Nitrogen Form and Rate of Nitrogen and Chloride Application for the Control of Summer Patch in Kentucky Bluegrass

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ABSTRACT

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The influence of nitrogen form and rate of nitrogen and chloride application on turf quality and summer patch severity was assessed in Kentucky bluegrass cv. Fylking at one site for 2 yr. Plots were artificially inoculated with a five-isolate mixture of *Magnaporthe poae* in 1990. Every 3 wk, varying rates of ammonium sulfate or calcium nitrate (to supply 0, 98, or 196 kg N ha^{-1} yr^{-1}) and combinations of potassium sulfate and potassium chloride (to provide 0, 122, or 244 kg Cl ha^{-1} yr^{-1}) were applied from May to October during 1990 and 1991. In 1990, patch diameter, patch severity, and rhizosphere pH were slightly reduced by the application of ammonium sulfate. In 1991, onset of summer patch symptoms was delayed, and patch development and pH of the rhizosphere and bulk soil were greatly reduced where ammonium sulfate was applied. The high (196 kg N ha^{-1} yr^{-1}) rate of ammonium sulfate reduced summer patch severity up to 75% compared with the same rate of calcium nitrate. Chloride application did not influence disease severity, turf quality, or soil pH. In general, turf quality was not significantly influenced by the form of nitrogen or the rate of nitrogen application.

Additional keywords: cultural management, fertility

Patch diseases caused by several root- and crown-infecting fungi are among the most destructive turfgrass diseases in the northeastern United States. Snow and Watschke (31) reported that at least two-thirds of the golf courses in the northeast have been damaged by patch diseases. Once established, these diseases can markedly reduce the overall appearance and quality of sport and recreational turf (24,30).

A recent survey of high-maintenance turf affected by patch diseases in New Jersey, metropolitan New York, and southeastern Pennsylvania found that *Magnaporthe poae* Landschoot & Jackson, the causal agent of summer patch (17,18), was associated with approximately 85% of the patches observed (16). *M. poae* is an ectotrophic root colonizer on many grasses but usually only produces summer patch symptoms on annual bluegrass (*Poa annua* L.), Kentucky bluegrass (*P. pratensis* L.), and fine fescues (*Festuca* spp.) in the field (19).

Nitrogen (N) fertilization affects diseases in many crops. Huber and Watson (12) established that N form (nitrate vs. ammonium) is more important than N rate in determining the severity of many plant diseases. Forms of N that acidify the soil and rhizosphere have been used to suppress cortical and root-infecting fungi for years on nonturf crops (12). A reduction in the rhizosphere pH of wheat roots has been reported to increase the uptake and availability of manganese (Mn) and to reduce the development of take-all, caused by *Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *tritici* J. Walker (11,13). Ammonium sulfate has also been used to control take-all patch on bentgrass (*Agrostis* spp.) putting greens, caused by *G. g. avenae* (E.M. Turner) Dennis (2,5). More recently, sulfur-coated urea was used to reduce summer patch in Kentucky bluegrass (3,4).

Ammonium forms of N cause a reduction in the pH of the rhizosphere soil when taken up by the plant and in the bulk soil as nitrification takes place, whereas nitrate N causes the rhizosphere pH to increase (29). Sulfur-coated urea slowly releases N as the sulfur coating is degraded, resulting in moderate acidification of the bulk soil (14,25).

Chloride (Cl) has been reported to reduce the severity of at least 16 different foliar and root diseases on 11 nonturf crops (1,8,27,28,32). In one instance, the ratio of Cl to potassium in plant tissue was found to be highly correlated with visual symptom development (27). Increased Cl uptake can reduce the synthesis of malate in potato plants (20), a carbon substrate that might be utilized by plant pathogens.

Davis and Dernoeden (4) reported that bulk soil pH and summer patch severity were decreased when sulfur-coated urea was applied to turf. However, it is difficult to evaluate the significance of this report, since disease occurred during only 1 yr of their study.

