.

Sulfate of ammonia, which also tends to make the soil more acid, gave its best results on next to the most acid garden and its next best results on an alkaline garden. The pH of these gardens was changed from 5.3 to 4.8 in the first instance and from 7.1 to 5.5 in the second. Activated sludge, which also tends to increase soil acidity, made its best showing on one of the more acid gardens, the pH changing from 5.7 to 4.9.

Lime, one of our most effective materials for decreasing soil acidity, made its best showing on the bluegrass plots on a garden with a nearly neutral soil having a pH of 6.6. On a garden with a pH of 6.7 the lime plot was even poorer than the check and again made a very poor showing on a garden with a pH of 5.7. Lime made its second best showing on the most acid garden.

Comparison of Mixed Bents and Kentucky Bluegrass

It is interesting to compare in the table on page 234 the response of mixed bents with that of Kentucky bluegrass to some fertilizers applied under the varying environmental and cultural conditions of the nine gardens. In this connection it should be borne in mind that the bents are considered as acid-tolerant grasses whereas Kentucky bluegrass is considered as preferring a more nearly neutral soil. The Kentucky bluegrass plots received in the 5 years 60 percent of the amount of fertilizer applied to the bents. The figure for each fertilizer represents the average improvement obtained on the nine demonstration gardens during the 5 years. The average rating of the mixed bents on the unfertilized plots was 38 percent and that of Kentucky bluegrass was 40 percent of the maximum score possible with the rating method in use. The condition of the turf on these check plots was typical of that on most unfertilized areas.

The response of Kentucky bluegrass to the complete inorganic fertilizers corresponded to that of the bent grasses. Both grasses produced the best turf on plots which had been fertilized with 6-12-4 inorganic fertilizer and which had an acidity of pH 5.2 at the close of the experiment. The bent grasses, which received about 1.7 times as much fertilizer as did the Kentucky bluegrass, showed 1.8 times as much improvement with the 6-12-4, 2 times as much with the 12-6-4, and 1.5 times as much with activated sludge, as did the Kentucky bluegrass, although in the bents the improvement produced with 6-12-4 and 12-6-4 was about one-third again as much as with activated sludge.

The outstanding difference between the two grasses in this comparison was in their response to sulfate of ammonia. Sulfate of ammonia was a particularly favorable source of nitrogen for bent. The improvement shown in bent fertilized with sulfate of ammonia was second only to that shown in bent fertilized with the complete inorganic fertilizers. On the other hand, the Kentucky bluegrass plots fertilized with sulfate of ammonia alone were the poorest of all of the fertilized plots included in this comparison. Nevertheless where sulfate of ammonia was used in conjunction with superphosphate and muriate of potash, it gave good results on Kentucky bluegrass as well as on bents, as is evidenced by the improvement recorded for the 6-12-4 and the 12-6-4 plots.

Kentucky bluegrass responded more favorably to bonemeal than did the mixed bents. Although the bent plots received 1.7 times as much bonemeal as did the Kentucky bluegrass plots, they showed only 0.84 times as much improvement.

In general the results under these widely varying conditions were similar to those obtained with these fertilizers on the same grasses at Arlington Experiment Farm, as described elsewhere in this issue of Turf Culture.

Summary and Discussion

Demonstration turf gardens were established by the Green Section on golf courses in different parts of the country. These gardens included series of plots for testing the responses of the bent grasses and Kentucky bluegrass to different fertilizers under various soil and climatic conditions.

This article reports the results of the fertilizer tests from the nine gardens which were continued over a 5-year period, from 1929 to 1933 inclusive.

Although these tests were conducted for only 5 years it is interesting to compare the results with those obtained from the bent plots on the Arlington Turf Garden, some of which have been fertilized with a single combination of materials for the past 18 years, and have been under continuous observation during that time.

The application of nitrogen at the annual rate of 5 pounds to 1,000 square feet has consistently improved bent turf, the amount of improvement varying with the source of nitrogen, the other fertilizer ingredients with which the nitrogen source was combined, and the acidity of the soil.

On the demonstration gardens, the most decided improvement was produced in bent turf with the 6-12-4 and the 12-6-4 inorganic mixtures. There was appreciably more improvement over the unfertilized turf in these plots than in the ones which received sulfate of ammonia alone or ammonium phosphate. Since the nitrogen in these mixtures was supplied chiefly in the form of sulfate of ammonia with small amounts of ammonium phosphate, the increase in improvement has been credited to the presence of moderate amounts of phosphoric acid and potash. It should be remembered that the tests were conducted for only 5 years. Had they been continued for a longer time all four of these plots probably might have become increasingly acid until the grass suffered as it has on the bent plots at Arlington.

