Nitrate and Phosphorus Leaching and Runoff from Golf Greens and Fairways

2000 Annual Report to the United States Golf Association

Dr. Larry M. Shuman

University of Georgia, Griffin, GA

Executive Summary

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Two runoff experiments were carried out in 2000 on bermudagrass plots with a 5% slope. We repeated an experiment using 10-10-10 at 3 rates and carried out a similar experiment except that 0.25" irrigation was added after application (watered-in) before simulated rainfall events. Most P was transported at the first rainfall event where step-wise increases in P concentration and mass were found for the 5 and 11 kg P ha^{-1} rates. Results compare well with these found the first year. The results of "watering-in" have not been evaluated.

An eight-source experiment at one rate (11 kg P/ha) was carried out in the greenhouse on columns made to USGA specifications for greens and sodded with bermudagrass. Treatments were added 4 times. Cumulative P mass rose rapidly for the soluble 20-20-20 and the granular 16-25-12 (Fig. 1). The next two were the granular 13-13-13 and 10-10-10 with the other 4 sources being lower with respect to P leaching. Five sources had similar N rates (24 kg N/ha)and could be compared. A soluble 20-20-20 source had the highest N loss based on that added (15.7%) whereas a poly- and sulfur-coated microgranule 13-13-13 and sulfur-coated urea had the lowest (3.4 and 1.8%, respectively).

Four treatments at three rates were made to field lysimeters in 1999 with the sources being a granular poly- and sulfur-coated 13-13-13 and a water soluble 20-20-20. In the spring of 1999 we started a series of treatments that showed treatment effects. Treatments were added first on April 2, 1999 (week 32) and again on weeks 40 and 47. The P treatments began to be evident as increased P concentration in the leachate after week 64 in November, 1999. This is really the only P response found in the entire three years of the experiment. The soluble 20-20-20 source gave a higher and earlier peak than for the controlled-release 13-13-13 for the high P rate (Fig.2).

The 1999 P concentration and mass data show that P in the leachate was again very low for the practice green built in 1994 in Atlanta. The new playing greens, built in the fall of 1998, show a P concentration peak just after start-up with decreases thereafter. This data corresponds with data from 1995 for the practice greens where P concentrations were high initially. The P comes from starter fertilizer and possibly from the peat in the sand-peat mix. Nitrate concentrations and mass followed a trend similar to that for P and were generally below the 10 mg L^{-1} drinking water standard.

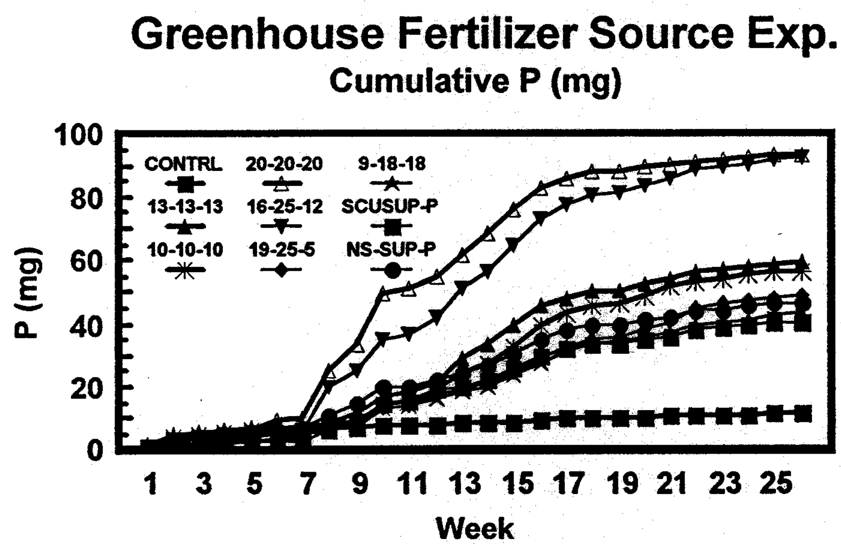

Fig. I. Cumulative mass of P transported through simulated green columns in the greenhouse for 8 fertilizer sources.

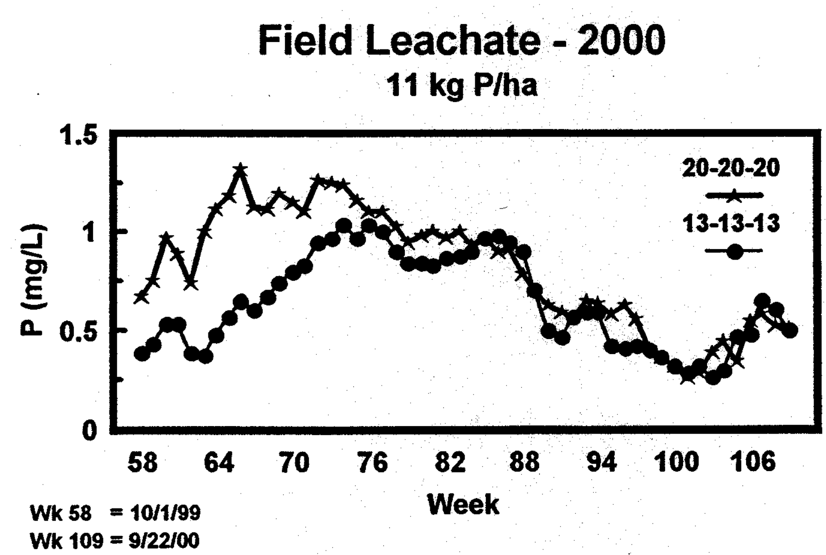

Fig. 2. Concentration of P transported through simulated green field lysimeters for 2 fertilizer sources at 11 kg P/ha.

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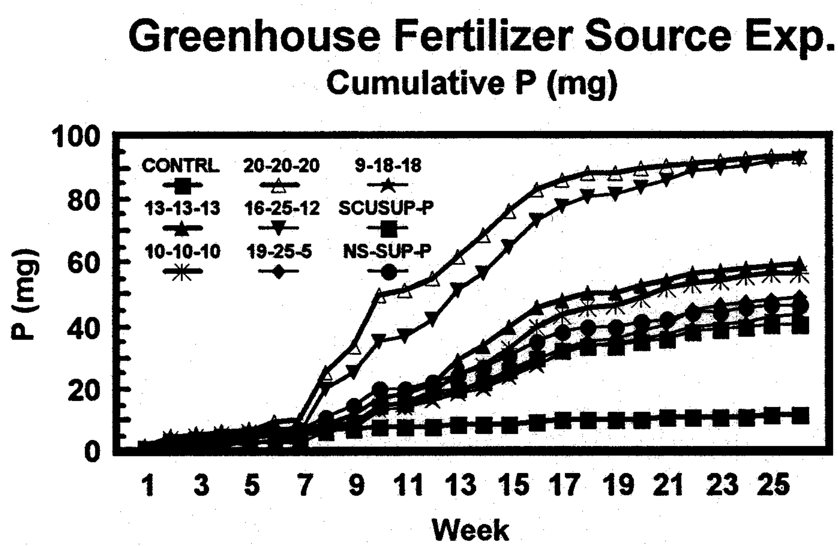

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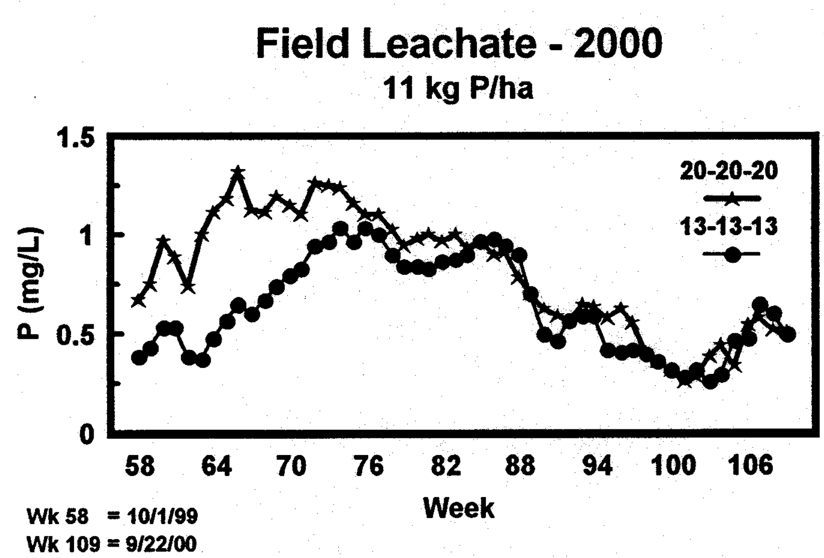

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INTRODUCTION

The number of golf courses in the U.S. are rapidly expanding at about one per day. The course areas consist of about 2% greens, the rest being divided about equally between fairways and other areas such as roughs, golf cart paths, streams and lakes. The greens are constructed of 80% by volume of sand in order to give a high percolation rate. This porous medium coupled with high inputs of fertilizer and irrigation could lead to leaching, not only of the more soluble nitrogen sources, but even to losses of less soluble phosphate fertilizer. Golf course managers have as their goal the maintenance of high quality, dense turf that will resist wear and can be maintained in a playable condition for most of the year in the southern states. Fertilizer cost is minimal compared to other inputs, so applications are frequent and the yearly amounts can seem quite high compared to most homeowner applications. The perception by the public is that there could be potential transport of these nutrients to surface water and groundwater, thus degrading water supplies through eutrophication.

Fertilizer applications to fairways are less frequent than for greens and tees, but the application rates are usually higher. Many courses have fertilizer spread by large trucks which applies it not only to the fairways, but to cart paths, roughs, and other non-target areas. Since these applications are usually only once or twice per year, the rates per treatment are higher than for greens. Many higher-end courses in the South convert the fairways from a warm-season turfgrass in the summer to a ryegrass in the winter months. At the time of "transition" fairly high rates of fertilizer are applied to get the new seedlings off to a good start. The danger from nutrient transport from fairways is not so much from leaching, but from runoff to surface waters. In the Piedmont region of the Southeast, the soils are high in clay and oxides that can crust and compact. These impervious soils can cause high rates of runoff during heavy rainfalls, especially on sloped areas. As much as 70% of the rain can be lost through runoff. This can cause fertilizer losses through "floatoff" of recently applied particles and runoff of soluble species.

The plant nutrients that are likely to be of most concern when transported to natural waters are nitrogen and phosphorus. These nutrients, especially P, cause eutrophication of surface water leading to problems with its use for fisheries, recreation, industry, or drinking water due to increases in growth of undesirable algae and aquatic weeds. Phosphorus is usually the single most limiting element for algae growth, since many blue-green algae are able to utilize atmospheric N_2. Although most of the P transported from land cultivated for crops is lost adhering to particles, most of the P lost from grassed areas is in the soluble form that is immediately available for algae growth.

This is the third year of a research program with the goal of evaluating the potential movement of nitrogen and phosphorus following application to golf courses and to develop best management practices to reduce potential transport to potable water systems where eutrophication may lead to reduced water quality. Specific objectives include determination of the amounts of N and P that will be found in runoff from a typical Piedmont soil, determination of the leaching of N and P from simulated greens in a greenhouse setting and in a field setting, and finally to monitor the N and P leaching from three working greens on a golf course in Atlanta. Last year changes were made to the greens so that we now have one of the old greens and two new greens with lysimeters starting in the spring of 1999. During the third year, a repeat of a first-year run-off experiment was carried out and an experiment on management practices was initiated on the simulated fairway site. This year, in addition to the two runoff experiments, a source leaching experiment at one rate was completed in the greenhouse and another using three sources at three rates with reduced irrigation was initiated, a leaching experiment was continued on the field lysimeters, and monitoring of N and P in the leachate from the greens on the working course in Atlanta were also continued. The form of P found in leachate and runoff was evaluated, as well as the amounts of dissolved C in the water that may exacerbate leaching.