This study was conducted to determine: 1) the effect of applying various rates of ammonium or nitrate N on the soil and rhizosphere pH of Kentucky bluegrass turf; 2) whether lowering the soil and rhizosphere pH influences summer patch, Mn concentration in plant tissue, or turf quality; and 3) the impact of Cl applications on soil and plant tissue Cl levels, summer patch development, and turf quality.

MATERIALS AND METHODS

This study was conducted during 1990 and 1991 in New Brunswick, New Jersey, on a 2-yr-old stand of the Kentucky bluegrass cv. Fylking. The turf was growing on a Sassafras sandy loam (Typic Hapludult) with an initial pH of 6.6 (1:1, v/v, soil:water suspension). Initial soil test phosphorus and potassium levels were reported at 279 kg ha^{-1} and 249 kg ha^{-1}, respectively (Rutgers University Soils Laboratory). The turf was mowed weekly at a height of 3.8 cm. Irrigation was used to supplement measured rainfall and provide a total of 2.5 cm of water per week. No insecticides or herbicides were applied.

Ammonium sulfate or calcium nitrate were applied to supply 0, 98, or 196 kg N ha^{-1} yr^{-1}. Potassium chloride and potassium sulfate were applied in different ratios to provide 405 kg K_2O ha^{-1} yr^{-1} and 0, 122, or 244 kg Cl ha^{-1} yr^{-1}. Individual plots were 1.5 × 1.5 m. Treatments were arranged in a randomized complete block with four replications. All nutrients were dissolved in 2 L of water and applied to each plot with a plastic watering can; the watering cans were thoroughly rinsed between treatments. The first application of each growing season was made after the initiation of active growth and green coloration, 5 May 1990 and 19 April 1991. Subsequent applications were made every 3 wk for a total of 10 applications each year. Treatments were applied to the same plots in both years. Approximately 1 cm of irrigation was applied following fertilization.

Five isolates of *M. poae* that were highly virulent on Kentucky bluegrass in controlled environment studies (*data not shown*) were selected for the inoculum.

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The five isolates were grown separately on sterile oats (*Avena sativa* L.) for 6 wk at the ratio of 250 g of oats to 230 ml of water, air-dried, and then mixed in equal quantities to produce the inoculum. Individual plots were inoculated on 6 June 1990 at two sites with 20 cm^3 of inoculum and two sites with 40 cm^3 of inoculum. The four inoculation sites were randomly arranged at the four corners of a 0.6 × 0.6 m square in the center of each plot. Colonized oat inoculum was placed in a 5.0-cm-diameter hole so that the top of the inoculum was 2.5 cm below the surface. The inoculum was then covered with soil and sod to attain the original turf height.

Summer patch was evaluated every 7–14 days beginning with the first observation of symptoms. The diameter of an individual patch was calculated by averaging two perpendicular measurements. Each patch was given a disease intensity rating on a 0–3 scale, where 0 = no observable symptoms, 1 = a few necrotic grass plants in the patch, 2 = many necrotic grass plants in the patch, and 3 = all plants in the patch necrotic. Patch severity was calculated by multiplying patch diameter by patch intensity. The area under the disease progress curve (AUDPC) was calculated as a summation, for all dates of observation, of the average patch severity between two consecutive observation dates, multiplied by the number of days between the observations. Turf quality was assessed at the time summer patch was evaluated on a 1–10 scale, with 10 = the best quality turf. Turf quality incorporated many factors, including stand density and plant color, but did not take summer patch severity into consideration. Turf rated 8 or higher was generally considered acceptable in quality, a rating between 7 and 8 indicated a slight decline in quality, and ratings below 7 indicated a substantial decline; ratings below 6 indicated very weak turf or turf severely damaged by environmental stress or chemical applications.