The application of sulfate of ammonia and compost did not produce so much improvement as did the application of sulfate of ammonia alone. This has been explained by the fact that in this mixture only one-half of the nitrogen was supplied by sulfate of ammonia and the remainder by the compost in which the nitrogen was more slowly available.

The improvement shown on the plot which received sulfate of ammonia and lime was much less than that on the plot which received sulfate of ammonia alone. This may be explained by the fact that more lime than necessary was used to neutralize the acid residue from the sulfate of ammonia. It is well recognized that lime is distinctly beneficial to bent turf when added to soil which has had too much sulfate of ammonia added to it. On these plots lime was added the first year and each year thereafter, and it more than counteracted the acidity which was caused by sulfate of ammonia when applied alone.

The other inorganic source of nitrogen in these tests was nitrate of soda, and the plot which received it was one of the two poorest plots in the series. Nitrogen applied at the annual rate of 5 pounds to 1,000 square feet in nitrate of soda produced less than half as much improvement as did the same amount of nitrogen applied in sulfate of ammonia.

The inorganic fertilizers, except for nitrate of soda and the combination of sulfate of ammonia and lime, produced more improvement than did the organic materials. Among the organic fertilizers, activated sludge gave decidedly the best results.

Phosphorus, when not applied at too heavy a rate, increased the improvement obtained from the application of nitrogen alone, as has been shown by comparing the 6-12-4 and 12-6-4 plots with the sulfate of ammonia plot, or the activated sludge and the poultry manure tankage plots with the one which received urea.

The ammonium phosphate plot received, in addition to ammonia nitrogen, a large amount of phosphoric acid which, as has been shown on the bent plots at Arlington, is injurious in acid soil. Over the 5-year period the ammonium phosphate plot was not so good as the sulfate of ammonia plot which had received nitrogen only. At the Arlington Farm in 1939 the plots which have received ammonium phosphate over a much longer period of time have been the poorest of the entire series. They have been made very acid, however. Had the demonstration gardens been continued for a similar length of time, the plots might have become steadily worse, as they have at Arlington.

The bonemeal plot, which received an even greater amount of phosphorus than did the ammonium phosphate plot, was the poorest of the entire bent series. It has been pointed out that the cause of this low response may have been associated with the nearly neutral soil condition as well as with the excessive amount of phosphoric acid. This conclusion has been supported by the fact that the nitrate of soda plot which showed the same high pH produced turf comparable to that on the bonemeal plot.

The beneficial effect of potassium on bent turf was clearly evident on two gardens which were situated on sandy soil. Neither of these gardens is included in the nine, the results from which are tabulated in this report because they were not in operation during the entire period from 1929 to 1933, inclusive. On the heavier soils of the nine gardens reported, no such striking results were observed.

Considering the average of the nine demonstration gardens, the greatest improvement in the bent turf over that on the checks resulted on the four plots in which the fertilizers produced an average acidity between pH 5.2 and 5.4. These results are comparable to those obtained on the bent plots at Arlington, where the best turf has been produced with those fertilizers which results in a soil acidity ranging from pH 4.6 to 5.9. The least response of bents to fertilizers on the demonstration gardens was shown on the two approximately neutral plots with a pH of 6.9 which received the widely different materials, nitrate of soda and bonemeal.

The nine gardens varied in the acidity of their unfertilized soil from pH 4.7 on the most acid garden at Wheatley Hills, to pH 7.5 on the most alkaline garden at Meadowbrook. It has been demonstrated that the bents showed least response to fertilizers on the alkaline gardens and most on the decidedly acid gardens. Soid acidity tests showed that the fertilizers had much less effect on the pH of the soil on the alkaline gardens than on the acid gardens.

The response of Kentucky bluegrass on the demonstration gardens to various fertilizers and lime has been reported.

Several fertilizers produced a decided improvement over the check plots. The 6-12-4 fertilizer produced the best turf and the activated sludge and 12-6-4 tied for second place. The bonemeal was fourth—somewhat below these three.

