Nitrate and Phosphorus Leaching and Runoff from Golf Greens and Fairways

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Goals:

- *Evaluate the potential movement of nitrogen and phosphorus following application to golf courses.*
- *Develop best management practices for reducing potential transport of nutrients to potable water supplies.*

A project was initiated to determine the potential transport of nitrogen and phosphorus by runoff of surface water from fairways and by leaching through golf greens. The research especially emphasizes studies on phosphorus transport. Experiments are being carried out at four research venues developed by Dr. Albert Smith to study pesticide fate. An overview of the results from three of these areas are reported here summarizing preliminary data, since this is the first year of the project.

Runoff of phosphorus from bermudagrass plots with a 5 % slope from rates of a 10-10-10 fertilizer were greatest at the first simulated rainfall event (Fig. I). The runoff decreased dramatically during subsequent rainfall events. Step-wise increases in P concentrations in the runoff were found for the 5 and 11 kg ha^{-1} rates for the first runoff event. The total mass of P transported for all four events was 10.6 and 11.5 % of that added for the 5 and 11 kg ha^{-1} rates, respectively. Nitrate runoff followed a different pattern resulting in a higher mass of nitrate during the second rainfall event, when the runoff water volume was highest. Since the ammonium form of nitrogen was applied, the amounts of nitrate in the runoff would depend on rates of nitrification as well as transport parameters.

A greenhouse experiment was carried out with columns made to USGA specifications for greens and sodded with bermudagrass. Two sources of balanced fertilizers were applied at four rates to determine potential leaching. The sources applied were a water soluble fertilizer and a sulfur and poly-coated micro-granular fertilizer to study both fast and slow-release types. These rates were added every other week for a total of six weeks with the last treatment being made at week eleven. Phosphorus concentrations in the leachate were much higher for the soluble source at the end of the eleventh week of the experiment (Fig. II). The difference is especially great at the lowest P rate (5 kg ha^{-1}). In fact, at that rate the granular source resulted in P concentrations in the leachate that were not different from control.

Leaching of nitrogen and phosphorus has been monitored for two working putting greens at an Atlanta country club since January, 1995. The bentgrass greens were constructed in the fall of 1994 and were fitted with three lysimeters each. The nitrate concentrations in the leachate did not exceed the 10 mg L^{-1} drinking water standard for the first three years of monitoring. For 1997 the nitrogen concentrations increased in the leachate about 20 to 30 days after application. For all the years, increases in the mass of nitrogen tended to correspond with rainfall events. The concentration of nitrate and the total mass in the leachate is increasing over time. Phosphorus concentrations in the leachate were highest the first year and decreased dramatically thereafter. These initial higher concentrations were probably caused by higher P applications in 1994 during grow-in.

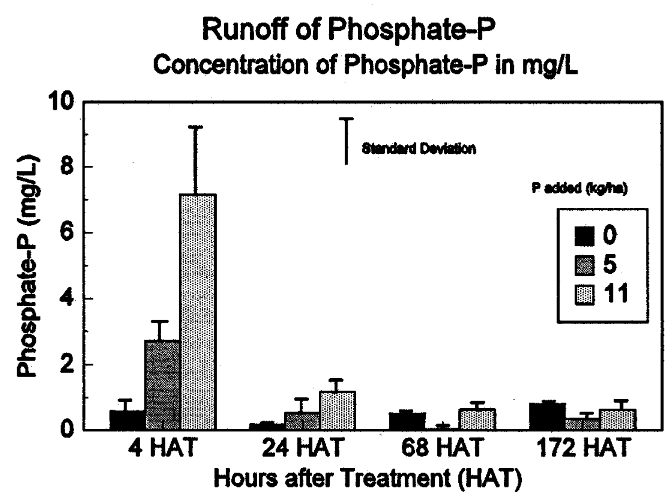

Fig. I. Phosphate concentration in runoff for 3 rates of 10-10-10. Simulated rainfall at 2" for 4 HAT, 2" at 24 HAT, 1" at 68 HAT, and 1" at 172 HAT.

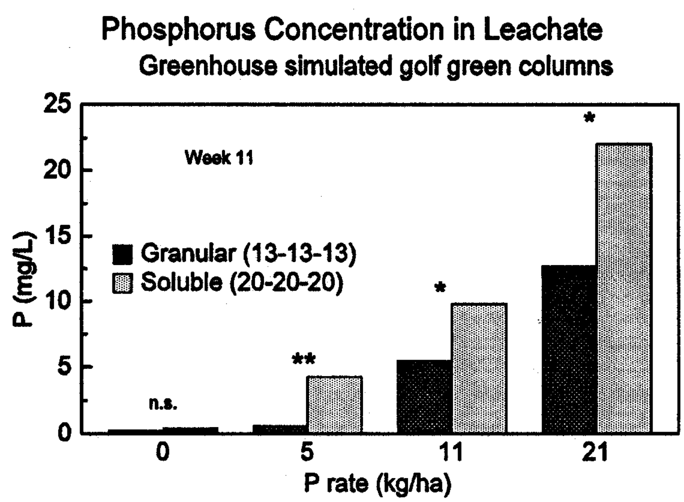

Fig. II. Concentration of P transported through simulated green columns. Rates applied are once every other week for a total of 6 times ceasing on week 11. *,** indicate significance for sources at each rate at the 5 and 1 % levels, respectively.

Nitrate and Phosphorus Leaching and Runoff from Golf Greens and Fairways

1998 Annual Report to the United States Golf Association

Dr. Larry M. Shuman

University of Georgia, Griffin, GA

Executive Summary

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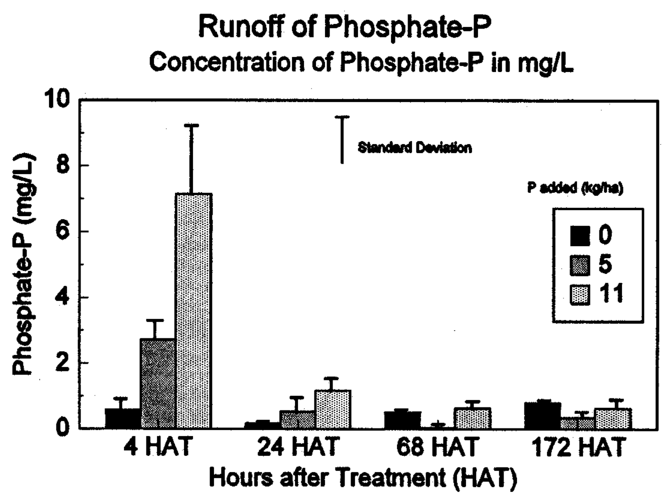