Levels of Cl were evaluated from soil obtained at the 0–15 cm and 15–30 cm depths on 13 July 1990. Soil (0–15 cm depth) and plant tissue were assayed for Cl levels on 20 June and 24 June 1991, immediately before and 4 days after an application of Cl, respectively. Plots were not mowed between 20 and 24 June. Three soil cores, 2.5 cm in diameter and 15 cm deep, and 100 grab samples of leaves were randomly selected from each plot and used to estimate the Cl level. Concentration of Cl was determined with a Chloridometer (Buchler Instruments, Lenexa, KS). Soil was air-dried and mechanically ground to pass through an 18-mesh screen (1.0-mm openings). Plant tissue samples were dried in an oven at 70 C and ground in a Wiley mill to pass through a 20-mesh screen (0.84-mm openings). Chloride was extracted from soil (25 cm^3) or dried ground plant tissue (0.5 g) by agitation in 50 ml of an acid solution (6.4 ml of 15.8 N nitric acid, 100 ml of 17.4 N glacial acetic acid, and 900 ml of distilled water) for 5 min or 12 hr, respectively (10). Soil Cl was measured in the clear supernatant after 4 hr. Tissue Cl levels were measured after 24 hr and compared with a tomato leaf standard. The Mn concentration of leaves, obtained on 24 June 1991, was determined using 1.0 g of dried ground subsamples that were ashed, dissolved in acid, and assayed by emission spectrometry with a Direct Current Plasma Excitation Spectrometer (Fison Instruments, Dearborn, MI).

The pH of bulk and rhizosphere soil was measured on 7 July 1990. In 1991, the pH of bulk soil and the rhizosphere pH were measured on 28 May and 16 July. Soil samples were collected from plots as described for Cl collection. Rhizosphere soil was collected by gently crumbling bulk soil from the grass roots, allowing the soil adhering to the roots to air-dry for 24 hr, and then removing the remaining "rhizosphere" soil from the roots. Soil pH was measured in a constantly stirred 1:1 soil:water suspension of 25 cm^3 of bulk soil or 5.0 g of rhizosphere soil (v/v for bulk soil, w/w for rhizosphere soil). A 0.01 M $CaCl_2$ buffer:soil suspension was used in addition to the water suspension during the pH measurement on 28 May 1991.

Data were analyzed by the Statistical Analysis Systems (SAS, Cary, NC) analysis of variance and linear regression programs. The Waller-Duncan k-ratio t test was used at $k = 100$, which approximates $P = 0.05$, for multiple comparison of means and estimation of the minimum significant differences between means.

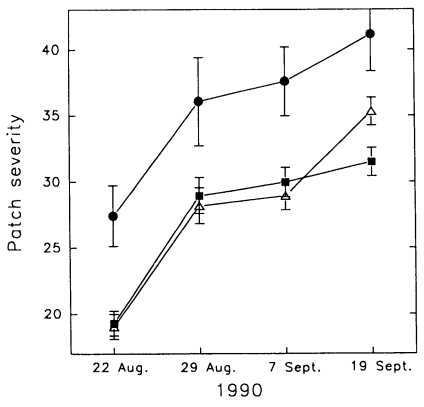

Fig. 1. Summer patch development in 1990 on Kentucky bluegrass cv. Fylking treated with ammonium sulfate (■), calcium nitrate (●), or no nitrogen (△) during the 1990 growing season. For each nitrogen form, patch disease severity values represent the average of the 98 and 196 kg N ha^{-1} yr^{-1} treatments, since no other significant differences ($P < 0.05$) were detected. Bars indicate standard errors of the means. Patch severity values are averages of 96 distinct disease patches (four patches × two nitrogen rates × three chloride rates × four replications).

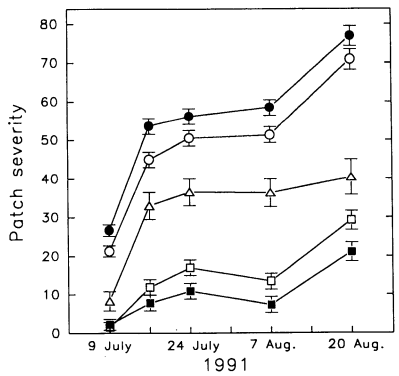

Fig. 2. Summer patch development in 1991 on Kentucky bluegrass cv. Fylking treated in 1990 and 1991 with ammonium sulfate (□ = 98 kg N ha^{-1} yr^{-1}, ■ = 196 kg N ha^{-1} yr^{-1}), calcium nitrate (○ = 98 kg N ha^{-1} yr^{-1}, ● = 196 kg N ha^{-1} yr^{-1}), or no nitrogen (△). Bars indicate standard errors of the means. Patch severity values are averages of 48 distinct disease patches (four patches × three chloride rates × four replications).