This report will cover just the third year's data. A follow-up report will be submitted later that summarizes our experience over the entire three years and give additional data such as the DOC measurements for some of the leachate and runoff samples and the total and biologically available P measurements in relation to soluble P.

MATERIALS AND METHODS

Determination of Nitrate and Phosphate Transport from Simulated Fairways

Details of the runoff facility are included in former reports made by Dr. Albert Smith, who developed the area. Twelve individual plots separated by landscape timbers are built in a grid with a 5% slope from the back to the front. The topsoil is a Cecil sandy loam (clayey, kaolinitic, thermic Typic Kanhapludult) that has a mixed surface horizon (49.8, 18.0, and 32.2% sand, silt, and clay, respectively). The soil is typical of the Piedmont area of the Southeast. The slope was developed by removing the topsoil, grading the subsoil, and returning the topsoil over the area. The plots were sprigged with `Tifway' bermudagrass on 17 May, 1993. A trough is installed in a ditch at the front of each plot to collect the runoff water in a tipping bucket sample collection apparatus. The tipping bucket tips each time that 2 L of runoff water is collected tripping a microswitch attached to a data collecting device that counts the tips. With each tip a slot between the buckets collects a subsample of the runoff water in a stainless steel container that is analyzed after each simulated rainfall event. WOBBLER™ (Senninger Irrigation Inc., Orlando, FL) off-center rotary action sprinkler heads are mounted 7.4 m apart and 3.1 m above the sod surface. Operated at 138 kPa, the system produces simulated rainfall at an intensity of 2.77 cm hr^{-1}.

The first experiment for 2000 repeated a 10-10-10 granular fertilizer test that was carried out in 1998 in order to have two years of data for publication. The rates were 0, 0.11, and 0.22 lb. P/1000 sq. ft. (0, 5 and 11 kg P/ha) which gave N rates of 0, 0.25 and 0.50 lb. N/1000 sq. ft.(0, 12, and 24 kg N/ha). Treatments were made from the beginning of March to the end of April, 2000. The fertilizer was spread by hand after weighing out the amounts for each plot. Each rate was added to every plot so that each were replicated 12 times. Rainfall events were simulated at 24 hours (2.5 cm) before treatment and at 4 hours (5.0 cm.), 24 hours (5.0 cm.), 72 hours (2.5 cm.), and 168 (2.5 cm.) hours after treatment (HAT). Samples were collected after each simulated rainfall event and also for any natural rainfall events during the course of the experiment. Treatments were spaced to allow natural runoff and incorporation into the soil to lower the potential carry-over from one treatment to the next. The N and P in the initial simulated rainfall event prior to treatment was used as background data. Soil moisture was determined before each simulated rainfall event.

The second experiment also used 10-10-10 fertilizer, but the simulated rainfall was done differently than before. After a background rainfall event was run, the fertilizer was added to the plots and a simulated rain (watering-in) was done using only 0.25 inches of water. On the third day after that, the same simulated rainfall scheme was initiated with a 2-inch event and subsequent simulated events as before. The rates were 0, 0.11, and 0.22 lb. P/1000 sq. ft. (0, 5 and 11 kg P/ha) which gave N rates of 0, 0.25 and 0.50 lb. N/1000 sq. ft.(0, 12, and 24 kg N/ha). These were the same as for the repeated experiment so that comparisons can be made. Treatments were started in May and June. However, they were suspended during July and August and most of September due to a severe drought in the Griffin area. During that time the only irrigation allowed was enough to keep the turfgrass alive. The experiment was completed in October, so the data are not available for this report.

Subsamples collected from each rainfall event were stored at 4° C prior to analysis. Nitrate-N and phosphate-P were determined for samples filtered through 0.45 μm filters, which is considered to be the soluble form. Nitrate was analyzed colorimetrically using a LACHAT flow analyzer. The instrument first reduces nitrate to nitrite using a copper-cadmium column and the nitrite color is developed with a sulfanilamide / N-(1-naphthyl)EDTA reagent. The magenta color is read at 520 nm. Phosphate was also determined colorimetrically. The LACHAT instrument uses an ammonium molybdate-ascorbic acid method.

Determination of Nitrate and Phosphate movement through Simulated Greens

Greenhouse Lysimeters

Greenhouse lysimeters (36) are constructed to include turfgrass growth boxes (40 X 40 X 15 cm deep) on top of bases. The bottom of the wooden growth boxes are perforated steel and at the inside-center of the growth boxes a 13-cm length of polyvinyl chloride (PVC) tube (15 cm diam.) is fastened to the bottom with acrylic caulk. The base of the lysimeter consists of a 52.5 cm length of PVC tubing (15 cm diam.)

capped at the bottom. The cap has a drain tube for the collection of leachate in gallon plastic bottles. The PVC bases contain three equally spaced rings of acrylic caulk on the inside to help prevent flow along the edge of the columns. The bases of the lysimeters are enclosed so as to be able to cool the soil. This area was not cooled during this experiment, because we were growing bermudagrass instead of bentgrass, which is more heat sensitive. The lysimeters are housed in a greenhouse covered with LEXAN thermoclear sheet glazing. This covering has about 90% the light transmission of glass. The temperature and relative humidity in the greenhouse were recorded using a RH sensor and a thermister connected to a data-logger. The greenhouse was cooled by an evaporative cooling system consisting of water-soaked pads on one wall and exhaust fans on the other wall.

The rooting mixture (sand:sphagnum peat moss) used had proportions of 80:20 sand:peat by volume (96.8:3.2 by mass) to give a final percolation rate of 33 cm hr^{-1}. This mixture has been prescribed by the USGA for bermudagrass greens. The loss on ignition for the mixture used was 0.97%, which is more in the range of an 85:15 mix according to the Tifton Physical Soil Test Laboratory, Tifton, GA. The lysimeter bases are filled with sized gravel (10 cm), coarse sand (7.5 cm), and rooting mix (35 cm) in ascending sequence from the bottom simulating USGA specifications for greens construction. The layers were packed into the columns while being vibrated to give an even bulk density. The top of the lysimeter column was fitted against the ring on the bottom of the growth box. Sodded `Tifdwarf' bermudagrass was placed on the rooting medium in the growth boxes on October 1, 1999. The total area of the box was sodded, but only the center portion was involved in the leachate collection.

A fertilizer experiment using eight sources at one rate was carried out with the first leachate collected on October 8, 1999, and the last on March 31, 2000. The sources were Lesco poly- and sulfur-coated micro-granular 13-13-13, an agricultural 10-10-10, Peters soluble 20-20-20, Scotts 16-25-12, Scotts 19-25-5, Scotts 9-18-18, sulfur-coated urea with super phosphate, and a liquid slow release N (N-Sure) with super phosphate. The rate was based on P at 0.22 lb P/1000 sq. ft (11 kg P/ha). Where N was added separately, it was added at 0.5 lb N/1000 sq. ft. (24 kg N/ha) to be compared with the balanced sources (13-13-13, 10-10-10 and 20-20-20). Irrigation was adjusted to give approximately one L of leachate a day. This irrigation rate was lower than used previously. The above rates were added on weeks 3, 5, 7, and 9 with the experiment terminating after week 26. Leachate samples were taken weekly and analyzed for N, SP, and total P (TP). Samples were refrigerated at 4° C prior to analysis for nitrate-N and phosphate-P. Soil was sampled at the end of the experiment at intervals in the column. The box was sampled and the columns sampled divided into three equal segments. The samples were extracted by the Mehlich 1 procedure and the solutions analyzed for P by flow analyzer.

A fourth greenhouse experiment was initiated this year with three sources at three rates (soluble 20-20-20, poly- and sulfur-coated granular 13-13-13, and ammonium nitrate-superphosphate at 0, 0.11, and 0.22 lb P/1000 sq. ft. and 0, 0.25, and 0.50 lb N/1000 sq. ft.). Treatments were added every other week for a total of seven times. The difference in this experiment from those before was that we used a low irrigation rate based on evapotranspiration. The volume of leachate was kept at about 500 mL per week for most of the experiment to the best of our ability. The turfgrass was sodded on the boxes on May 5, 2000, and the first leachate collected on May 26, 2000. The first treatment was added on June 23, 2000. The experiment is still ongoing at the time of this report.

Field Lysimeters

The area consists of two narrow strips of simulated green each subtended with ten lysimeters with a collection area in a covered walkway between the strips. The green areas have two rooting media that are USGA specification for bermudagrass (sand: sphagnum peat moss, 80:20, v:v) and for bentgrass (85:15). At the present both green areas are sodded to Tifdwarf bermudagrass. Much of the turf area was resodded in July of 1998 due to deterioration. Stainless steel inserts are placed into fiberglass jackets to form the lysimeters. The interior diameter of each is 55 cm. and the depth is 52.5 cm. The lysimeters are filled with layers of gravel, coarse sand, and the rooting media the same as was done for the greenhouse lysimeters. The tops of the lysimeters are 5 cm. below the base of the sod. A horizontal moving irrigation system is in place for simulating irrigation and rainfall events and an automatic moving rain shelter covers the area during natural rain events. Irrigation is at 0.25 cm. per day. This rate may be increased depending on the leaching that is observed. The turf is mowed twice weekly at a height of 1.0 cm. and the clippings removed.

Fertilizer treatments year added this year were the same soluble and granular sources used for the 1998 greenhouse experiment (Peters soluble 20-20-20 and Lesco poly- and sulfur-coated granular 13-13-13). There were six treatments of two sources at three rates and replicated three times. The rates were 0, 0.25, and 0.5 lb. N/1000 sq. ft. (0, 12, and 24 kg N/ha) and 0, 0.11, and 0.22 lb. P/1000 sq. ft. (0, 5, and 11 kg P/ha). Sampling of leachates was begun on September 1, 1998, (week 1) and treatments were added at that time. However, through the fall and winter, variable leachate volumes were observed and no treatment effects were evidenced in the N and P data. In the spring of 1999 we started a series of treatments that did show treatment effects. Treatments were added first on April 2, 1999 (week 32) and again on weeks 40 and 47. Only N was added several times thereafter and nothing was added over the winter. This year the same treatments were added on April 14, 2000, (week 86) and May 12, 2000, (week 90). Nitrate only was added several times during the summer. Data will be reported here starting on week 58 (October 1, 1999) and ending on week 109 (September 22, 2000). Leachate samples were collected once a week and analyzed for nitrate-N and phosphate-P on samples filtered through a 0.45 μm filter. Total P is also being determined. The termination date for this experiment is October 13, 2000.