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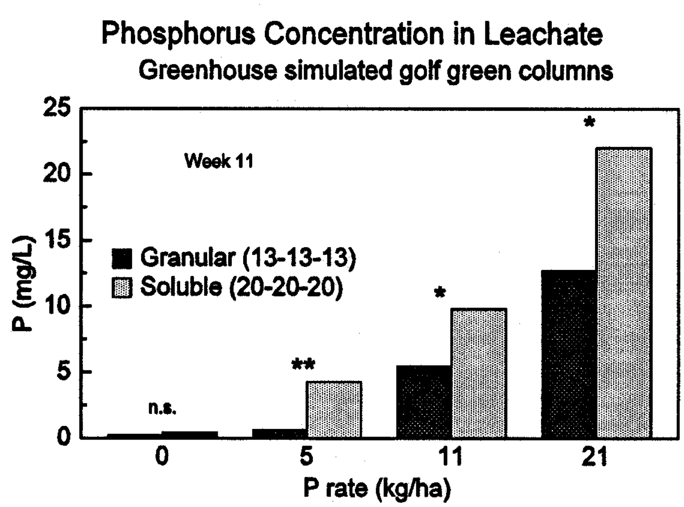


Fig. II. Concentration of P transported through simulated green columns. Rates applied are once every other week for a total of 6 times ceasing on week 11. *,** indicate significance for sources at each rate at the 5 and 1 % levels, respectively.

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.

A research program was initiated this year 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 two working putting greens on a golf course in Atlanta. Eventually, management practices will be evaluated, especially for reducing runoff of P from the simulated fairways. The form of P found in leachate and runoff is also being evaluated, as well as the amounts of dissolved C in the water that may exacerbate leaching. The research areas and facilities are those developed at the Georgia Experiment Station for studies on pesticide leaching and runoff. This year a fertilizer rate experiment was completed on the runoff plots, a source-rate leaching experiment was completed in the greenhouse, a leaching experiment was initiated on the field lysimeters, and monitoring of N and P in the leachate from the putting greens on the working course in Atlanta were continued. Nitrate and P data for 1995-1997 for the leachate from the putting greens were collated and are presented here in graphic form along with the rainfall data.

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. This year we carried out considerable maintenance and repair work and made some improvements in the water collection system. We also took measurements of the uniformity over the plot area of the simulated rainfall from the irrigation system.

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 2.7 cm hr^{-1}.

Treatments were made with 10-10-10 granular fertilizer at rates to give 0, 0.25, 0.5 and 1.0 lb. N/1000 sq. ft. (0, 12, 24, and 49 kg N/ha) and rates of 0, 0.11, 0.22, and

0.44 lb. P/1000 sq. ft. (0, 5, 11, and 21 kg P/ha). Treatments were made through the summer months from April to August. The fertilizer was spread using a calibrated drop spreader. 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.

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 and was used for all samples prior to this year. During the year we discovered that the instrument was losing sensitivity to P, so all the P data reported herein for 1998 were obtained using the same method, but by running the analyses by hand. That is, we developed the color in 50 mL volumetrics and measured absorbance using a spectrophotometer at a wavelength of 880 nm.

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 1-L dark glass 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 14 and 15 May, 1998. The total area of the box was sodded, but only the center portion was involved in the leachate collection.

A track irrigation system controlled the rates and times of irrigation. Nozzles passed over the boxes at a rate of 2.9 m/min. and produced a flow rate of 1.82 mL/sec at 138 kPa. The boxes were irrigated daily at 0.25 in. (0.625 cm.) for the first seven weeks of the experiment. The irrigation rate was too low to effect any leaching, so the rate was doubled for the next seven weeks. The turf was mowed twice a week at a height of 1.0 cm. using a hand clipper to simulate a reel-type mower. A fungicide was added twice during the first seven weeks to prevent algae growth.

The fertilizer source-rate experiment consisted of two sources at four rates and, since there were more units available, we added an extra rate to the granular source. The sources were a Peters water-soluble 20-20-20 and a Lesco sulfur and poly-coated micro-granule 13-13-13. The rates were 0, 0.25, 0.5 and 1.0 lb. N/1000 sq. ft. (0, 12, 24, and 49 kg N/ha) and 0, 0.11, 0.22, and 0.44 lb. P/1000 sq. ft. (0, 5, 11, and 21 kg P/ha). A higher rate of the 13-13-13 was included at 2.0 lb. N/1000 sq. ft. and 0.88 lb. P/1000 sq. ft. (98 kg N/ha and 43 kg P/ha). Each treatment was replicated four times. The soluble source was added dissolved in water and the granular source was spread over the surface by hand. Treatments were placed on the turf on 9 June, 1998 (week 1), and the same rates repeated every two weeks for a total of six treatments. The last treatment was on 18 August, 1998 (week 11). The first leachate samples were taken on 9 June, 1998, and continued weekly until the present. They are refrigerated at 4° C prior to analysis for nitrate-N and phosphate-P. Data reported here are up to and including week 18, which was the sampling on 6 October, 1998.

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 is in place to move over 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. This summer was used to renovate the sod and repair the irrigation system. A source-rate experiment was initiated on 11 September, 1998.

The fertilizer treatments added were the same soluble and granular sources used for the greenhouse experiment. 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). Leachate samples are being collected once a week and analyzed for nitrate-N and phosphate-P on samples filtered through a 0.45 μm filter.

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. The same methods were used as described above.

SUMMARY OF RESULTS

Determination of Nitrate and Phosphate Transport from Simulated Fairways

Four experiments were completed using four rates of 10-10-10 fertilizer. Some of the results presented here have been presented at the 1998 American Society of Agronomy meetings. Phosphorus runoff was the greatest at the first simulated rainfall event (4 HAT) in all cases and was much less at the subsequent events (Fig. 1). Step-wise increases in P in the runoff were found for the 5 and 11 kg ha^{-1} rates at the first runoff event. The total mass of P transported was 10.6 and 11.5 % of that added for the 5 and 11 kg ha^{-1} rates, respectively.