RESULTS

Summer patch symptoms were more severe when the turf was fertilized with nitrate N than with ammonium N (Figs. 1 and 2, Table 1). In 1990, patch diameter was approximately 2.5 cm larger (*data not shown*) and patch severity was significantly greater when nitrate N was applied than when ammonium N was used (Fig. 1). Inoculum level had a significant impact on summer patch severity in 1990 (*data not shown*), but the effect was smaller than that of the N form. The differences in summer patch severity between turf treated with ammonium N and that treated with nitrate N observed in 1990 were intensified in 1991 (Fig. 2). A significant interaction occurred between the N form and the rate of N application in 1991 (Table 1). The greatest amount of disease occurred where the high rate of nitrate N was applied, followed by the low rate of nitrate (Fig. 2). In contrast, the least amount of disease developed where the high rate of ammonium N was applied. Summer patch severity was slightly increased where the lower rate of ammonium N was applied as compared with the high rate. Summer patch severity was reduced by 75% where turf received the high rate of ammonium sulfate as compared with the high rate of calcium nitrate. When no N was applied, summer patch development was intermediate between the nitrate N and ammonium N treatments.

The rate of Cl application did not significantly influence summer patch severity (Table 1). Soil Cl levels varied according to the amount of Cl applied (Table 2). The Cl levels were greater in the top 15 cm of soil than at 15–30 cm and were also greater immediately following application than at 3 wk after application. In 1991, there was no significant effect of N application rate on

the level of Cl in leaf tissue 3 days after fertilization (24 June). However, 3 wk after fertilization (20 June), leaf tissue Cl levels increased where the rate of N application was increased. The form of N and the rate of Cl application did not significantly affect leaf tissue Cl levels.

In 1991, Mn concentrations in leaf tissue were twofold greater with ammonium N fertilization than with nitrate N fertilization (Table 2). Significant ($P < 0.05$) negative linear relationships were identified between Mn leaf tissue concentrations and the pH of bulk and rhizosphere soil ($R^2 = 0.19$ and 0.53, respectively).

In 1990, the rhizosphere pH, but not the bulk soil pH, was decreased by the application of ammonium N compared with nitrate N (Table 3). The rhizosphere pH of turf fertilized with the high rate of ammonium N was approximately 0.4 units lower than when with the high rate of nitrate N. In 1991, the rhizosphere pH continued to decrease with further application of ammonium N. Where turf received either 122 or 244 kg Cl ha^{-1} plus the high rate (196 kg N ha^{-1}) of ammonium N, the rhizosphere pH was decreased on 28 May and 16 July. Bulk soil pH was also reduced by the application of ammonium N compared with nitrate N in 1991. The greatest reduction in rhizosphere and bulk soil pH occurred at the high application rate of ammonium N. For a small subset of samples, 0.01 M $CaCl_2$ buffer was used in the soil suspension in addition to evaluation in water. The 0.01 M $CaCl_2$ buffer caused a reduction in the soil pH of 0.4–0.5 units when the water suspension pH values were above 6.0 and a reduction of 0.1–0.3 units when the water suspension pH values were below 6.0 (*data not shown*).

In 1990 and 1991, significant positive linear relationships were observed between either bulk or rhizosphere pH and patch severity, represented as the AUDPC (Fig. 3). The R^2 values were 0.70 ($P = 0.0076$) and 0.58 ($P = 0.0378$) for bulk and rhizosphere soil, respectively, on 17 July 1990. In 1991, the R^2

Table 1. Analysis of variance for the effect of nitrogen form and the rate of nitrogen and chloride application on summer patch severity, evaluated as the area under the disease progress curve[a], in Kentucky bluegrass cv. Fylking during 1991

Source	df	Mean squares	$P > F$
Nitrogen form (NF)[b]	1	125956088.3	0.0001
Nitrogen rate (NR)[c]	1	25974.4	0.7509
Chloride rate (CR)[d]	2	508711.7	0.1414
NF × NR	1	2859734.9	0.0011
NF × CR	2	46789.8	0.8337
NR × CR	2	698530.3	0.0690
NF × NR × CR	2	189725.9	0.4795
Error[e]	164	256979.3	...