Nitrate and Phosphorus Leaching Through Golf Course Putting Greens

Three stainless steel lysimeters were placed in each of two practice putting greens on a working golf course located in Atlanta, GA. As the greens were built, stainless steel kitchen sinks were placed 5.0 cm. below the surface of each green that was seeded to creeping bentgrass in August of 1994. The lysimeters had tubes installed at the drain of the sink that were run to the edge of the green for collecting leachate. The rooting mixture was a prescribed mixture for bentgrass, namely, an 85:15, sand:sphagnum peat moss mix. The infiltration rate for the mixture was 37 cm/hr. The greens were maintained by the superintendent according to usual practice and records kept of fertilizer applications. Samples are taken weekly and stored at 4°C prior to analysis at Griffin, GA. Nitrogen and P were determined on weekly leachate samples which continued from Dr. Smith's project through 1998. The course was renovated removing one of the former practice greens in October, 1998. In cooperation with Dr. Armbrust, three lysimeters each were installed on two playing greens as they were built on the renovated course. The 1999 data reported here include one old green and two new playing greens (12th and 15th) with the first leachate from the new greens being collected on March 30, 1999. One of the lysimeters in the 15th green was broken during construction, so only two are operable on that green.

SUMMARY OF RESULTS

Determination of Nitrate and Phosphate Transport from Simulated Fairways

Three runoff experiments were carried out which included 3 rates of 10-10-10 agricultural fertilizer. The P rates were 0, 5, and 11 kg P/ha and the N rates were 0, 12, and 24 kg N/ha. This was a repeat of the 1998 experiment. As found before, the greatest runoff was at the first simulated rainfall event (4 HAT) in all cases and was decidedly less at the 3 subsequent times (Fig. 1). Step-wise increases in P runoff were found at the 4 HAT runoff event for P concentration and mass, but the first rate (5 kg P/ha) was a bit higher than the higher rate would predict. The concentration of nitrate-N in the runoff was low as was found in 1998 (Fig. 2). The reason was that the ammonium form was added, and it did not have time to revert to nitrate. As before, the higher concentration of N was found at the 168 HAT event, but the mass was higher for the first two events where the runoff volume was higher (Fig. 3). These results compare very well with those found in 1998.

A second experiment was carried out this year where the 10-10-10 fertilizer was watered in at 0.25" of simulated rainfall. This experiment was just finished in October, so the results will be given later in the three-year summary.

Determination of Nitrate and Phosphate movement through Simulated Greens

Greenhouse Lysimeters

This year a fertilizer source experiment at one rate of phosphorus was carried out. Five of the eight treatments had the same nitrogen rate, and could be compared. Soluble P concentration did not increase in the leachate until week 6 for the soluble 20-20-20 and week 8 for other sources (Fig. 4). There were two P concentration peaks at weeks 10 and 14 with a gradual tailing off during weeks 17 to 26. The cumulative mg of P rose rapidly for the soluble 20-20-20 and the granular 16-25-12 source (Fig. 4). These had by far the highest mg of P leached of any of the sources. The next two highest were the granular 13-13-13- and 10-10-10 with the other 4 sources being lower with respect to mg P leached.

Unlike that for P, the N concentration first increased above control at week 3 for all sources (Fig. 5). Most sources resulted in a peak in N concentration at week 3, but the soluble 20-20-20 source gave a larger peak at week 6, as did the NS liquid source. Essentially all the N was leached by week 12. None of the sources resulted in Nitrate-N concentrations above the 10 mg/L drinking water standard. The 20-20-20 N source resulted in the highest total mg N leached, the NS liquid and 10-10-10 granular were intermediate, and the 13-13-13 and sulfur-coated urea were lowest (Fig. 5). The percentage of added N leached by the sources were:

20-20-20	15.7%
NS-SUP-P	10.5%
10-10-10	8.1%
13-13-13	3.4%
SCU-SUP-P	1.8%

Preliminary data show that P was slow to leach in the fourth experiment where low amounts of irrigation were added (Fig. 6). Treatments were started on week 5 and P concentration did not rise significantly until week 14 at treatment 5 with the exception of the soluble 20-20-20, which showed some increases at week 12. The most difference came at week 17 where the data stops for this report. This experiment is continuing with the 7th treatment being added on week 18. A similar pattern is seen for nitrate-N (Fig. 7) where the concentration does not increase until week 16 for the two granular sources and at week 14 for the soluble source. The peaks at week 2 are from initial 0.5 lb N/1000 sq. ft. ammonium nitrate added at weeks 1 and 3 to get the turfgrass started and to let the roots grow into the rooting medium.

Field Lysimeters

Nitrogen treatments were not evident over the winter of 1999-2000, but nitrate-N varied with volume of leachate as can be seen by the peak at week 79 for all plots (Fig. 8). Treatments added in the spring of 2000 (weeks 86 and 90) caused increased nitrate-N for the 13-13-13, which is unusual, since it usually the soluble source which causes leaching. The increase in the fall at weeks 104 and beyond were caused by an increase in leachate volume as the days cooled down and evapotranspiration decreased. Since the P was increasing according to the treatments starting in the winter of 1999-2000 (Fig. 9), the decision was made to not add any more P (only N) for the summer of 2000 so as to determine the total P leached before the termination of the experiment. The two treatments on weeks 86 and 90 were the last P treatments made for the experiment. The P treatments began to be evident as increased P concentration in the leachate after week 64 in November, 1999. This trend continued until about week 90 in the spring of 2000. This is really the only P response found in the entire three years of the experiment. The P came from treatments made in 1999 (and possibly 1998). Thus, it was very slow in making its way through the columns. The treatments made in 2000 may be evident for the 13-13-13 as a peak during weeks 92-94. The peaks in the fall of 2000 at week 106 were caused by an increase in leachate volume, similar to the increase in N concentration in the leachate for those weeks. Note that the N and P transported through these field lysimeters are much lower than found for the same sources and rates used in the greenhouse lysimeters with similar amounts of irrigation.

Nitrate and Phosphorus Leaching Through Golf Course Putting Greens

Phosphate

The data for 1995 through 1998 were reported last year. The 1999 P concentration and mass data show that P in the leachate was again very low for the old green (green 1, Fig. 10). The new greens (12 and 15) show a peak just after start-up with decreases thereafter. This data corresponds with data from 1995 for the practice greens where P concentrations were high initially. The P comes from starter fertilizer and possibly from the peat in the sand-peat mix. The fertilizer additions shown are for Green 1. The application data are incomplete for the new greens. We are still trying to obtain that data from the golf course superintendent. The cumulative mass of P data (Fig. 12) show the increase in the spring of P in the leachate, a gradual increase in mass during the summer, and a sharper rise in the late fall. The fall increase was from additions of fertilizer P. The P concentration average for Green 1 had been decreasing steadily, but increased during 1999 (Table 1). The mass of P was also higher. The numbers of samples collected in 1999 were fewer than in years previously, but the volumes collected were higher, which at least partially accounts for the increase in mg of P leached. Also, no P was added in 1998, whereas there were additions in 1999.

The averages for average P concentration and mass were similar for the two new greens (Table 3). Although these values are relatively high, they reflect higher fertilizer inputs during the grow-in period of the greens, and will most likely decline in the future.

Nitrate

Nitrate concentrations and mass followed a trend similar to that for P (Fig. 11). The old green N concentrations and mass were generally relatively low showing an increase late in the season near julian date 250. The new greens (12 and 15) were initially high, but were low the rest of the season. As with P, this N early in the season probably come from initial fertilization and/or from mineralization of the peat as temperatures increased. The cumulative mass of nitrate-N showed a similar pattern to P in that it increased early in the year and again in late fall (Fig. 12). The average nitrate-N concentration for the old practice Green 1 decreased from last year reversing an increasing trend (Table 2). However, the mass of nitrate-N remained nearly the same as for 1998. The new greens showed differences in average nitrate concentration and mass with Green 12 being much higher than Green 15 (Table 3).

FUTURE PLANS

This is the final year of this project. No new experiments will be undertaken, however, more work will go on concerning the project. Several sets of data have not been collated and analyzed including the total P and biologically available P data from the runoff and leachate experiments, the soil moisture data taken before each runoff event, and the DOC data that was collected during the summer of 2000 mostly on greenhouse leachate samples. Once this data is analyzed, several manuscripts will be written and a final report covering the three years of work will be submitted to USGA. Finally, Dr. Armbrust and I plan to hire a Post Doc on the new small watershed projects just beginning. This person may be able to use much of the data generated in this project to use in modeling N and P runoff and leaching from golf courses.

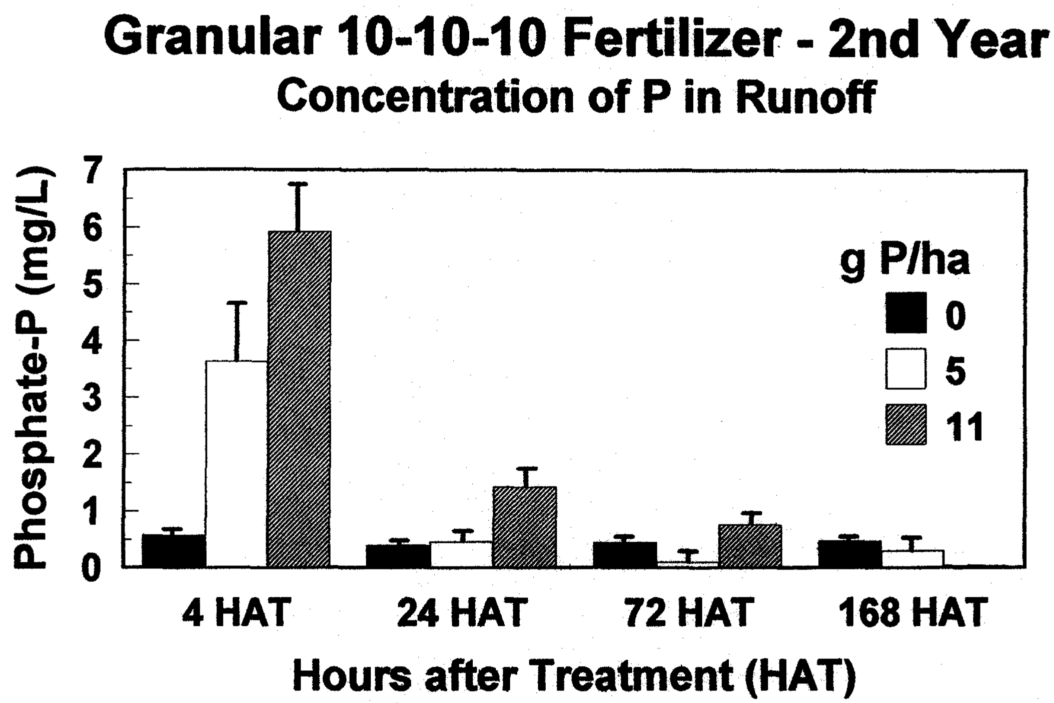
PUBLICATIONS

Shuman, L. M., A. E. Smith, and D. C. Bridges. 2000. Potential movement of certain nutrients and pesticides following application to golf courses. p. 78 - 93 In Clark, J. M. and M. Kenna (Eds.) Fate of Management of Turfgrass Chemicals, ACS Symposium Series 743, Boston, MA, August 23-27, 1998, Amer. Chem Soc., Washington, DC.

Shuman, L. M. 2000. Fertilizer source and rate effects on phosphorus runoff from simulated golf fairways. ABSTR. Amer. Soc. Agron., Minneapolis, MN, p. 150.

Pending publications

Shuman, L. M. 2000. Phosphate and nitrate movement through simulated golf greens. Water, Air and Soil Pollut. (In Press, proof attached).