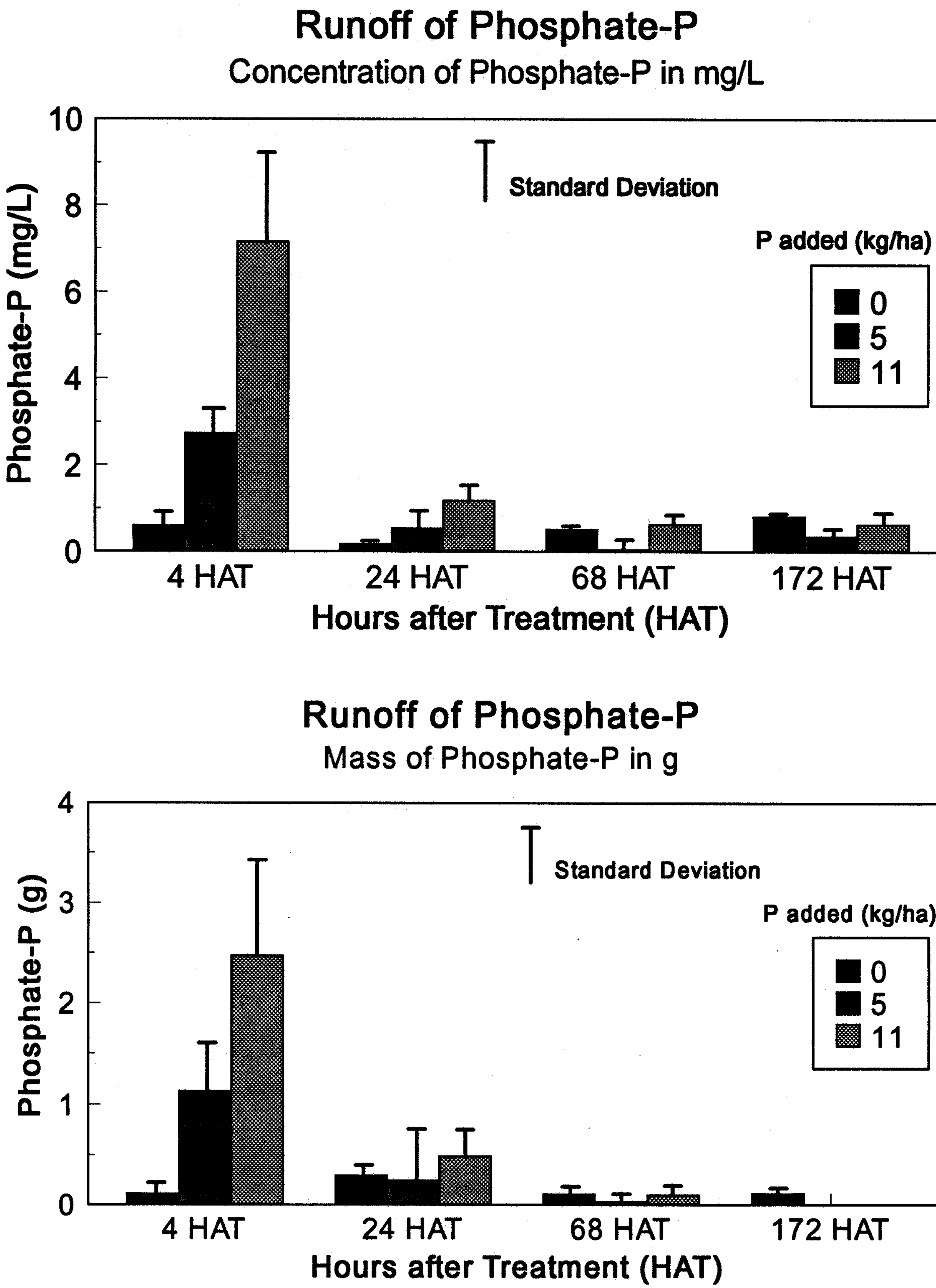


Fig. 1. Concentration and mass of P for 3 P rates and 4 simulated rainfall events.

Transport data for nitrate shows a different pattern than for phosphate. Since the ammonium form as mono-ammonium phosphate was added, nitrification rates would come into play in the amount of nitrate available for runoff. The nitrate-N was quite low in terms of concentration and was similar for the first three simulated rainfall events and higher at 172 hours (Fig. 2). The mass of N at 24 HAT was highest for the 0 and 49 kg ha^{-1} rate, indicating that runoff volume was the determinant of N transport, which was not true for P in that most of the P came off at the first runoff event even though the volume was lower there (Fig. 3).

The runoff volume at the first simulated rainfall event was most likely determined by the soil moisture at that time (the moisture data is available for several of the experiments, but not collated at the time of this report). The runoff volume for the second and subsequent simulated events are fairly uniform probably because the soil was saturated by the time the second rainfall event occurred. The total volume of the runoff water for the 4 simulated rainfall events averaged over the experiments was 29.3 % of that added and varied very little.

The importance of the runoff volume at the first simulated rainfall event for P is shown by the data in Fig. 4, where a higher rate of P (21 kg ha^{-1}) gave about half the mass of runoff P as that at a lower rate (11 kg ha^{-1}). The percent P runoff for the 21 kg ha^{-1} rate was only 3.4% of that added. The most likely reason is the lower runoff volume for the 4 HAT event for the higher P rate. Since the P was not transported at the first rainfall event, the P evidently reacted with the soil and was not transported to a great extent during subsequent rainfall events. Thus, the implication is that if the fertilizer P is irrigated a little, so that runoff is minimized, that it will lower its tendency to be transported in subsequent rainfall events. This preliminary finding will be followed up by experiments in the future where comparisons will be made between a high and low initial simulated rainfall followed by the simulated rainfall events as reported here. The soil moisture at the beginning of the experiment can also be varied to give different volumes of runoff initially as probably happened in this case.

Determination of Nitrate and Phosphate movement through Simulated Greens

Greenhouse Lysimeters

This experiment is still ongoing at the time of this report. The first seven weeks the irrigation was at 0.25 in./day which was too low to give significant amounts of leachate. Thus, at week seven the irrigation was doubled to 0.5 in./day. The P concentrations rose dramatically at week 9 as the P collected in the columns for the first seven weeks resulted in a breakthrough peak (Fig. 5). The volumes of leachate dropped in week 10 giving a lower P concentration which increased for week 11 and 12 before decreasing. The rates of P added are very evident in the P concentration data and the cumulative mass data (Figs. 5 and 6) beginning with week 9. A comparison of the two fertilizer sources for week 11 indicates that the soluble source was transported to a greater extent than the granular coated source at all addition rates (Fig. 7). The