[a]The area under the disease progress curve is based on the disease severity of individual diseased patches. Summer patch severity was calculated as the product of patch diameter and patch intensity. Patch diameter was measured in two perpendicular directions and averaged. Patch intensity was evaluated on a 0–3 scale, where 0 = no observable patch symptoms, 1 = a few necrotic plants in patch, 2 = many necrotic plants in patch, and 3 = all plants in patch are necrotic. The area under the disease progress curve was calculated as a summation of the average patch severity between 2 days of observation × the number of days between the observations.

[b]Nitrate and ammonium nitrogen were applied as calcium nitrate and ammonium sulfate, respectively.

[c]Nitrogen was applied at the rate of 98 or 196 kg N ha^{-1} yr^{-1}. Applications were made every 3 wk during the growing season beginning 5 May 1990 and 19 April 1991. Ten applications were made each year.

[d]Chloride was applied with the N as potassium chloride at the rate of 0, 122, or 244 kg Cl ha^{-1} yr^{-1}. Potassium sulfate was applied at different ratios with potassium chloride to provide 405 kg K_2O ha^{-1} yr^{-1}.

[e]There were four replications of each treatment arranged in a randomized complete block design.

Table 2. Influence of nitrogen form and the rate of nitrogen and chloride application on the concentration of chloride in soil during 1990 and 1991 and on the concentration of chloride and manganese in leaf tissue of Kentucky bluegrass cv. Fylking during 1991

			Soil chloride (g/kg)[d]				Leaf chloride and manganese[e]		
			13 July 1990		20 June 1991	24 June 1991	Cl (g/kg)		Mn (mg/kg)
Nitrogen form[a]	Nitrogen rate[b] (kg/ha/yr)	Chloride rate[c] (kg/ha/yr)	0–15 cm	15–30 cm	0–15 cm	0–15 cm	20 June 1991	24 June 1991	24 June 1991
Nitrate	98	0	9.5	2.8	4.3	9.6	0.89	0.81	43.3
Nitrate	196	0	7.6	5.7	4.3	11.0	0.98	0.78	44.3
Ammonium	98	0	11.0	4.8	3.5	8.9	0.83	0.82	64.6
Ammonium	196	0	9.3	4.5	2.8	10.8	0.90	0.81	84.1
Nitrate	98	122	13.1	7.5	6.2	15.8	0.87	0.88	44.5
Nitrate	196	122	16.1	7.5	6.4	13.9	0.99	0.85	44.0
Ammonium	98	122	16.8	6.9	6.0	14.1	0.88	0.88	70.2
Ammonium	196	122	14.3	7.8	5.4	16.4	0.96	0.95	81.6
Nitrate	98	244	19.1	10.1	7.9	14.3	0.88	0.85	49.0
Nitrate	196	244	17.9	10.8	7.7	17.2	0.98	0.89	39.9
Ammonium	98	244	18.5	9.6	7.7	21.3	0.90	0.93	75.1
Ammonium	196	244	18.8	10.7	7.7	17.4	0.97	0.95	79.4
None	0	0	9.3	6.1	4.6	8.9	0.74	0.70	48.6
MSD ($P = 0.05$)[f]			4.4	3.6	2.4	5.8	0.06	0.07	9.2

[a]Nitrate and ammonium nitrogen were applied as calcium nitrate and ammonium sulfate, respectively.

[b]Nitrogen was applied every 3 wk for a total of 10 applications each year during the 1990 and 1991 growing seasons beginning 5 May 1990 and 19 April 1991.