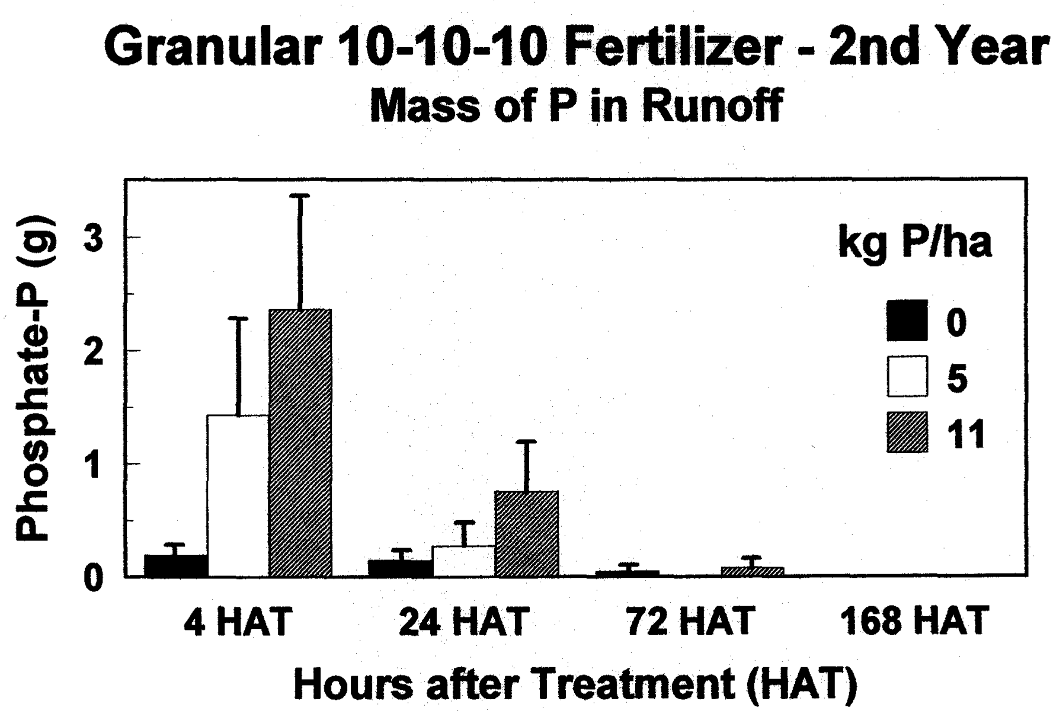


Fig. 1. Concentration and mass of P in runoff for 3 rates of 10-10-10 fertilizer and 4 simulated rainfall events (second year data).

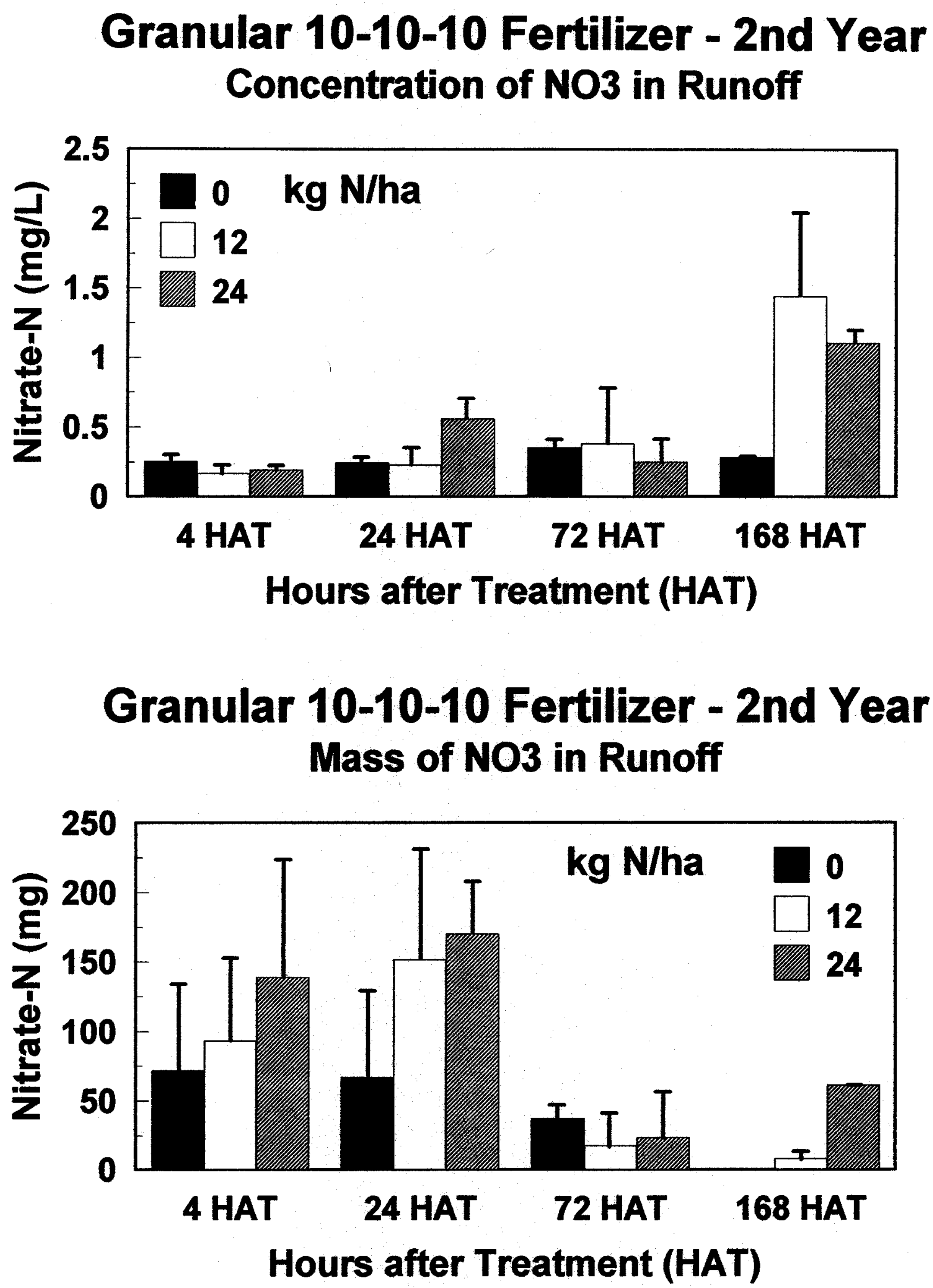


Fig. 2. Concentration and mass of N in runoff for 3 rates of 10-10-10 fertilizer and 4 simulated rainfall events (second year data).

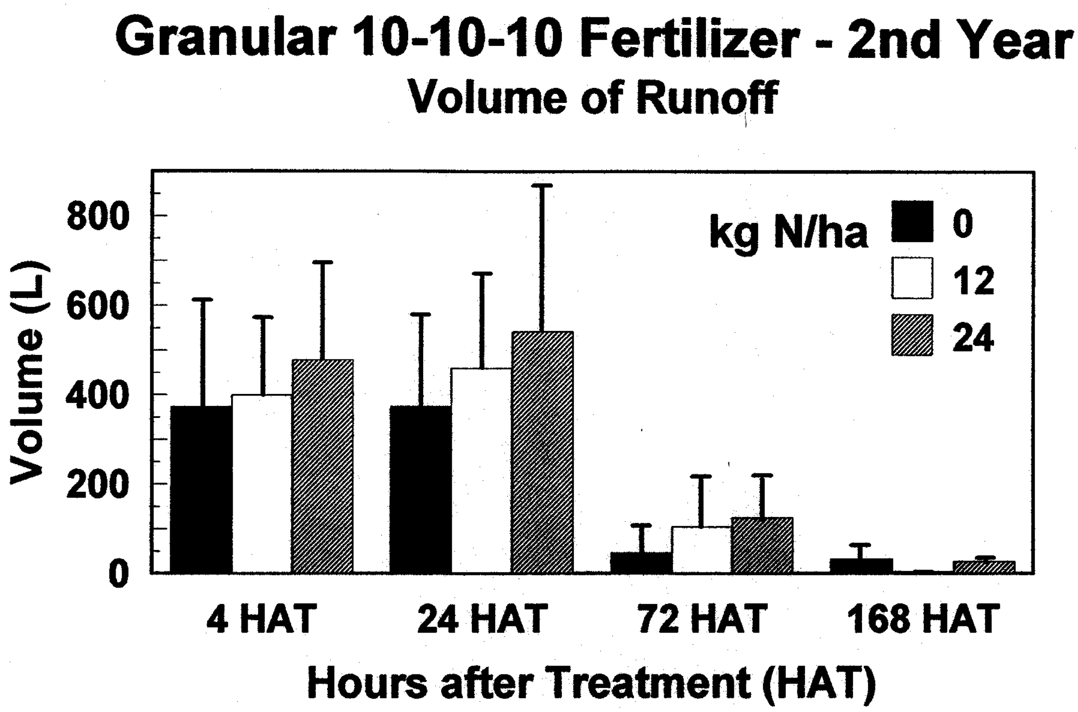
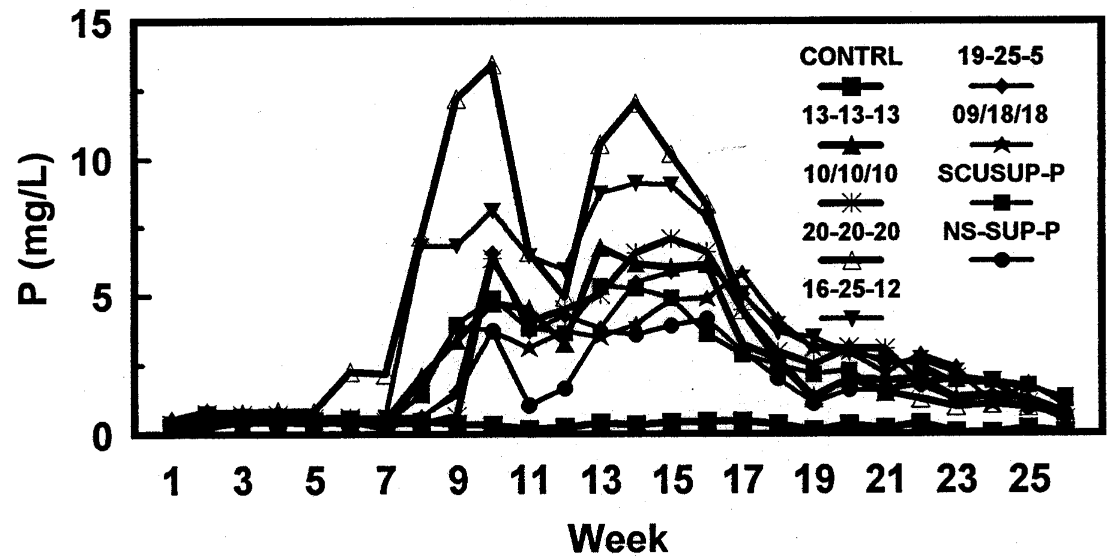


Fig. 3. Runoff volume for 3 rates of 10-10-10 fertilizer and 4 simulated rainfall events (second year data).