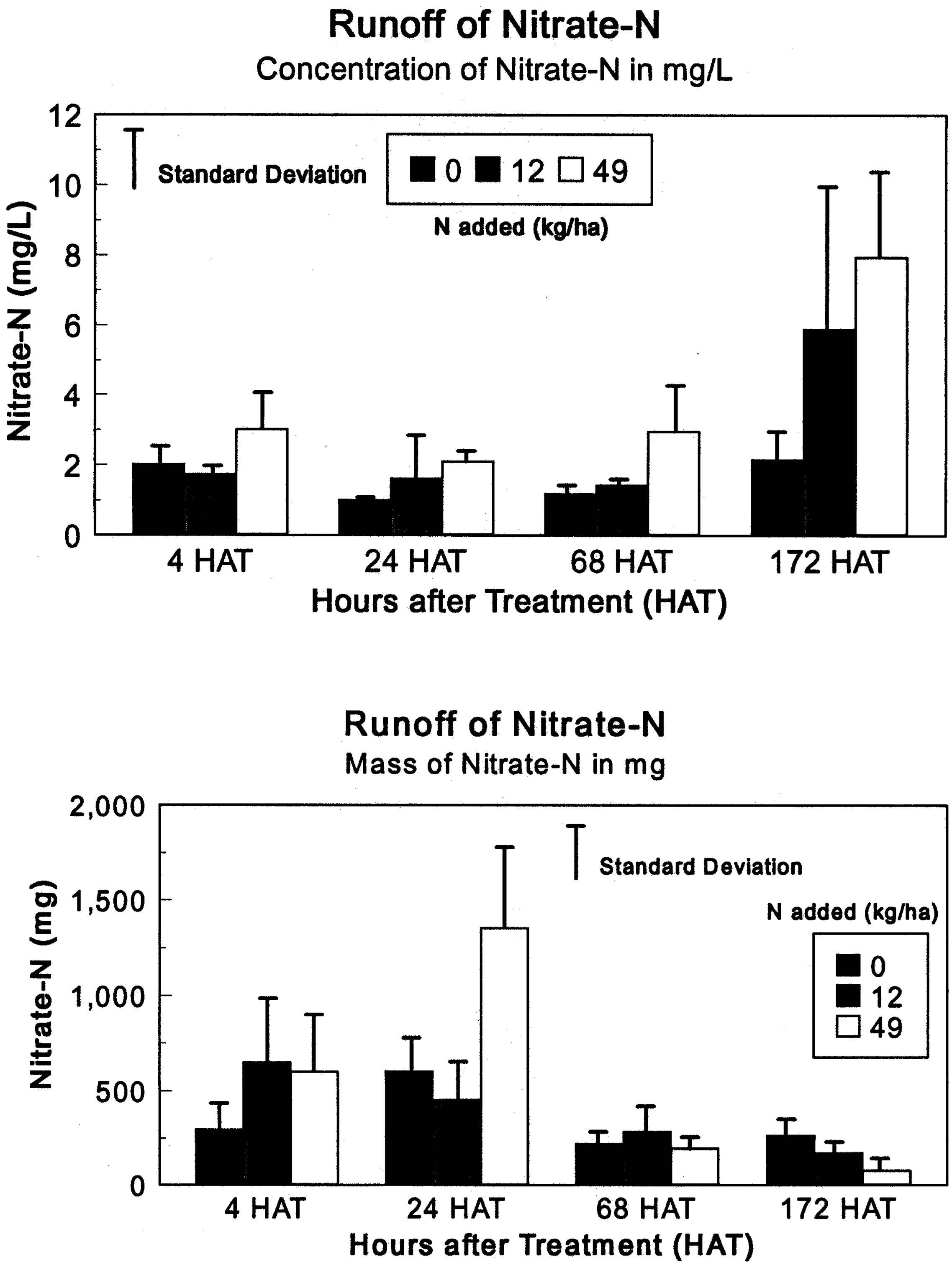


Fig. 2. Concentration and mass of N for 3 N rates and 4 simulated rainfall events.

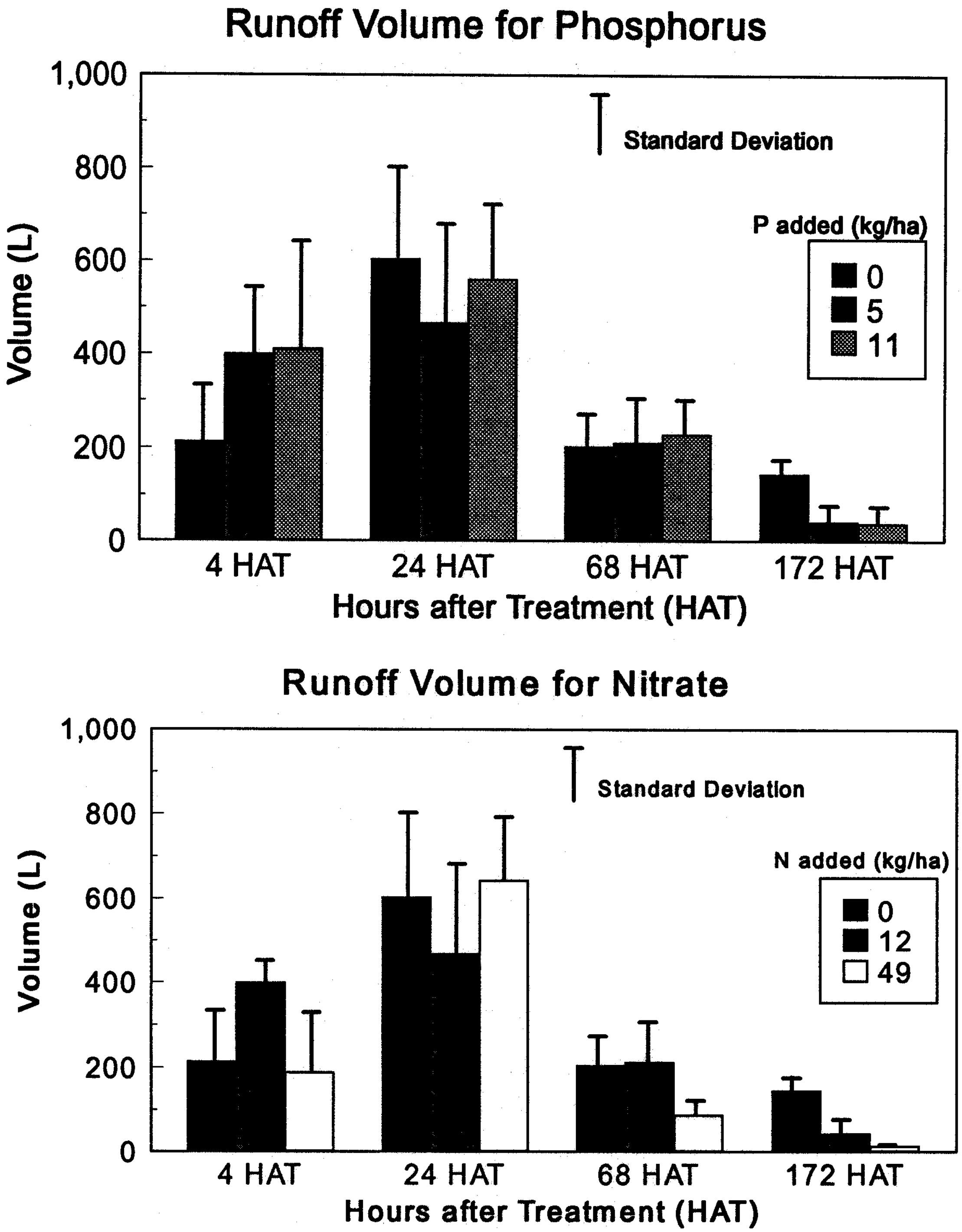
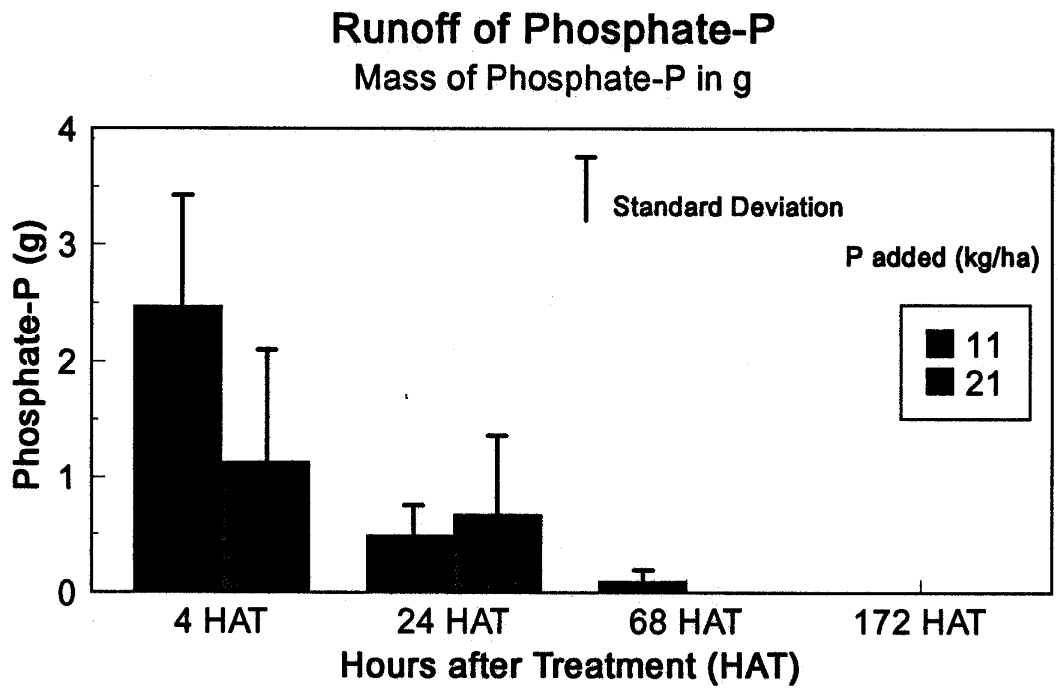