[c]Chloride was applied with the nitrogen treatment as different ratios of potassium chloride and potassium sulfate to provide the different chloride rates and an equivalent potassium level of 405 kg K_2O ha^{-1} yr^{-1}.

[d]Soil chloride concentration was determined in a 25-cm^3 subsample from three 2.5-cm-diameter × 15-cm-deep soil cores per plot. Soil samples, taken on 13 July 1990 and 24 June 1991 were obtained 3 or 4 days after an application of chloride, respectively; samples taken on 20 June 1991 were obtained 1 hr before a chloride application.

[e]Leaf chloride and manganese concentrations were determined in 1991 in a 0.5-g and 1.0-g subsample, respectively, of ground, dried leaf tissue. Tissue samples, obtained on 20 and 24 June 1991, were taken just before and after a chloride application, respectively.

[f]Minimum significant difference between means according to the Waller-Duncan k-ratio multiple comparison t test at $k = 100$.

values increased to 0.93 ($P = 0.0001$) and 0.87 ($P = 0.0001$) for bulk and rhizosphere soil, respectively, on 16 July.

Turf quality was acceptable at all times during the experiment (Table 4), although it was higher in 1990 than in 1991. In the early spring, turf quality was slightly lower when no N was applied than when turf was fertilized with either form or rate of N (*data not shown*). There were statistical differences in turf quality attributable to the N form and to the rate of N and Cl application, but they were neither large nor consistent.

DISCUSSION

The ability of ammonium N to reduce rhizosphere soil pH in nonturf crops is well documented (22,23,29). After two growing seasons of applying 196 kg ha^{-1} yr^{-1} ammonium N, a common rate of application in turfgrass culture, the bulk soil pH of Kentucky bluegrass turf in our study decreased from 6.6 to 5.8; the rhizosphere pH was 5.2 but was not initially measured. Marschner and Romheld (22), who grew roots in agar and measured pH with glass microelectrodes, reported that ammonium sulfate could lower the rhizosphere pH down to 4.0 to 4.5, depending on the plant species evaluated. Weinberger and Yee (33) reported ammonium N decreased the rhizosphere pH of wheat seedlings grown on nutrient agar to below 4.0.

In our study, we found a significant reduction in the development of summer patch, through the cumulative effect of lowering soil and rhizosphere pH over a period of 2 yr, by applying N as ammonium sulfate. Lower pH in the soil and rhizosphere may reduce the severity of summer patch by either direct or indirect means. One possible direct mode of action may be to reduce the growth of *M. poae*. Studies involving take-all disease of wheat have shown that the primary effect of reduced soil pH is through the increased availability of Mn (11,13,34). Take-all of wheat is also decreased when high rates of Cl are applied with ammonium N fertilizers (1). The mechanism of action for Cl has been postulated to be the inhibition of nitrification (26) and the increased availability of Mn in the soil (15). Inhibition of nitrification stabilizes N in the ammonium form and decreases the rhizosphere pH as it is taken up by the plant (29). In our study, Mn uptake was not increased by Cl; however, the concentration of Mn in leaf tissue was increased by the application of ammonium N. This corresponded to a subsequent decrease in rhizosphere pH. If Cl in the soil did inhibit nitrification, it was evident only in the reduced rhizosphere pH of plants fertilized with the high rate of ammonium N in 1991. However, these further reductions in rhizosphere pH where Cl had been applied may not have increased the availability of Mn, since the pH was already in the optimum range for high Mn availability. The lower soil pH following application of ammonium N was associated with a twofold increase in leaf tissue Mn concentrations, even though the Mn concentrations in leaf tissue of the nitrate fertilized turf were above levels considered sufficient for the growth of most crops (21).

Application of Cl did not affect summer patch development. Soil Cl levels were increased by raising the rate of Cl application, but tissue Cl levels did not increase similarly. The spread of Cl between plots seems unlikely, however, since the N sources used in this study have water solubilities similar to those of Cl and since distinct borders were always discernible between the N-fertilized and unfertilized plots. Apparently, factors other than the concentration of Cl in the soil may limit the uptake of Cl in Kentucky bluegrass.