These figures show a slight lead for the 6-12-4, but it should be remembered that they represent the average results on nine different gardens over a 5-year period. It has been shown that when these average figures are separated into the results for the different gardens, each one of these fertilizers led all the rest on some gardens and was the poorest of the three on others. When comparing these first three fertilizers in this way the results are about equal. The bonemeal was generally less effective. The effectiveness of all four fertilizers varied on the different gardens due to soil and climatic conditions.

Inorganic fertilizers effected a much quicker response than did the organic. This is especially noticeable in the results of the first 2 years.

Sulfate of ammonia and stable manure were less effective than the other fertilizers in producing an improvement of the turf. Lime was also less effective but produced better turf than did the manure.

In making a comparison of these results with those secured at the Arlington Experiment Farm the difference in type of turf and climatic conditions should be taken into consideration. On the demonstration gardens the experiments were started on the newly seeded turf. On the Capital course and at Arlington they were on a thin weedy old turf. Naturally the weed and clover seedlings appearing in the newly seeded turf were more easily crowded out and eliminated by clipping than were the large weeds in established turf.

The demonstration gardens were located in regions where crabgrass is not the serious problem that it is at Arlington, so the crowding out of the bluegrass due to the stimulation of the crabgrass by certain fertilizers was not so evident.

While improvement due to fertilizers on the demonstration gardens was high, the improvement of the old turf at Arlington and the Capital course was several times as much. This was due to the greater abundance of weeds and clover on the check plots on these latter areas and the great increase in density of turf on the fertilized plots. The soil at the Capital course and Arlington was extremely low in fertility and so supported a very poor turf, much worse than that on the average check plots on the demonstration gardens.

The best bluegrass turf was produced on plots having an average soil reaction of pH 5.2 on the demonstration gardens and of pH 5.3 at the Arlington Farm. The unfertilized soil on the various demonstration gardens ranged in acidity from pH 4.7 to 7.5, yet when properly fertilized good turf was produced on all of them. The greatest response to fertilizers was evident on soils having a pH of 5.3 and of 6.7. On the acid soil at Arlington a satisfactory turf could not be produced unless lime was added. However, on the plots having the best turf where lime was added the pH of the soil was still 5.3. These irregularities show that if a soil is acid in reaction it does not necessarily follow that it will grow better bluegrass if the acidity is reduced. Neither does it follow that because the soil is nearly neutral it will not benefit from applications of lime.

The organic fertilizers on the demonstration gardens rated much higher than at Arlington or the Capital course. The organic fertilizers were not so effective in reducing the amount of weeds and clover present in the old turf and naturally did not rate so high at Arlington or the Capital course. In earlier trials at Arlington on turf that had been established recently from seed the organics compared more favorably with the inorganics. The results on these plots were similar to those obtained from the demonstration gardens.

On two of the other gardens (not included in this article) that were located on a sandy soil, marked response from the addition of potassium was noted. On these two gardens, ammonium phosphate and bonemeal produced no marked improvement in the turf. A 12-6-4 produced excellent turf. Evidently this small amount of potassium was sufficient. On the four gardens where the 6-12-4 had a commanding lead, potassium might have been the determining factor. However, since other factors were also involved the potassium influence could not be determined. At Arlington the best turf was produced where potassium was not used.

The response of the turf on the various gardens to the relatively large amounts of phosphorus in the 6-12-4 fertilizer had no relation to the amount of available phosphoric acid originally in the soil. One of the gardens showing the best results from the 6-12-4 originally had the lowest amount of available phosphoric acid, while another garden where the 6-12-4 led had one of the highest amounts of P_2O_5 in the original soil. Activated sludge, with the smallest amount of P_2O_5 of the three leading fertilizers, also led the others on one garden with very low P_2O_5 and on another with the highest available P_2O_5.

The turf produced by any of the three leading fertilizers was good. The improvement produced by the three leading fertilizers was nearly equal on the demonstration gardens. Therefore the relatively small amounts of phosphoric acid or potash supplied by the activated sludge and 12-6-4 apparently were as effective as the larger amounts supplied by the 6-12-4. Since all fertilizers were applied on an equal nitrogen basis a good turf was produced with half the amount of total nutrients with 12-6-4 than with 6-12-4.

The low rating of the stable manure was presumably due to the tendency for it to stimulate the weeds and clover as well as the grass. It was thought that spring and fall may not have been the best time to apply manure. Therefore trials were carried on at the Capital course in which manure was compared with organic and inorganic fertilizers at different months of the year. In no case did it compare favorably with the commercial fertilizers.