Fig. 3. Volume of runoff water for 3 rates of P and N and 4 simulated rainfall events.



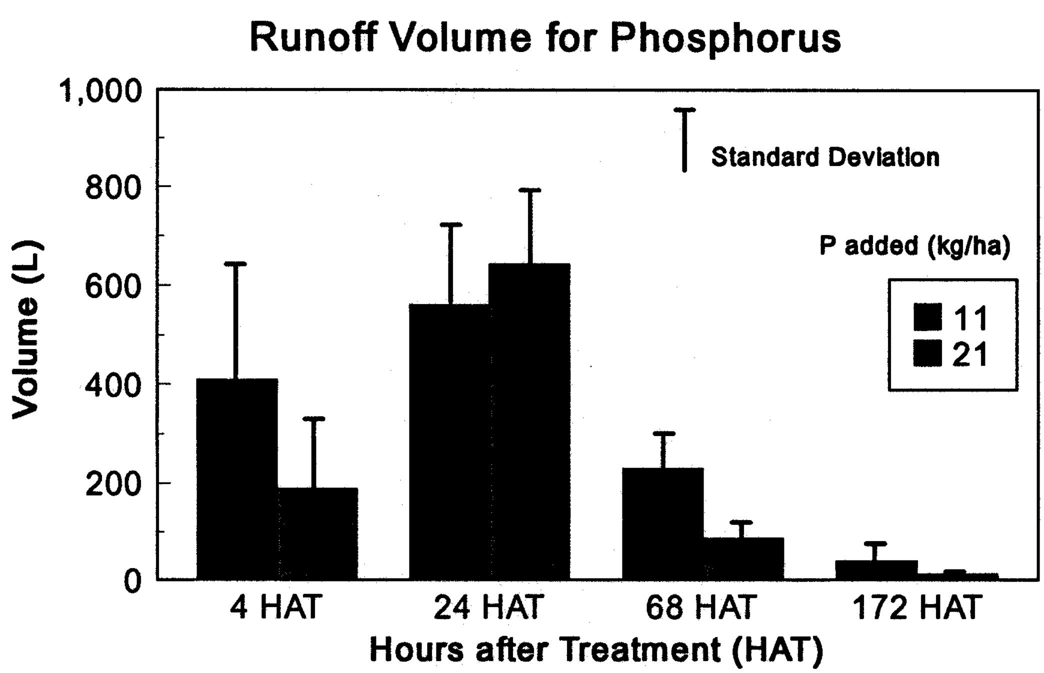


Fig. 4. Concentration of P and volume of runoff water for 2 P rates and 4 simulated rainfall events.