Greenhouse Fertilizer Source Exp.
P (mg/L)



Greenhouse Fertilizer Source Exp.
Cumulative P (mg)

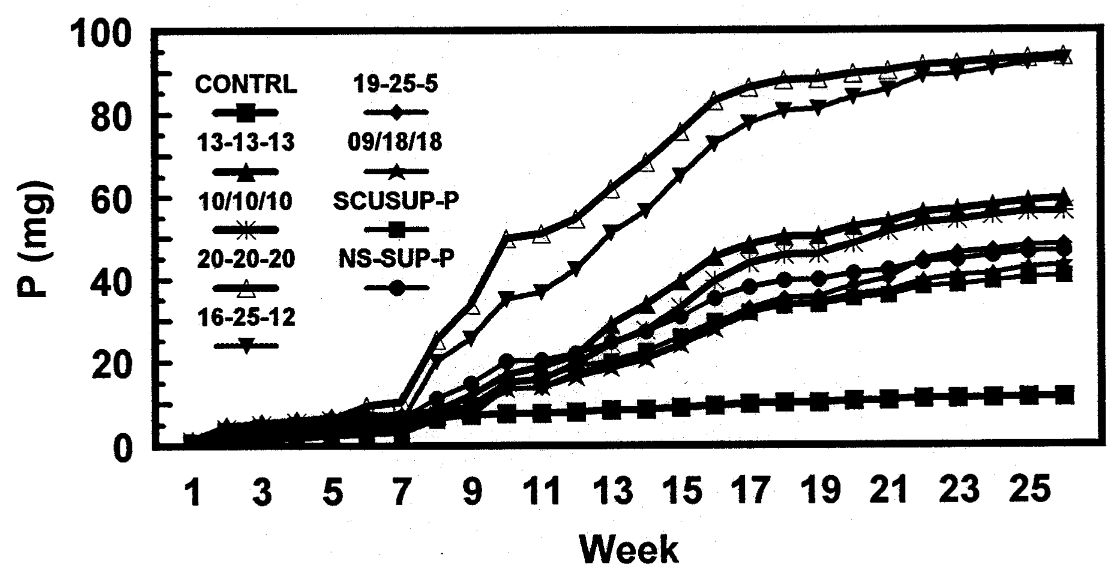
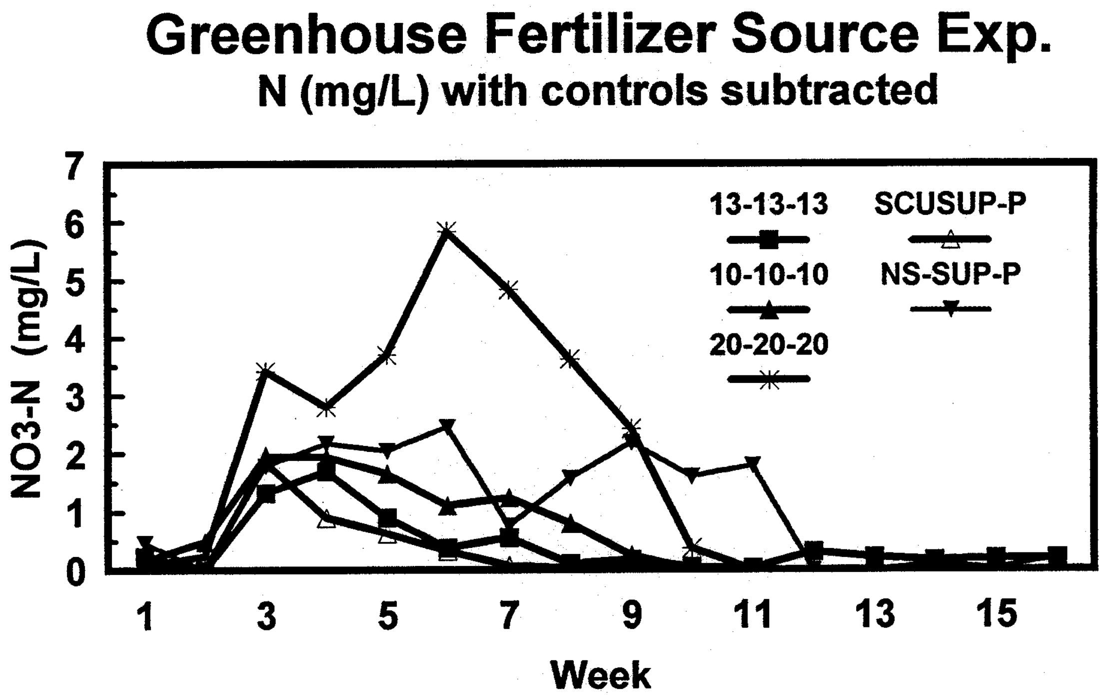


Fig. 4. Phosphorus concentration and cumlative mass for eight sources at 11 kg P/ha in leachate from simulated greens.



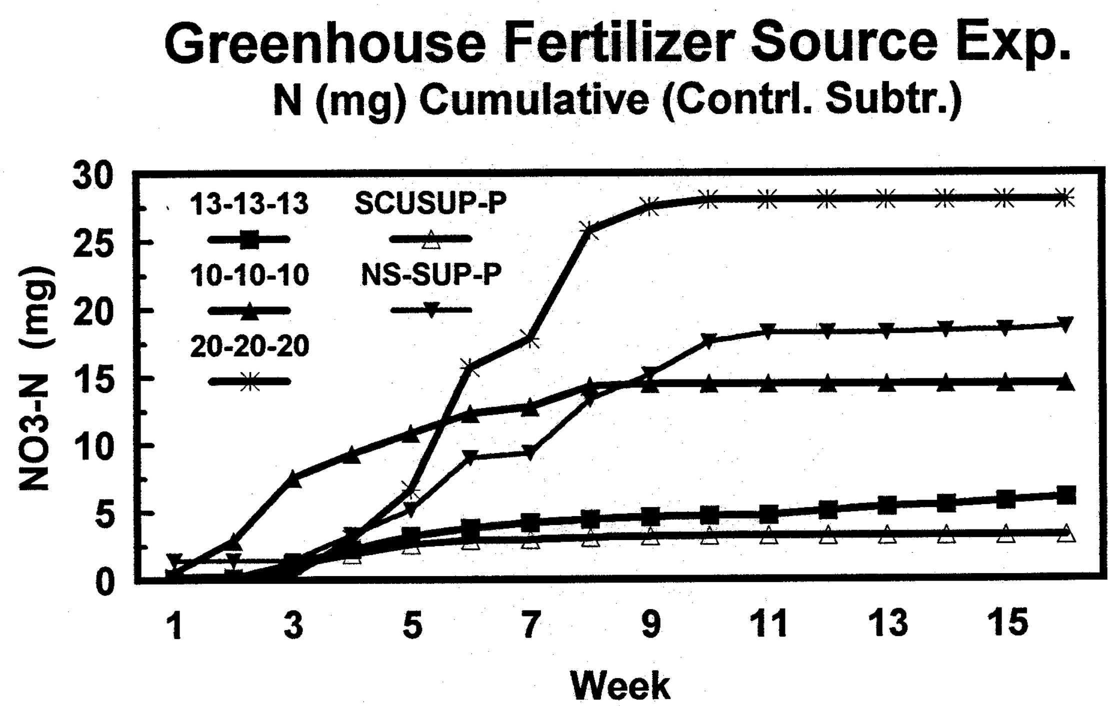
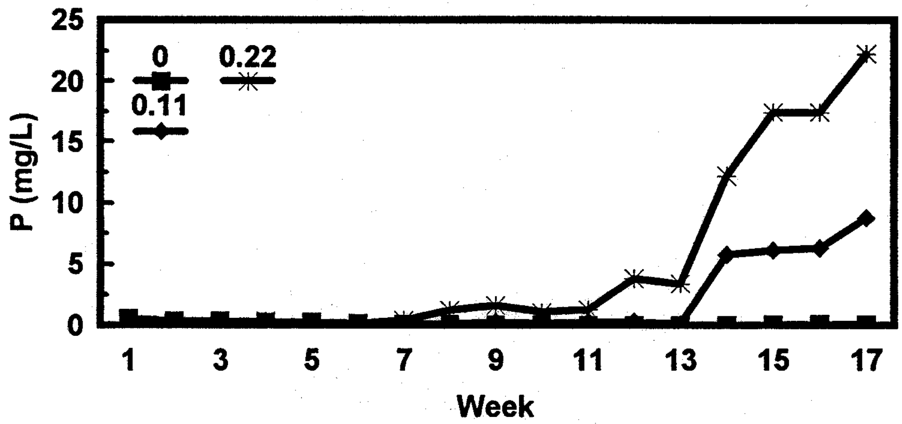
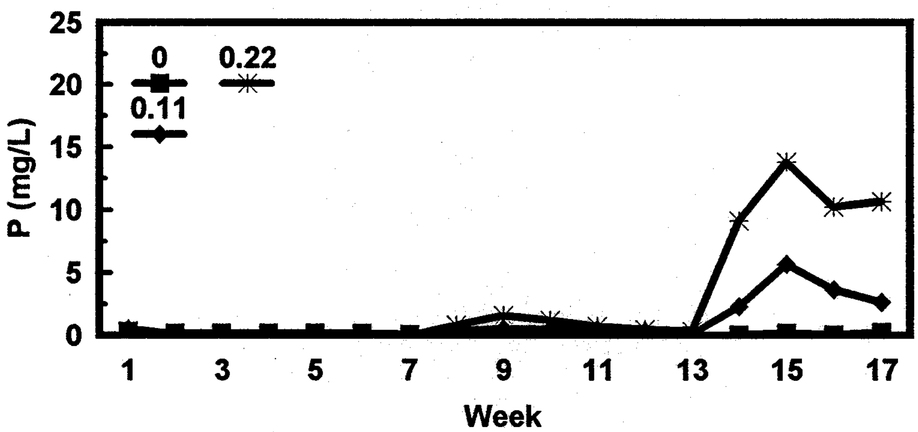


Fig. 5. Nitrate-N concentration and cumlative mass for five sources at 24 kg N/ha in leachate from simulated greens.

Greenhouse Exp. 4 - Low Water
Soluble 20-20-20



Greenhouse Exp. 4 - Low Water
Granular 13-13-13



Greenhouse Exp. 4 - Low Water
Ammonium Nitrate - Superphosphate

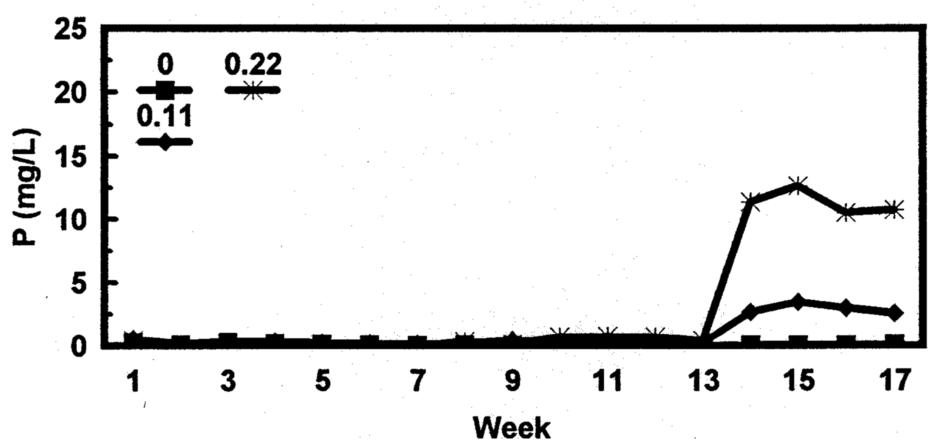


Fig. 6. Phosphorus concentration for three sources at three rates in leachate from simulated greens and irrigation based on ET.