The addition of lime alone produced a more marked response on the demonstration gardens than at Arlington or the Capital course. This was especially noticeable during the last year but at this time most of the response was due to the large increase on one garden. In combination with fertilizers at Arlington, however, there was a decided improvement from the use of lime.

The variations in the response of turf to these fertilizers in different years and different sections of the country show the desirability of continuing tests of this kind over a longer period than 5 years. More extended and long-time trials should tend to explain these variations and show whether harmful or beneficial materials accumulate in the soil from fertilizers applied annually to turf.

Peat, muck and sandy soils are generally more deficient in potash than are most clay soils. Fertilizer formulas should be modified accordingly.

WHAT OTHERS WRITE ON TURF

In this department will be given the substance of research in the various fields of scientific investigation which seems to have a definite bearing on turf improvement. The articles will summarize results of recent investigations made in various parts of the world. They are not published here as recommendations but simply as information for our readers and as suggestions which may have practical applications in many situations. Where the Green Section's tests or the information it has obtained from other reliable sources in this country substantiates or contradicts the results obtained by other investigators, comments to that effect may be included as a guide for our readers. In all other cases the reader will receive in brief the results and conclusions as given in the original papers.

LATE FERTILIZING AND SUSCEPTIBILITY OF KENTUCKY BLUEGRASS TO COLD

Numerous experiments have shown that fall is usually the best time to fertilize turf. There are even indications that in some sections fertilizers may advantageously be applied during winter. J. C. Carroll and F. A. Welton, of the Ohio Agricultural Experiment Station, have raised the question of whether the readily available nitrogenous fertilizers applied late in fall made the grass more susceptible to cold. They have investigated this point and have reported their work in Plant Physiology. The results appear to support their contention that grass heavily fertilized in late fall with a readily available source of nitrogen is not able to endure the same degree of cold as unfertilized grass.

Turf for the experiments was grown both in the open and in the greenhouse. Nitrogen was applied to one series of fertilized plots in the open at the rate of 2.5 pounds to 1,000 square feet, at three intervals from April to October, making a total of 7.5 pounds to 1,000 square feet each season. Another area was treated with sulfate of ammonia at the same rate of nitrogen on September 10 and October 12. The greenhouse plantings were made in subirrigated jars and the fertilized jars received three applications of sulfate of ammonia at the rate of 2.5 pounds of nitrogen to 1,000 square feet at each application.

Artificial refrigeration was employed to test the resistance of the grass to cold. Before being placed in the refrigerator the greenhouse grown grass was hardened by being kept at 32° F. for 12 hours. The grass grown in the open was lifted after being hardened naturally.

The hardened greenhouse samples were subjected to different low air temperatures for 8 hours and the percentage of survival noted after 2 weeks. Temperatures used varied from 10° F. to 0° F. At 10° F. 50 percent of the fertilized grass was killed while the unfertilized grass showed little injury. Damage was progressively greater at lower temperatures, and when exposed for 8 hours to 0° F. all of the fertilized and 90 percent of the unfertilized grass was killed.

The field grown samples were lifted at four dates from October 20 to December 1 and subjected to an air temperature of −13° F. for from 2 to 5¼ hours. Determination of the percentage of survival made later showed that in every case the fertilized grass was more readily killed than the unfertilized grass. For example, when the grass was lifted December 1 and exposed for 3 hours to −13° F., the unfertilized grass survived 100 percent, the fertilized only 45 percent. An exposure of 4 hours resulted in the death of 20 percent of the unfertilized grass and 90 percent of the fertilized. This 4-hour exposure lowered the soil temperature to 16° F. An exposure of 5 hours lowered the soil temperature to 9° F. and resulted in the death of 95 percent of the fertilized and 60 percent of the unfertilized grass.

The conclusion is drawn that heavy and late applications of nitrogenous fertilizers may be expected to lessen the resistance of Kentucky bluegrass to cold.

Although these workers have demonstrated a lack of cold resistance in heavily fertilized Kentucky bluegrass under the experimental conditions described it seems doubtful that such results would follow common practice in fertilizing turf. In the experiments described 7.5 pounds of nitrogen were applied to 1,000 square feet during the season, and in one case 5 pounds were applied in late fall. These rates are equivalent to applications of about 1,600 and 1,100 pounds of sulfate of ammonia to an acre respectively. In fertilizer trials on bluegrass fairways in Canada no killing due to low temperatures has been observed when fertilizer was applied at the usual rate.