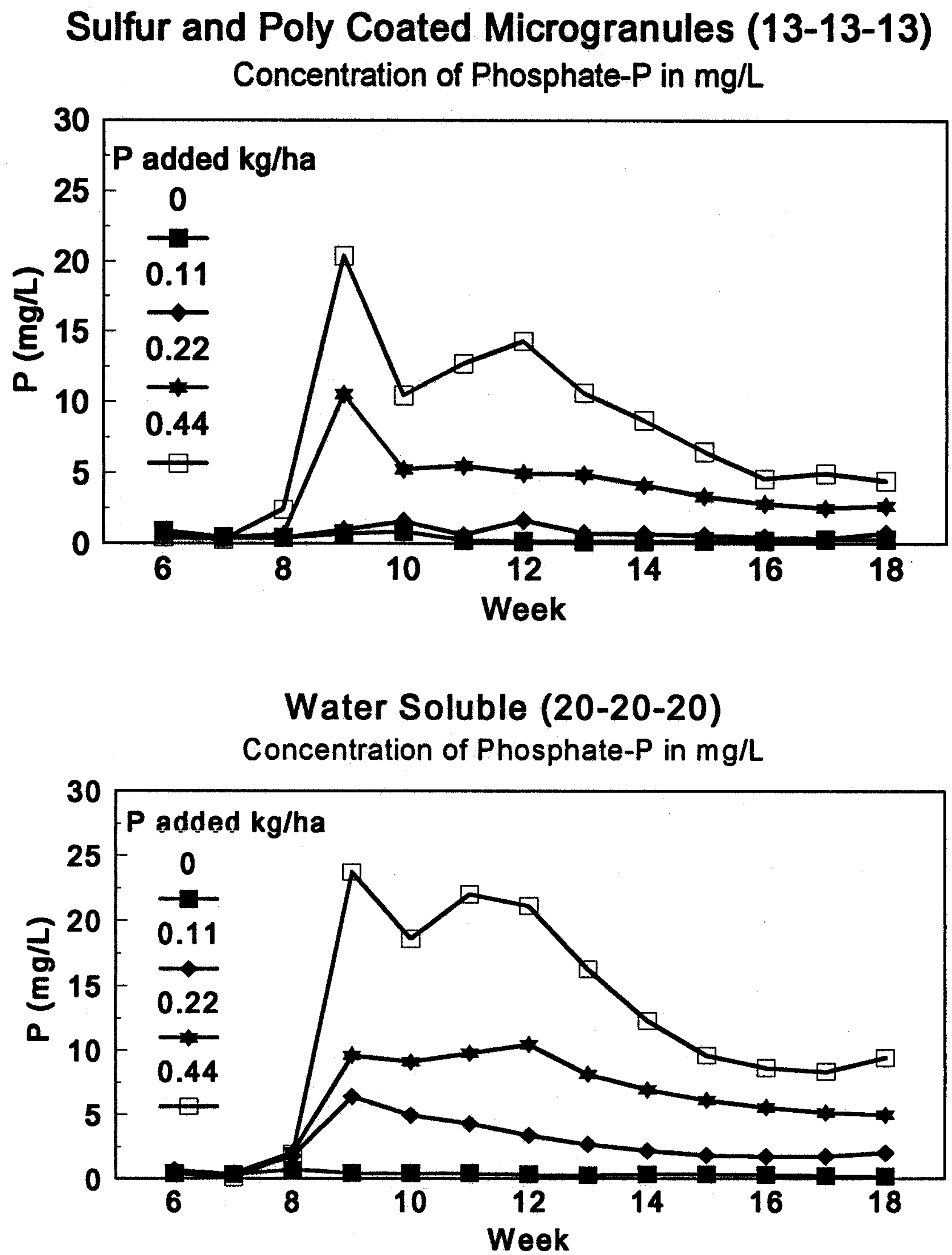


Fig. 5. Concentration of P transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied as stated every other week for a total of 6 times ceasing on week 11.

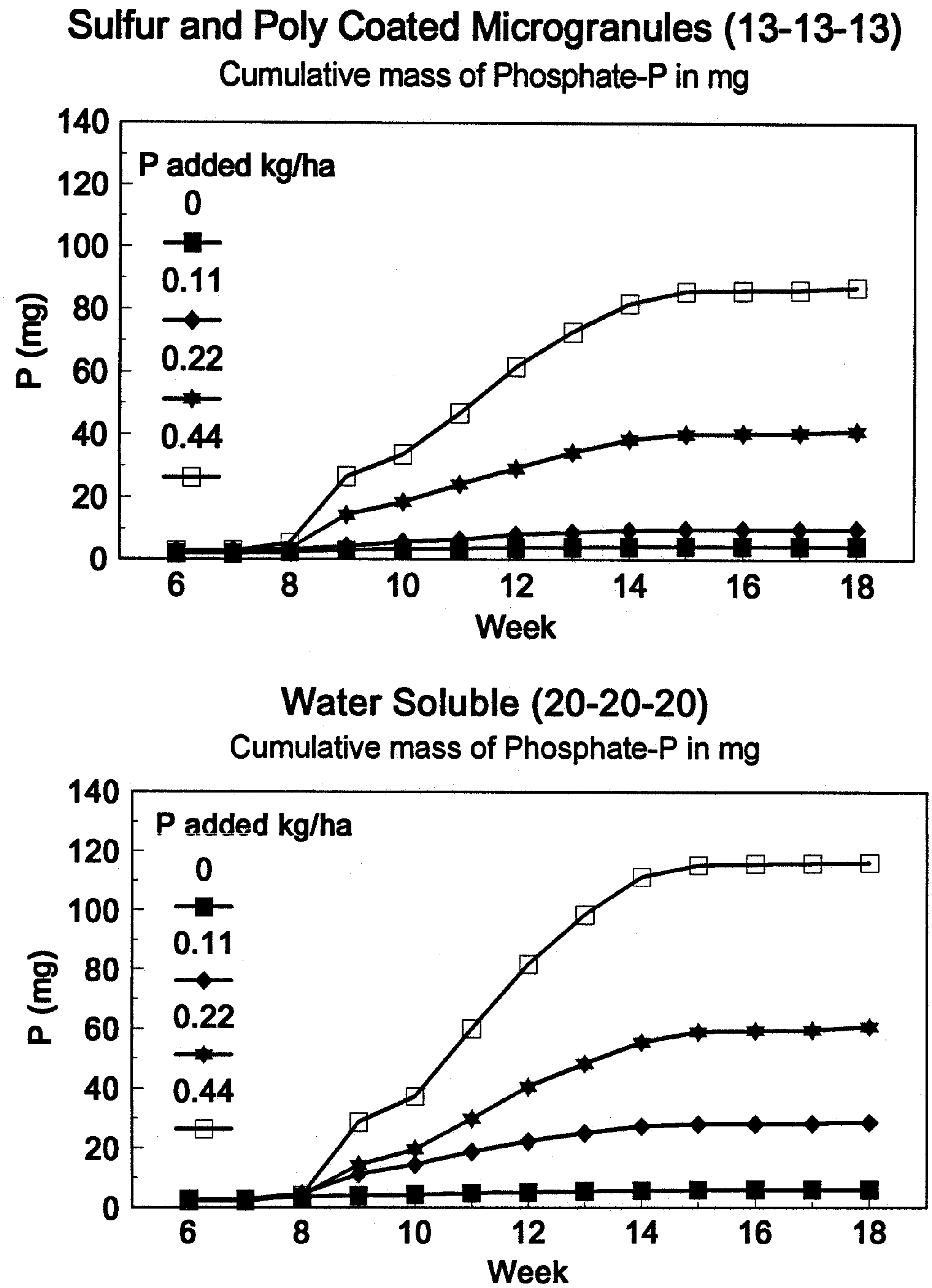
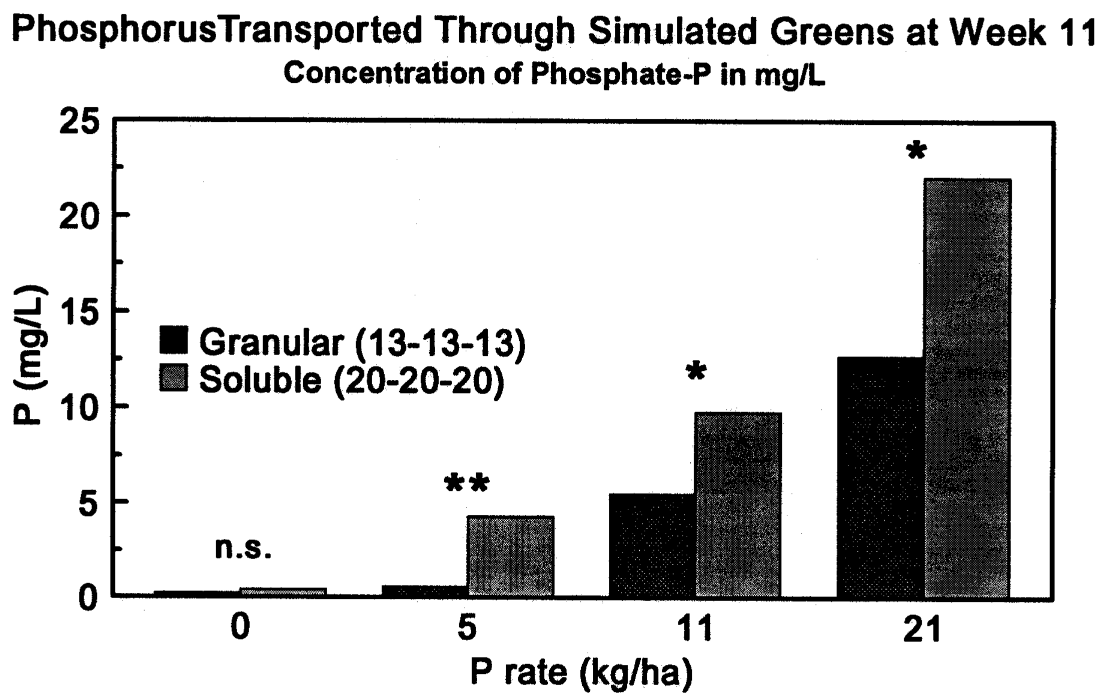