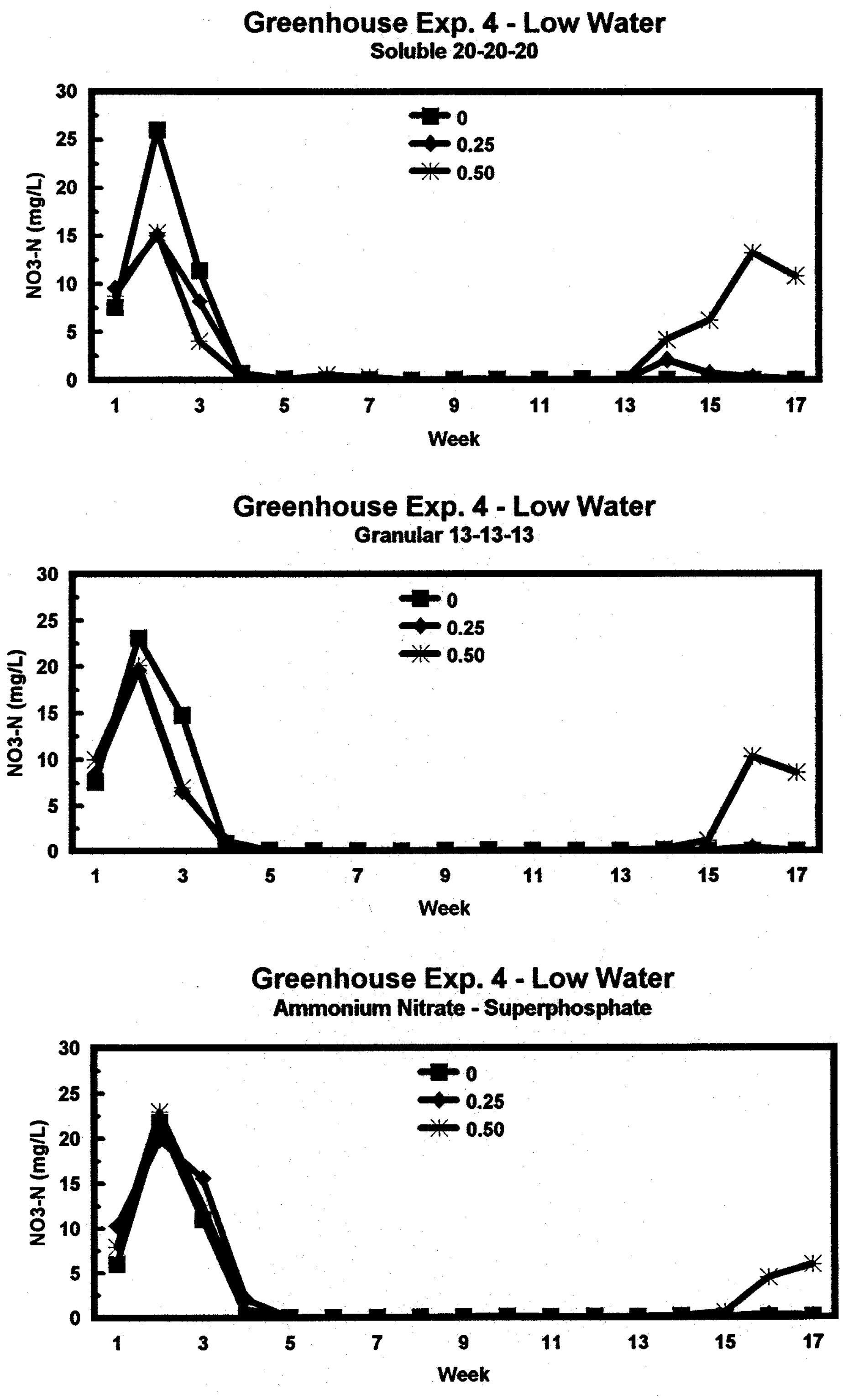
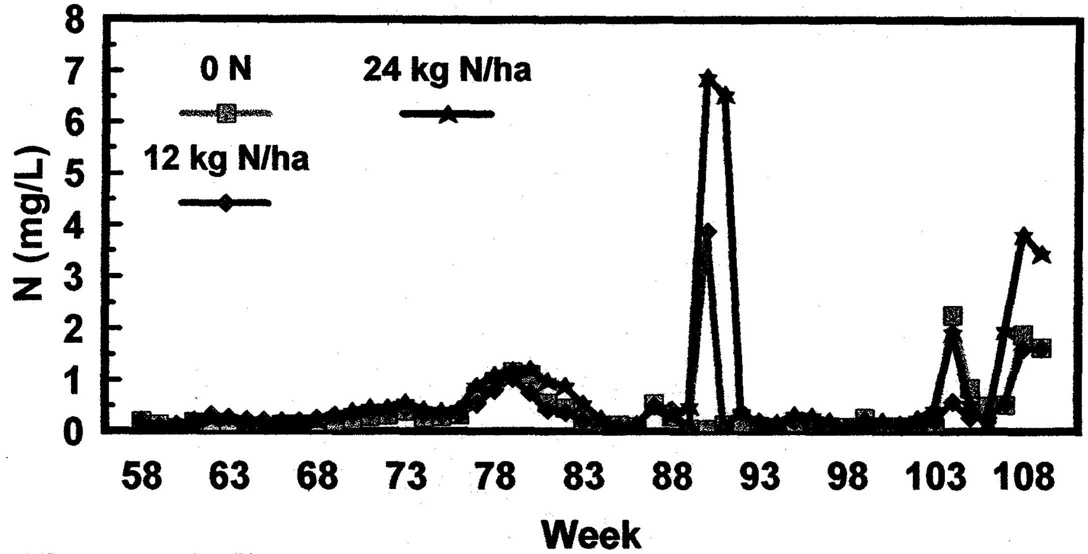


Fig. 7. Nitrate-N concentration for three sources at three rates in leachate from simulated greens and irrigation based on ET.

Field Leachate - 2000
Granular (13-13-13)



Wk 58 = 10/1/99
Wk 109 = 9/22/00

Field Leachate - 2000
Soluble (20-20-20)

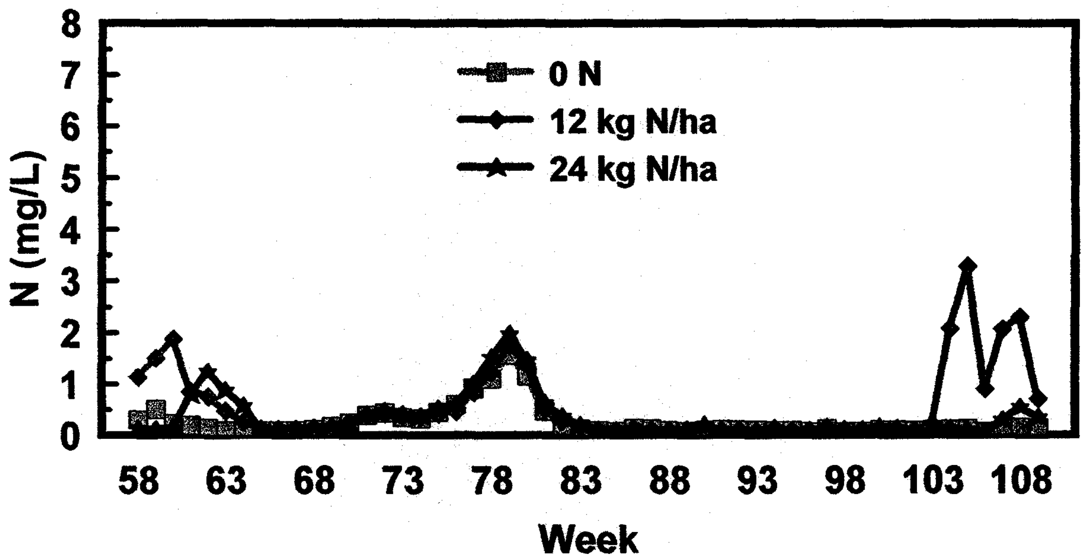
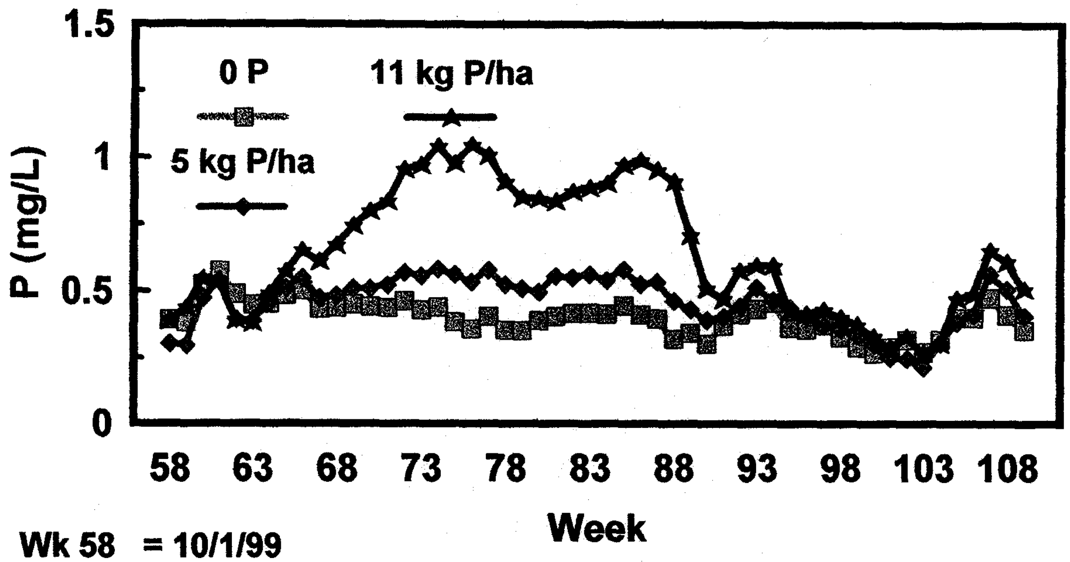


Fig. 8. Nitrate-N concentration for two sources at three rates in leachate from simulated field greens.