Thirty-five years of experience with ammonium sulfate fertilization of

Table 3. Influence of nitrogen form and the rate of nitrogen and chloride application on bulk and rhizosphere soil pH in Kentucky bluegrass cv. Fylking during 1990 and 1991

Nitrogen form[a]	Nitrogen rate[b] (kg/ha/yr)	Chloride rate[c] (kg/ha/yr)	Soil pH[d] 7 July 1990 B	7 July 1990 R	28 May 1991 B	28 May 1991 R	16 July 1991 B	16 July 1991 R
Nitrate	98	0	6.3	5.9	6.4	6.2	6.4	5.9
Nitrate	98	122	6.3	5.9	6.3	6.2	6.3	5.9
Nitrate	98	244	6.4	5.9	6.5	6.4	6.5	6.1
Nitrate	196	0	6.3	6.0	6.5	6.4	6.5	6.1
Nitrate	196	122	6.2	6.0	6.4	6.2	6.4	5.9
Nitrate	196	244	6.4	6.1	6.5	6.2	6.6	5.9
Ammonium	98	0	6.2	5.8	6.1	5.9	6.1	5.6
Ammonium	98	122	6.3	5.8	6.1	5.9	6.1	5.6
Ammonium	98	244	6.2	5.6	5.9	5.7	5.9	5.4
Ammonium	196	0	6.2	5.5	5.8	5.8	5.8	5.5
Ammonium	196	122	6.1	5.6	5.7	5.3	5.7	5.0
Ammonium	196	244	6.2	5.7	5.8	5.3	5.8	5.0
None	0	0	6.3	5.8	6.2	6.0	6.2	5.7
MSD ($P = 0.05$)[e]			0.2	0.2	0.2	0.3	0.2	0.3

[a] Nitrate and ammonium nitrogen were applied as calcium nitrate and ammonium sulfate, respectively.

[b] Nitrogen was applied every 3 wk for a total of 10 applications each year during the 1990 and 1991 growing seasons beginning 5 May 1990 and 19 April 1991.

[c] Chloride was applied with the nitrogen treatment as different ratios of potassium chloride and potassium sulfate to provide the different chloride rates and an equivalent potassium level of 405 kg K_2O ha^{-1} yr^{-1}.

[d] B = bulk soil pH measured on a 1:1 soil:water suspension of soil, gently removed from grass roots, using a 25-cm^3 subsample obtained from three 2.5-cm-diameter × 15-cm-deep soil cores per plot. R = rhizosphere soil pH measured using 5.0 g of soil in a 1:1 soil:water suspension. Rhizosphere soil was obtained by removing bulk soil, air-drying the remaining soil and roots for 24 hr, and then gently rubbing the rhizosphere soil from the dried roots.

[e] Minimum significant difference between means according to the Waller-Duncan k-ratio multiple comparison t test at $k = 100$.

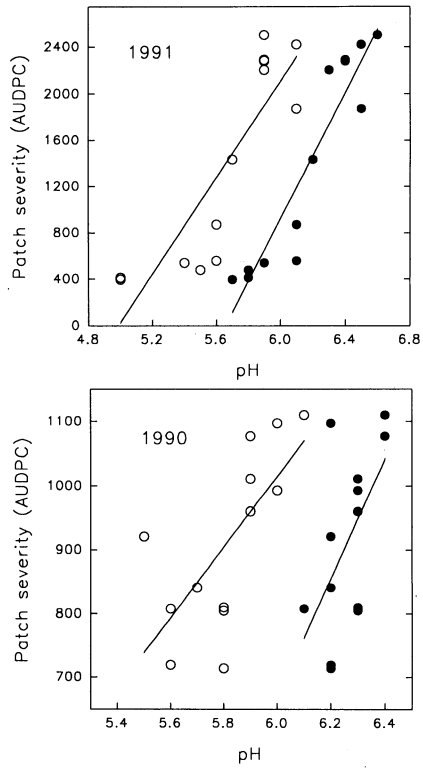

Fig. 3. Relationship between summer patch severity, expressed as the area under the disease progress curve (AUDPC), and bulk soil pH (●) and rhizosphere soil pH (○) of Kentucky bluegrass cv. Fylking treated with ammonium sulfate, calcium nitrate, or no nitrogen in 1990 and 1991. R^2 values for bulk soil pH and rhizosphere soil pH were 0.70 and 0.58, respectively, in 1990 and 0.93 and 0.87, respectively, in 1991.