Fig. 6. Cumulative mass of P transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied as stated every other week for a a total of 6 times ceasing on week 11.



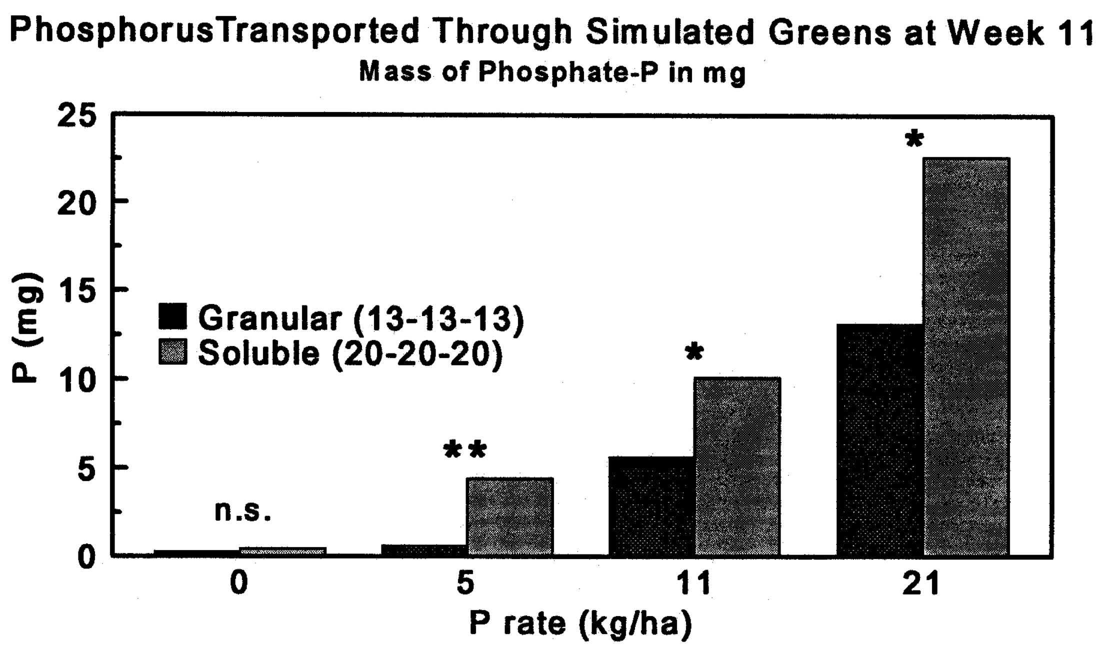


Fig. 7. Concentration and mass of P transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied as stated a total of 6 times every other week ceasing on week 11. *, ** indicate significance for sources at each rate at the 5 and 1 percent level, respectively.

difference is especially pronounced at the 5 kg ha^{-1} rate where there was no significant difference between the 0 and 5 kg ha^{-1} rate for the granular coated source but there was a significant difference in P transport between the 0 and 5 kg ha^{-1} rates for the soluble source (statistics for this comparison are not shown on the figure). This experiment is showing the trend in leaching for two widely different sources that will serve as points for comparison to other fertilizer sources to be studied in the future.

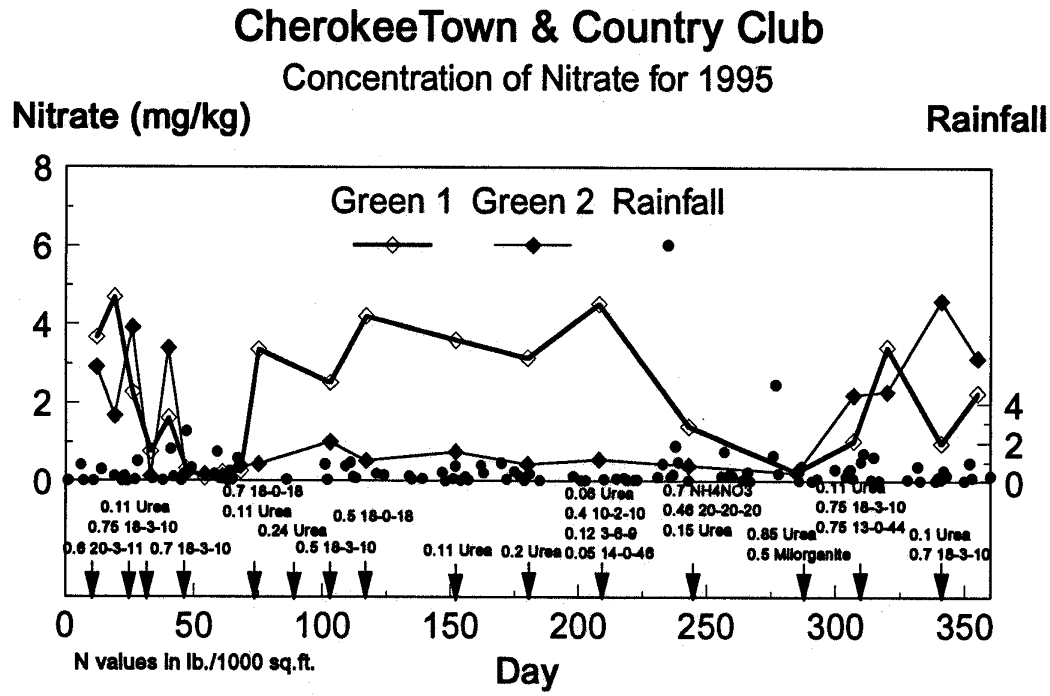
Field Lysimeters

Background leachate volumes and nutrient data indicated that the lysimeters were not getting a uniform distribution of irrigation water. Several repairs were made both to the irrigation system and the rain-out shelter mechanism. Uniformity of the irrigation was restored, and the output measured was 0.11 in. (0.25 cm.) per application. Daily applications at that rate are producing weekly leachate volumes of about 1.5 L. It remains to be seen if that is enough to transport the nutrients through the lysimeters. A fertilizer source-rate experiment similar to that carried out in the greenhouse was initiated on 11 September, 1998.