Field observations on the susceptibility of fertilized bluegrass to low temperatures are complicated by the fact that late fertilized grass is especially susceptible to snowmold. Much of the so-called winter killing of late fertilized bluegrass may be due to this disease rather than to low temperatures.

Kentucky bluegrass occurs naturally over most of North America. Under field conditions in Minnesota, soil temperatures as low as –4° F. for considerable periods have been reported at a depth of 2 inches under the sod. While no actual counts have been made under such conditions observations in the spring have not indicated any difference in the density of moderately fertilized turf due to cold. It would seem, therefore, that the work here reported does not justify a fear that harm will result from low temperatures when turf is moderately fertilized in fall.

WILL WAR AFFECT OUR FERTILIZER SUPPLIES?

Our supply of fertilizers was seriously reduced when the World War cut off some of our importations in 1914. Therefore the question naturally arises, "What effect may the present European war have on fertilizer prices in this country?" According to an editorial in the Fertilizer Review there is apparently no danger of a shortage, nor is there a likelihood of any extreme price increase, as America is in a much better position with reference to fertilizer materials than it was in 1914. The editorial states:

"Then we were almost entirely dependent on Germany for potash and on Chile for nitrates. Then the production of war munitions interfered with the manufacture of superphosphate because sulphuric acid was necessary in large quantities for the manufacture of explosives. Supplies of all three major plant foods—nitrogen, phosphoric acid, and potash—were seriously affected then by war needs or conditions.

"Today we find our own country producing in peace time nearly two-thirds of our potash consumption, with ability, if emergency conditions make it necessary, to produce from our California and New Mexico sources all the potash we need. In addition, France, Spain, Palestine, and Russia are all producing potash, a part of which will no doubt find its way here.

"Chile is no longer the only source of nitrates for plant food and powder. Synthetic processes for the fixation of nitrogen from the air, developed during and after the World War, include the domestic manufacture of nitrate of soda and nitrate of ammonia for agriculture, and nitric acid and its derivatives for explosives. Nitric acid is produced without the use of either nitrate of soda or sulphuric acid so that these materials are released for fertilizer use. Sizeable stocks of nitrate of soda from Chile are already in store and importation continues.

"Sulphuric acid will continue available for superphosphate production and will not be requisitioned for nitric acid manufacture as was the case in the World War. Our phosphate rock reserves are enormous and our production capacity far exceeds any possible domestic demand. In addition our exports of phosphate rock to Germany, our largest foreign customer for this material, have been interrupted by the British blockade.

"Production of ammonia solutions, now equal to the peace-time demand, can be easily and quickly increased to meet an increased war-time demand. Larger quantities of by-product sulphate of ammonia will undoubtedly be available as steel production forces the coking of more coal for blast furnace coke.

"Organic sources of nitrogen, such as vegetable meals and tankages, largely by-products of other industries, will be available in larger quantities as their respective industries increase operations. At present, for tenable reasons, organic materials are the only ones that have risen greatly in price.

"We have a surplus of cotton for bag manufacture and we have available paper bags if the importation of jute for burlap bags should be interrupted, or prices be unduly raised.

"In short, we seem to have on hand or in sight all the materials and supplies necessary for a normal fertilizer season next spring. If production costs increase because of general economic conditions, because of transportation costs, or because of general wage increases, then naturally the cost of fertilizer production will also increase."

As a result of these facts the conclusion is drawn that, "There seems to be no need, either on the part of the manufacturer or the consumer, to lay in extraordinary or unseasonable supplies of fertilizers or fertilizer materials for fear of shortage or unwarranted price increases."

BALANCE SHEET FOR PLANT NUTRIENTS

An interesting balance sheet regarding the annual losses from and additions to the soils of the United States of six of the plant food elements was published by the late Jacob G. Lipman in a New Jersey Agricultural Experiment Station Bulletin. Data were taken from 14,500 analyses of topsoils from all parts of the United States, from census figures of 1930, and from reports of the United States Department of Agriculture, the Geological

Survey, the Department of Commerce and Navigation, the Custom House and the Patent Office. From these data Dr. Lipman, in the light of his wide experience in the problems related to soil science, made the estimates which are included in the following table.