Table 4. Influence of nitrogen form and the rate of nitrogen and chloride application on turf quality of Kentucky bluegrass cv. Fylking during 1990 and 1991

Nitrogen form[a]	Nitrogen rate[b] (kg/ha/yr)	Chloride rate[c] (kg/ha/yr)	Turf quality[d] 13 Aug. 1990	19 Sept. 1990	7 July 1991	20 Aug. 1991
Nitrate	98	0	8.3	9.0	7.4	7.8
Nitrate	98	122	8.3	9.0	7.6	7.5
Nitrate	98	244	8.0	8.8	7.6	7.4
Nitrate	196	0	8.3	9.3	8.0	8.0
Nitrate	196	122	8.0	9.0	7.6	7.9
Nitrate	196	244	7.5	9.0	7.7	7.5
Ammonium	98	0	8.5	9.0	7.9	7.5
Ammonium	98	122	8.8	9.3	7.5	7.5
Ammonium	98	244	9.0	8.5	7.4	7.6
Ammonium	196	0	8.8	8.3	7.8	7.8
Ammonium	196	122	8.8	8.5	7.8	7.9
Ammonium	196	244	8.8	8.8	7.4	7.8
None	0	0	8.8	8.3	7.4	7.6
MSD ($P = 0.05$)[e]			0.3	0.4	0.3	0.2

[a]Nitrate and ammonium nitrogen were applied as calcium nitrate and ammonium sulfate, respectively.
[b]Nitrogen was applied every 3 wk for a total of 10 applications each year during the 1990 and 1991 growing seasons beginning 5 May 1990 and 19 April 1991.
[c]Chloride was applied with the nitrogen treatment as different ratios of potassium chloride and potassium sulfate to provide the different chloride rates and an equivalent potassium level of 405 kg K_2O ha^{-1} yr^{-1}.
[d]Turf quality was measured on a 1-10 scale, where 10 = the best quality turf. The turf quality was evaluated on many factors, including plant density and color, but did not consider summer patch severity.
[e]Minimum significant difference between means according to the Waller-Duncan k-ratio multiple comparison t test at $k = 100$.

Agrostis turf at the Sports Turf Research Institute, Bingley, England, has shown that use of ammonium sulfate leads to the development of fine, wear-tolerant turf that is free from weeds and earthworm activity (9). Unfortunately, they also found that the prolonged use of ammonium sulfate as the only N source may eventually cause soil to become too acidic, plants to lose vigor and have poor winter color, and turf to be more susceptible to drying out during periods of drought. To prevent such problems, they recommended the occasional use of other forms of N and the correction of soil acidity with lime when necessary. The weed reduction achieved with ammonium sulfate at Bingley included annual bluegrass. Eggens et al (6,7) also reported that increasing the percentage of ammonium in ammonium-nitrate fertilizers resulted in reduced growth of annual bluegrass and that at mid to high ammonium:nitrate ratios, the growth rate of some *Agrostis* cultivars was greater than that of annual bluegrass.

The pH level at which disease is suppressed, the impact of different soil types on disease development, and the mode of action of pH in reducing disease need to be determined. Additional methods of reducing pH and their incorporation into turfgrass management programs should also be evaluated. The reduction of take-all disease of wheat grown at a rhizosphere pH of 5.0–6.6 was attributed to an indirect biological effect (29). Below a pH of 5.0, disease reduction was considered to be a direct effect of rhizosphere pH on the fungus. Another possible explanation is that the level of disease resistance may have been enhanced by the increased availability of Mn (13). High biological activity present in the 5.0–6.6 pH range may offer additional opportunities to evaluate mechanisms of disease suppression.

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