Field Leachate - 2000
Granular (13-13-13)



Wk 58 = 10/1/99
Wk 109 = 9/22/00

Field Leachate - 2000
Soluble (20-20-20)

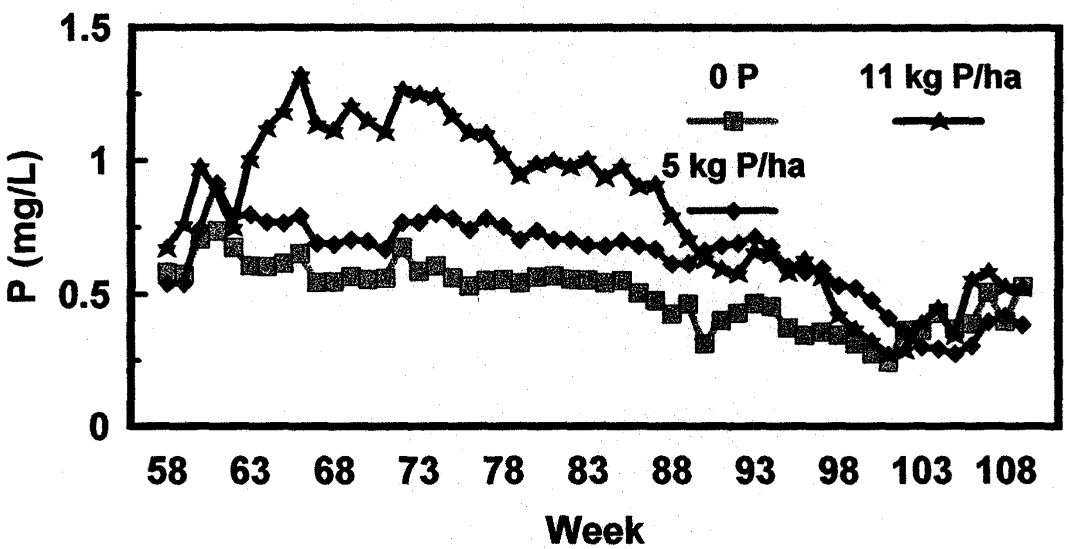
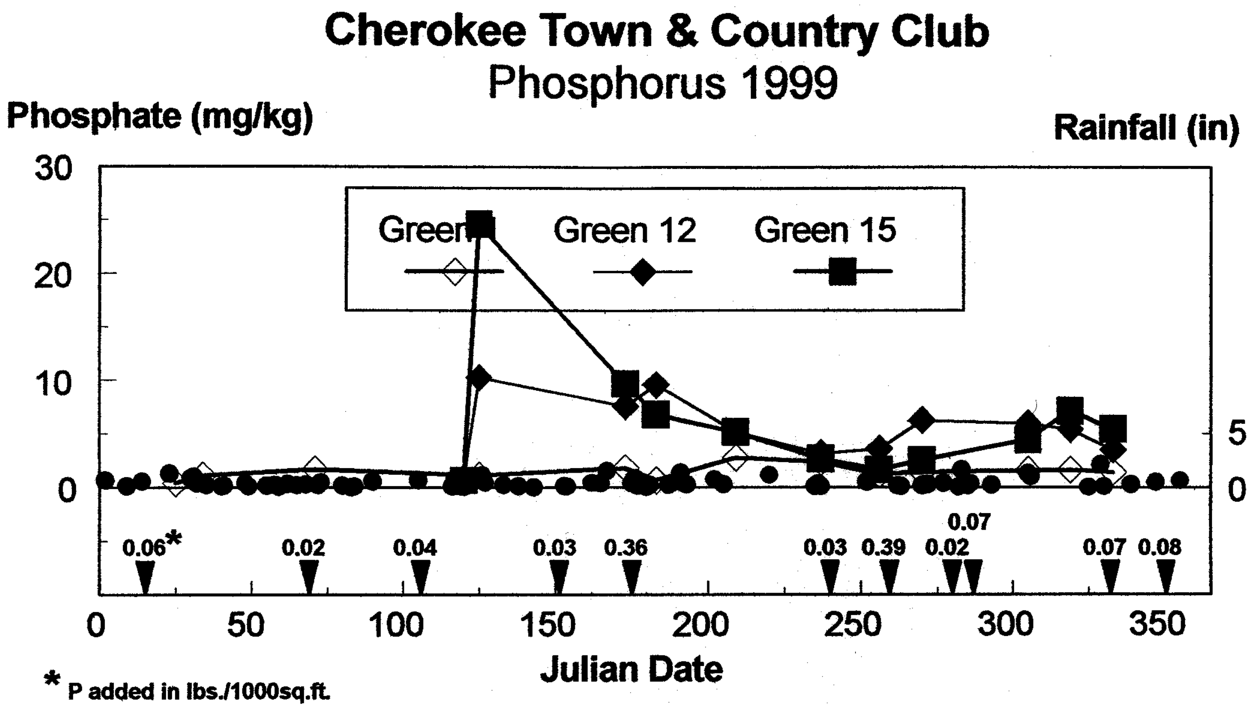


Fig. 9. Phosphorus concentration for two sources at three rates in leachate from simulated field greens.



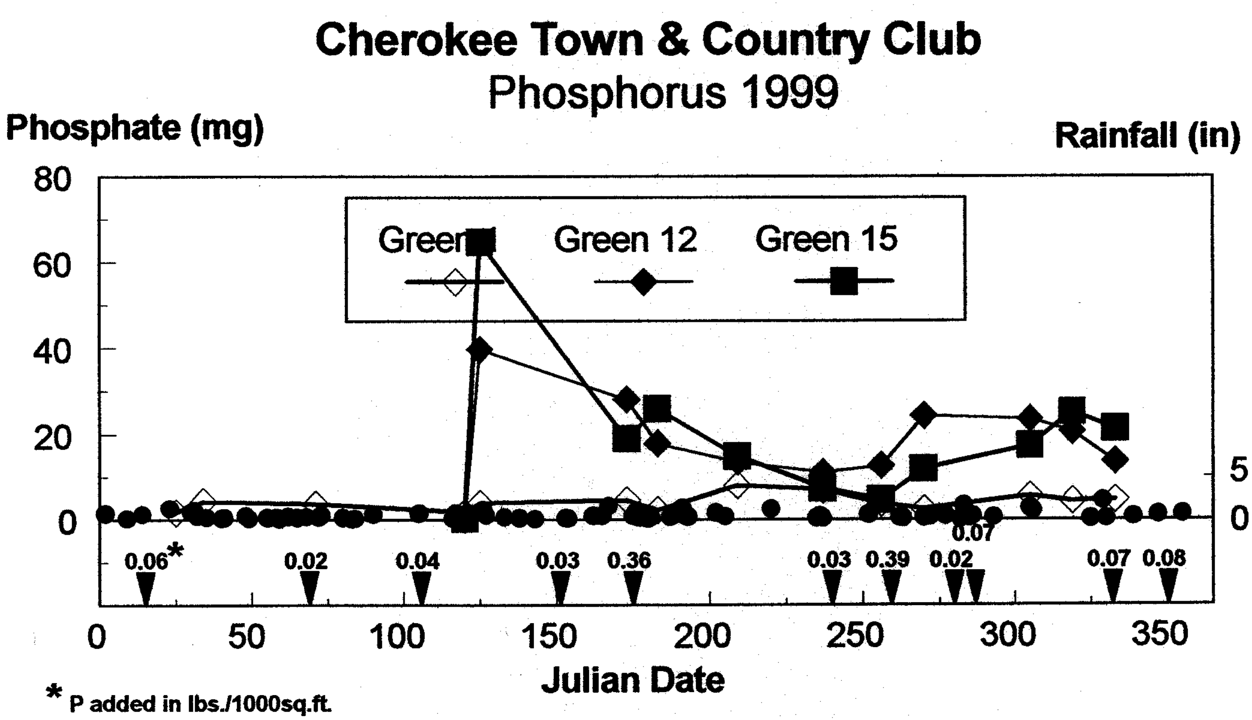
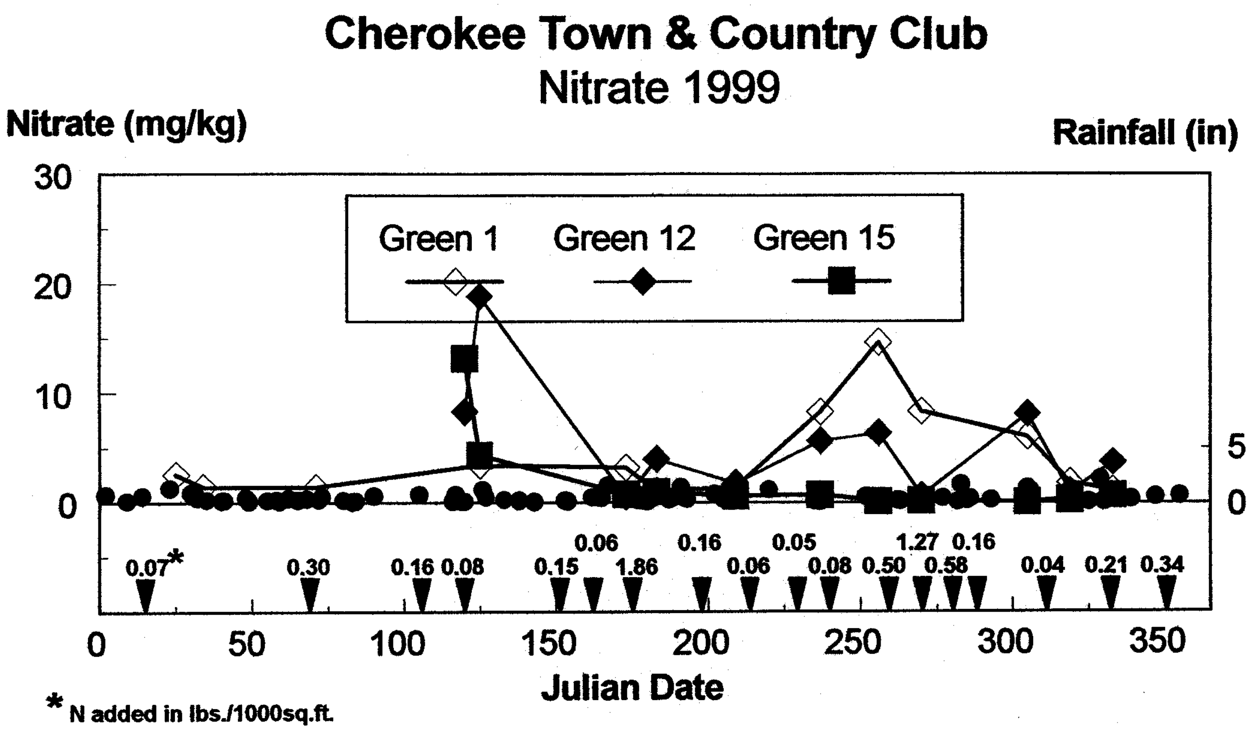


Fig. 10. Phosphate concentration and mass for 1999 for one putting green and two playing greens at the Cherokee Town and Country Club.