The figures in the table apply to the 1,455,390,414 acres which are considered to be agricultural land. This includes 413 million acres of harvested crop lands, 464 million acres of pastures on farms, and 578 million acres of pastures not on farms such as the large western grazing areas. The remaining land area of 450 million acres is omitted from consideration because of being definitely non-agricultural. It includes forest areas, urban and industrial areas, roads, railroads, parks, deserts, marshes and all waste lands.

The net annual loss of nitrogen is given in the table as somewhat more than 6.5 million tons, but Dr. Lipman considered that 10 million tons would be a reasonably conservative estimate of the annual loss from our crop lands. From figures given elsewhere in the article it is shown that this is 30 times the amount of nitrogen which is supplied annually in fertilizers.

Attention was drawn by the author to the net losses of calcium, potassium and magnesium, the removal of which involves a gradual increase in soil acidity. With the loss of the basic substances of which these elements are a part, there is more intense loss of phosphorus. Dr. Lip-

BALANCE SHEET FOR PLANT NUTRIENTS IN THE SOILS OF THE UNITED STATES IN 1930. ALL FIGURES ARE GIVEN IN TONS

Nutrient Element	Losses (from harvested crops, grazing, erosion, and leaching)	Additions (from fertilizing and liming materials, manures and bedding, rainfall, irrigation waters, seed, and nitrogen fixed by micro-organisms)	Net annual losses
Nitrogen	22,899,046	16,253,862	6,645,184
Phosphorus	4,221,302	1,447,835	2,773,467
Potassium	50,108,560	5,151,076	44,957,484
Calcium	68,185,730	12,561,673	55,624,057
Magnesium	24,557,881	4,040,813	20,517,068
Sulfur	12,043,911	9,029,690	3,014,221

man emphasizes that our soils are suffering a net annual loss of about 3 million tons of phosphorus, or almost 10 times as much as is supplied annually by chemical fertilizers.

Another table gives the sources of the nutrients and the amounts added from each source. It is interesting to note from this table the large amounts of all of these elements except phosphorus which are added to the soil annually in rainfall. In 1930, there were added through rainfall to the agricultural lands in the United States 3,347,395 tons of nitrogen, 1,529,400 tons of potassium, 5,735,250 tons of calcium, 2,294,-100 tons of magnesium, 5,768,900 tons of sulfur and no phosphorus. In that year, the rainfall contributed appreciably more calcium, magnesium and sulfur than did any other one source of these elements. The greatest amounts of nitrogen came from the fixation of atmospheric nitrogen by the micro-organisms in the root nodules of legumes and by those living in the soil itself. Large amounts were added also in rainfall, animal manures, and chemical fertilizers. The major additions of phosphorus were credited to animal manures and commercial fertilizers. The largest amounts of potassium came from animal manures, rainfall, and chemical fertilizers.

NITROGEN OF THE AIR IS NOW A SOURCE OF FERTILIZER

The air over a single acre of soil contains approximately 31,000 tons of free nitrogen, none of which is available to the majority of plants until it is "fixed" in a form which can be used by plants and applied to the soil as a plant nutrient. The bacteria in the nodules of legumes, such as clover and alfalfa, and certain micro-organisms living in the soil have the peculiar ability to "fix" the nitrogen present in the air of the soil and thus enrich the soil in which they grow. Before the World War this was the only way in which this universally distributed source of nitrogen was tapped in the United States for agricultural purposes.

For our nitrogen compounds we were dependent on the great natural deposits such as those of nitrate of soda in Chile. According to figures in a report on Chemical Nitrogen issued by the United States Tariff Commission, in 1900 two-thirds of the world's supply of nitrogen came from the deposits of nitrate of soda in Chile. The remaining one-third was produced as a by-product in the manufacture of coke and gas from coal.

Since 1915, however, procedures have been perfected for the commercial "fixation" of nitrogen of the air in the form of synthetic compounds. In 1934 these synthetic products resulting from the industrial "fixation" of nitrogen of the air furnished 74.5 percent of the world's supply of nitrogen. Only 7 percent came from the deposits in Chile and the remaining 18.5 percent from by-products in the manufacture of coke and gas from coal.

SOIL FERTILITY AFFECTS KENTUCKY AND CANADA BLUEGRASS

The reason why Kentucky bluegrass grows on one soil and Canada bluegrass on another was studied by Hartwig in New York, who published his results in the Journal of the American Society of Agronomy. Two areas were examined, in one of which Kentucky bluegrass (*Poa pratensis*) was dominant, in the other, Canada bluegrass (*Poa compressa*). In both areas patches of the other species occurred and soil samples were taken under each species in both areas.

These areas were studied in various ways. Contrary to the prevailing notion that *Poa compressa* is found on the more acid soils, Hartwig found the acidity of the soil under this species lower than under *Poa pratensis*.

The most important feature was that under *Poa pratensis* there was generally more total nitrogen and more available phosphate than under *Poa compressa*, though the difference in the quantity of phosphate was small. From this it would seem that the former occupied the more fertile spots. This idea is in harmony with Hartwig's observation that in the area where Canada bluegrass is dominant, pastures which receive much manure soon become set with Kentucky bluegrass.

SHADE AFFECTS ACTION OF SULFATE OF AMMONIA ON TURF

Recently two British investigators, Blackman and Templeman, publishing in the Annals of Applied Biology, have discussed certain conditions under which sulfate of ammonia does not benefit grass and discourage clover. Where the shade is deep enough to limit growth (where the light intensity is equal to less than .44 that of daylight) apparently it is the grass and not the clover which is adversely affected by the addition of sulfate of ammonia.

The production of leaves depends upon the grass plant taking up nitrogen from the soil and synthesizing proteins within its cells by chemically combining the absorbed nitrogen with the carbohydrates which are manufactured in the leaves. In full sunlight carbohydrates are assimilated rapidly and are then combined with the nitrogen absorbed from the soil to manufacture proteins and thus produce more leaves.

When grass is growing in the shade, however, it is not assimilating carbohydrates rapidly enough to make use of the nitrogen which is continually being absorbed from the soil. There are carbohydrate storehouses in the roots and lower parts of the shoots and the growing cells draw on these while they last. When the grass is cut a time or two, however, these carbohydrates are removed from the plant. The rate of growth of the grass leaves then becomes directly proportional to the quantity of carbohydrates which can be manufactured in the leaves and hence to the amount of sunshine which the plant receives. The amount of absorbed nitrogen which can be assimilated into proteins in the grass cells is proportional to the amount of carbohydrates produced and hence to the amount of sunlight. This means that not all of the nitrogen which is absorbed in the shade can be used and it therefore accumulates in the plant. The accumulation of nitrogen apparently depresses growth.

The writers were working with Colonial bent (*Agrostis tenuis*), red fescue (*Festuca rubra*) as well as clover (*Trifolium repens*). They demonstrated in their experiments that when these grasses were grown in shade of .44 (or less) of daylight, leaf production was depressed by a high nitrogen supply in the form of sulfate of ammonia. Nitrogen in the form of calcium nitrate depressed leaf production much more than did sulfate of ammonia. As would be anticipated from the foregoing discussion, the depressing effect of nitrogen in the shade became progressively greater with successive cuttings. At the same time there was no such depression in the leaf production of clover. This may have been due to the fact that the clover, unlike the grasses, did not continue actively to absorb nitrogen in the shade.

Copper sulphate is recommended for the control of earthworms, diseases, and other turf pests in Great Britain and New Zealand. In the United States copper compounds were commonly used in turf several years ago and are still used occasionally. They came into general disrepute when it was learned that under some conditions in this country copper accumulated in the soil and caused serious damage to turf.

OUR LETTER BOX

The Green Section receives numerous inquiries concerning local turf problems and is always glad to reply to them. With the hope that some of these questions and answers may be helpful to others besides the original correspondent, a few of them will be published. While most of the answers will have a general application, it should be remembered that each recommendation is intended for the locality designated at the end of the question.

A pitch shot will not stick on the green.—Our greens were raised a little too much when they were first built and it is very difficult to supply them with sufficient moisture. The stand of Bermuda grass is very good, however, and the putting surface is fairly good. Our trouble lies in the fact that it is impossible to make even a high pitch shot stick on the green. In other words, there is not enough of a mat or the mat is too hard to allow the ball to grab when it hits the putting surface. Is it possible to force something like peat moss into the green with a spiked roller? Can you offer another suggestion that might solve our problem? (Georgia.)

ANSWER.—Peat moss worked into the top soil of a putting green tends to make the surface somewhat softer. It is possible to work some of it into the soil by spreading it over the surface and running a spike roller back and forth over it. The most satisfactory method, however, is to mix the peat moss thoroughly with some top soil and apply this mixture in heavy topdressings.