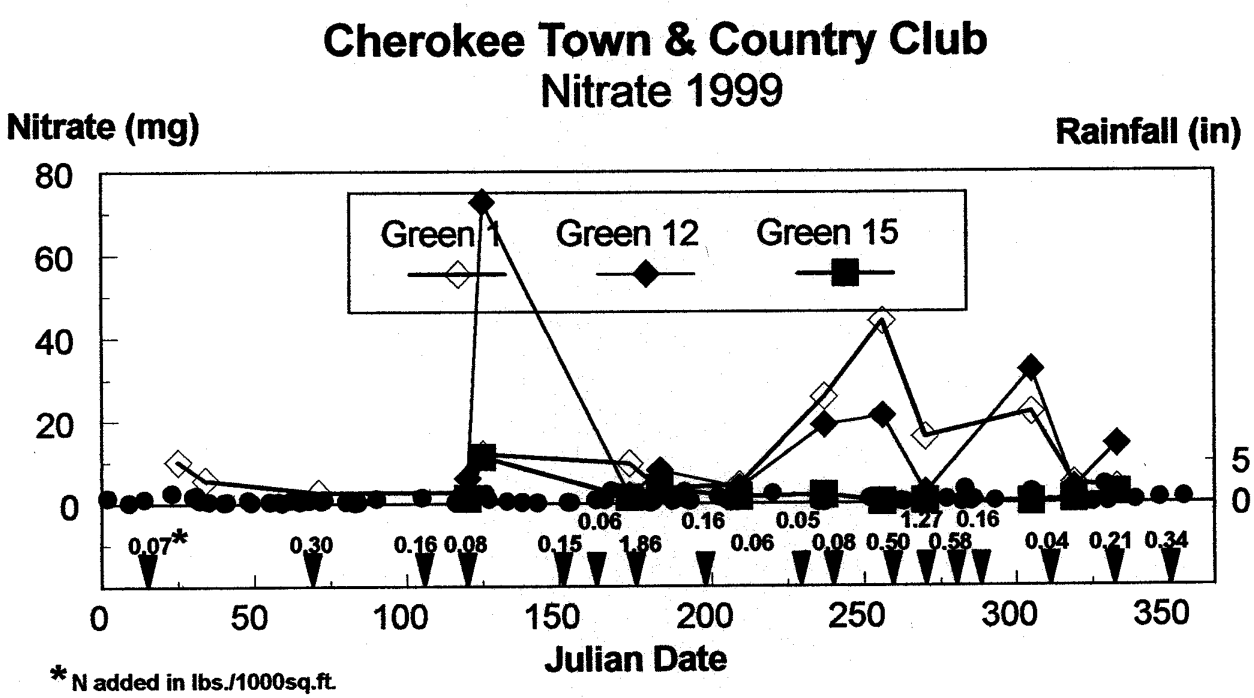
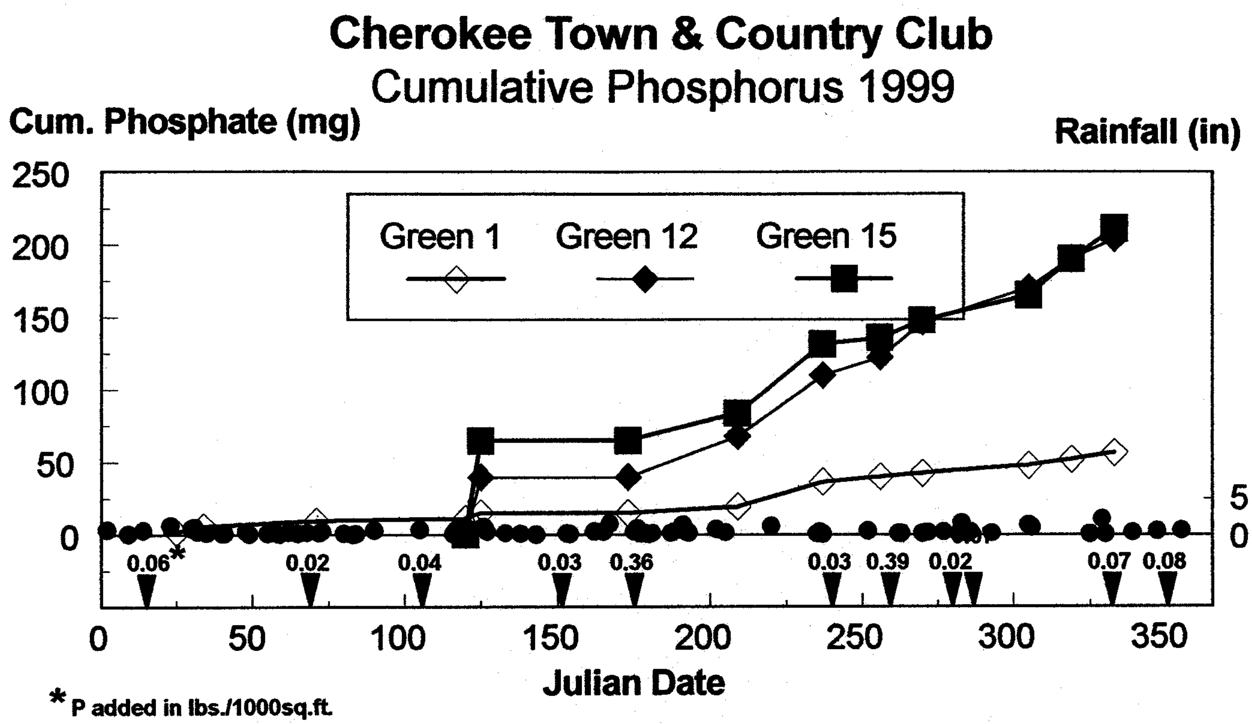


Fig. 11. Nitrate-N concentration and mass for 1999 for one putting green and two playing greens at the Cherokee Town and Country Club.



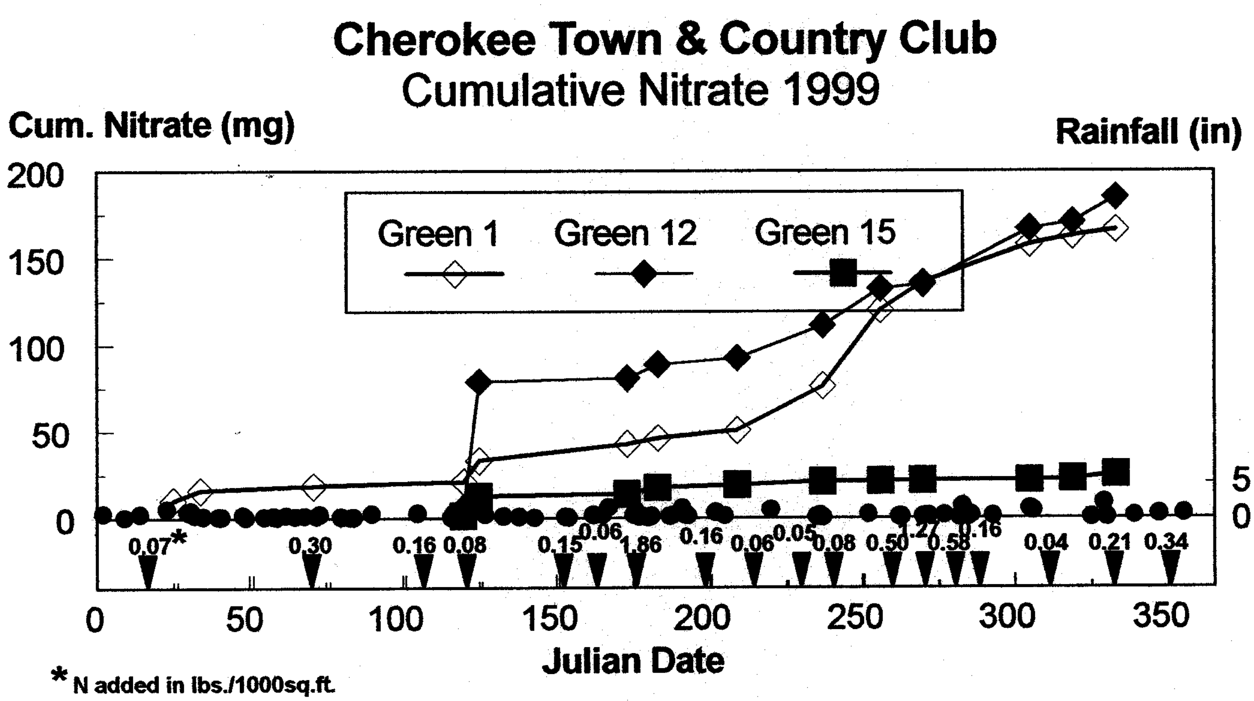


Fig. 12. Phosphate and Nitrate-N cumulative mass for 1999 for one putting green and two playing greens at the Cherokee Town and Country Club.

Table 1. Phosphorus leaching concentration (mg/kg) and mass (mg) averages for individual collection dates by year for five years for two USGA golf greens at the Cherokee Town and Country Club, Atlanta GA.

	Green 1			Green 2		
	Phosphate P concentration (mg/kg)					
	Mean	Min.	Max.	Mean	Min.	Max.
1995	**3.21**	0.65	6.07	**8.53**	5.55	13.27
1996	**1.14**	0.05	6.79	**1.30**	0.16	6.02
1997	**0.93**	0.05	5.34	**1.72**	0.15	4.11
1998	**0.68**	0.01	13.51	**0.58**	0.01	3.55
1999	**1.49**	0.37	3.65			
	Phosphate P mass (mg)					
1995	**7.06**	0.04	23.03	**22.34**	0.06	77.04
1996	**2.72**	0.03	20.29	**2.89**	0.06	13.53
1997	**2.90**	0.16	13.14	**4.41**	0.10	15.75
1998	**1.06**	0.03	3.23	**0.76**	0.20	1.43
1999	**3.99**	0.86	8.76			

Table 2. Nitrogen leaching concentration (mg/kg) and mass (mg) averages for individual collection dates by year for five years for two USGA golf greens at the Cherokee Town and Country Club, Atlanta GA.

	Green 1			Green 2		
	Nitrate N concentration (mg/kg)					
	Mean	Min.	Max.	Mean	Min.	Max.
1995	**2.23**	0.01	13.61	**1.14**	0.01	8.80
1996	**1.73**	0.01	16.09	**1.37**	0.01	13.69
1997	**2.63**	0.01	12.99	**2.60**	0.42	8.67
1998	**5.29**	0.00	36.70	**7.05**	0.01	30.16
1999	**2.98**	0.31	15.29			
	Nitrate N mass (mg)					
1995	**3.73**	0.01	33.90	**1.63**	0.01	30.09
1996	**3.91**	0.01	16.71	**2.71**	0.01	17.25
1997	**7.88**	0.02	36.96	**6.55**	0.07	33.65
1998	**9.91**	1.16	56.23	**12.61**	1.23	56.56
1999	**8.47**	1.20	37.00			

Table 3. Nitrogen and Phosphate leaching concentration (mg/kg) and mass (mg) averages for individual collection dates for the first year for two USGA golf greens at the Cherokee Town and Country Club, Atlanta GA.

	Green 12			Green 15		
	Nitrate N concentration (mg/kg)					
	Mean	Min.	Max.	Mean	Min.	Max.
1999	**6.18**	0.21	21.32	**1.83**	0.00	9.53
	Nitrate N mass (mg)					
1999	**17.11**	1.28	85.29	**2.40**	0.00	15.01
	Phosphate P concentration (mg/kg)					
1999	**5.55**	0.24	10.26	**7.65**	0.63	34.21
	Phosphate P mass (mg)					
1999	**20.31**	0.10	39.60	**21.68**	0.13	95.79

Fertilizer Source and Rate Effects on Phosphorus Runoff from Simulated Golf Fairways.

L.M. SHUMAN, *Univ. of Georgia.*

Because of public concern over possible water quality impairment from turf amendments, experiments were carried out to evaluate the potential movement of phosphorus following application to golf course fairways. Six runoff experiments included 3 rates of two fertilizer sources. The P rates were 0, 11, and 21 kg P/ha and sources were a 16-25-12 and superphosphate, both granular. The greatest runoff was at the first simulated rainfall event (5 cm) at 4 hours after treatment (HAT) in all cases and was decidedly less at 3 subsequent times. Evenly spaced, step-wise increases in P concentrations in runoff were found at the 4 HAT runoff event for both sources for P rates. Preliminary calculations show that 21 and 22% of the total P applied was found in the runoff water for the 11 and 21 kg P/ha rates, respectively, for the superphosphate and 14 and 29%, respectively, for the 16-25-12. These differences were likely due to some differences in the volume of runoff for the different experiments. Results from runoff experiments indicated that a potential problem exists should P fertilizer be placed on fairways before a significant rain event, but judicial management could easily prevent most of this movement.

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