It may be that the more liberal use of fertilizers would encourage a stronger growth of Bermuda grass, which would provide a better mat to hold pitched shots. A heavier growth of grass will usually have much more of a beneficial effect on the holding of pitched shots than will soil improvement by the addition of material such as peat moss.

* * *

Tiling of greens.—We have three greens that are in a location close to a creek in which water flows continuously, yet they are sufficiently high above the water in the creek to permit good drainage if they were tiled. In late spring and summer the ground on these greens becomes sour, and we are of the opinion that this results from the fact that the water does not get away fast enough.

Is fall the proper time of year for tiling? (Illinois.)

ANSWER.—Fall and early winter are good times to install drainage systems. The freezing and thawing of the soil will open up channels to the drains so that by next spring they should function properly. It might be well for you also to check up on the air drainage over your three greens to make sure that no underbrush and trees are interfering with the proper air circulation.

* * *

Variations in color on greens.—Our greens are constructed of heavy clay and sand, but there are places where there has been very little sand worked through the heavy clay. When hard frosts come our greens are left spotted in color. Has soil texture anything to do with the way our greens take on this spotted appearance? (Ohio.)

ANSWER.—The difference in the color of the patches of grass in your greens is probably due to differences in the individual grasses rather than in the soil. Some individual plants are more quickly checked by cold weather than are other plants. Those which continue to grow after the others have become semidormant give the green a spotted appearance.

There are times when a single strain of grass shows these irregularities. This is no doubt due to some soil condition but as yet no one has determined just what these peculiar soil conditions may be. This condition in a single variety is most likely to occur in a heavy poorly drained soil, although it often occurs on an open - textured soil that is well drained.

* * *

Are there different strains of Bermuda grass?—The contention is made that the Bermuda grass growing wild in Virginia is quite different from the plants developed from seed obtained in the Southwest, particularly from the state of Arizona. The stolons of the latter are said to be shorter and do not develop the long internodes so undesirable on lawns and fairways. Is this contention correct? (Virginia.)

ANSWER.—Variations in Bermuda grass may be due to individual differences or to treatment. The fact that the Virginia grass is coarser may be due to the fact that the coarser plants survive the winter better, but it is also due in part to the lack of competition in spring by reason of the winter killing of some of the grass. Arizona seed represents a conglomeration of strains, both coarse and fine. In the seedling stage all Bermuda grass tends to be much finer than it is when well established. As a result the seedlings of Arizona Bermuda grass appear finer regardless of how much of the coarser stock there may be in it.

* * *

Best bents for northern sections.—To assist our club in reaching a decision as to the best type of grass for the greens, I am writing to find out what information and advice you can give me in respect to the three different types that are under consideration. The grasses in question are New Brunswick bent, Washington bent and Metropolitan bent. (Ontario.)

ANSWER.—New Brunswick bent is a seaside creeping bent, seed of which is produced in New Brunswick. Washington and Metropolitan bents are both creeping bents and are propagated by stolons. Any of these three grasses should give you satisfactory turf for putting greens. The seaside bent is much more susceptible to snowmold than most of the other common bents used for putting green turf. The Washington and Metropolitan bents, although they are subject to attacks of snowmold fungus under certain conditions, are very resistant to the disease and ordinarily are not seriously damaged by it. Since you are in a region where the snowmold disease may be very troublesome it would perhaps be wise for you to use some grass other than the New Brunswick bent. Either the Washington or the Metropolitan should be satisfactory. The Washington is a little finer than the Metropolitan bent but it has the objection that it becomes discolored during cool weather. This discoloration, however, does not affect its putting qualities.

* * *

Pearlwort.—We are sending to you today a piece of sod infested with a weed. Will you kindly tell us if this weed is pearlwort and what is the best method of extermination? What can we do to prevent it from coming into our sod another year? (New York.)

ANSWER.—The weed you sent was pearlwort. Although under certain conditions this weed may grow in turf that is kept fairly dry, as a rule it is most troublesome in poorly drained or overwatered turf. We therefore suggest that you immediately check up on the possibility of poor drainage, especially seepage water coming into the area from hillsides. If the drainage is adequate we suggest that you try watering less. One of the best remedies for pearlwort is to sprinkle sulfate of ammonia on the spots in much the same way as you treat for clover.

UNITED STATES GOLF ASSOCIATION
ORGANIZED 1894