Nitrate and Phosphorus Leaching Through Golf Course Putting Greens

Nitrate

Nitrate concentrations in the leachate did not rise above the 10 mg L^{-1} drinking water standard for any of the samplings during the three years of monitoring reported here (Figs. 8-10). These values are averages of the data for the three lysimeters in each green. During 1995 and 1996, nitrogen additions were so frequent that the peaks in concentration cannot be related to the amendments (Figs. 8 and 9). For 1997 there were fewer N additions spaced further apart, so that some relationship between additions and peaks can be seen (Fig. 10). The trend is for the N to appear as nitrate in the leachate about 20-30 days after applying, but rainfall was also an important factor in determining when the nitrate concentration increased in the leachate. The mass of nitrate leaching increased each year as can be seen in the increase in the maximum for the Y axis each year (Figs. 8-10). In every case the mass of nitrate was higher for green 1 than for green 2. The difference is probably a result of the slope of the green in relation to the placement of the lysimeters. The increases in mass of nitrate in the leachate often correspond to rainfall events. The increasing mass of nitrate in the leachate is evident in the average mass data shown in Table 1 for the three years. The concentration averages also show some increase, especially for 1997. The maxima data are for individual lysimeters, so do show a slight elevation above the 10 mg L^{-1} drinking water standard. The current data is not completely analyzed, but it appears that the nitrate concentrations are even higher for 1998.



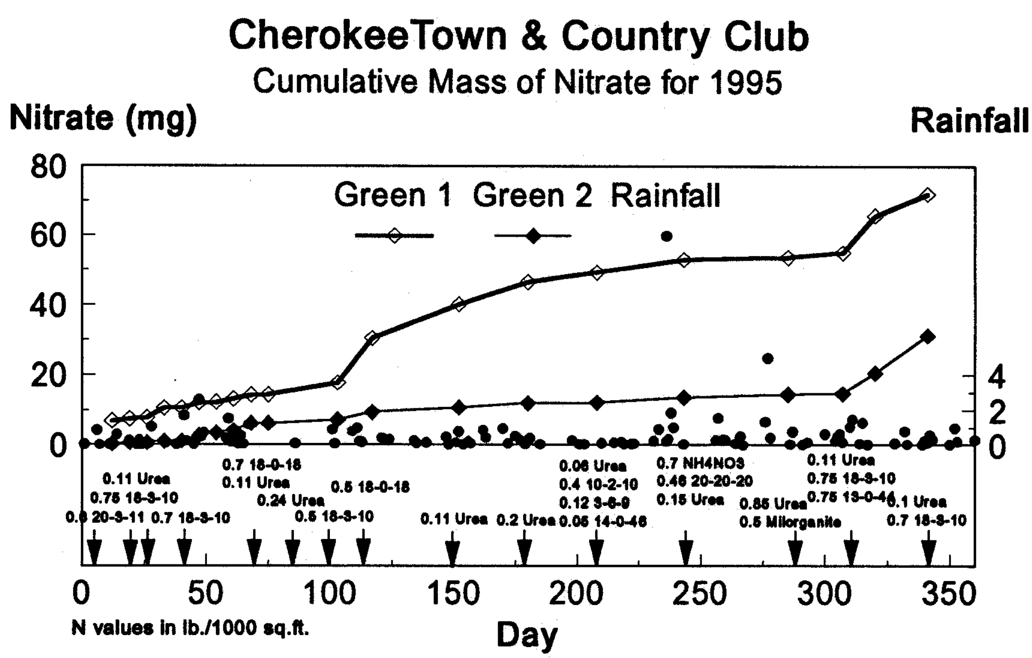
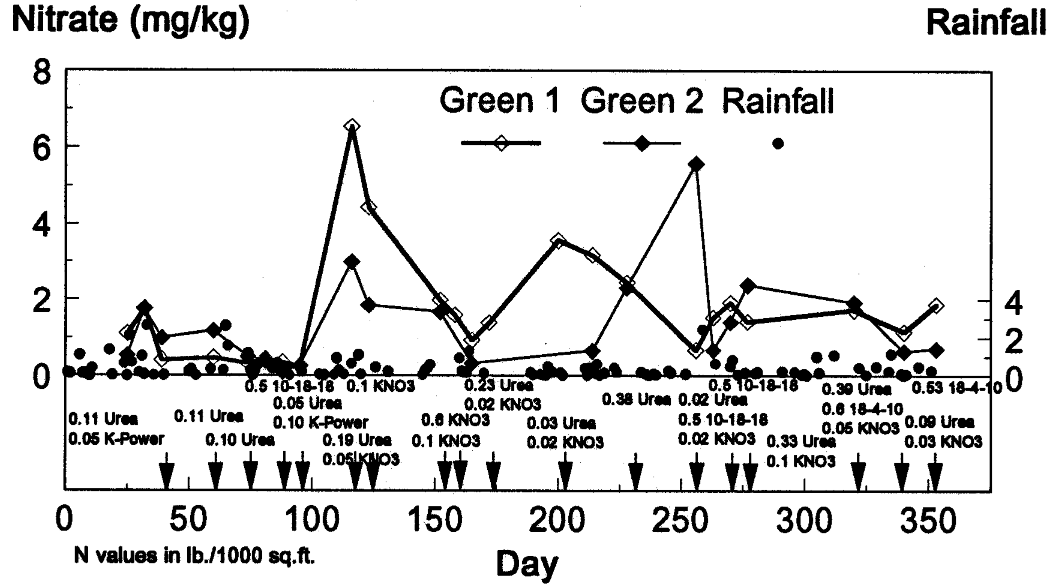


Fig. 8. Nitrate concentration and cumulative mass for 1995 for two putting greens at the Cherokee Town and Country Club.

Cherokee Town & Country Club

Concentration of Nitrate for 1996



Cherokee Town & Country Club

Cumulative Mass of Nitrate for 1996

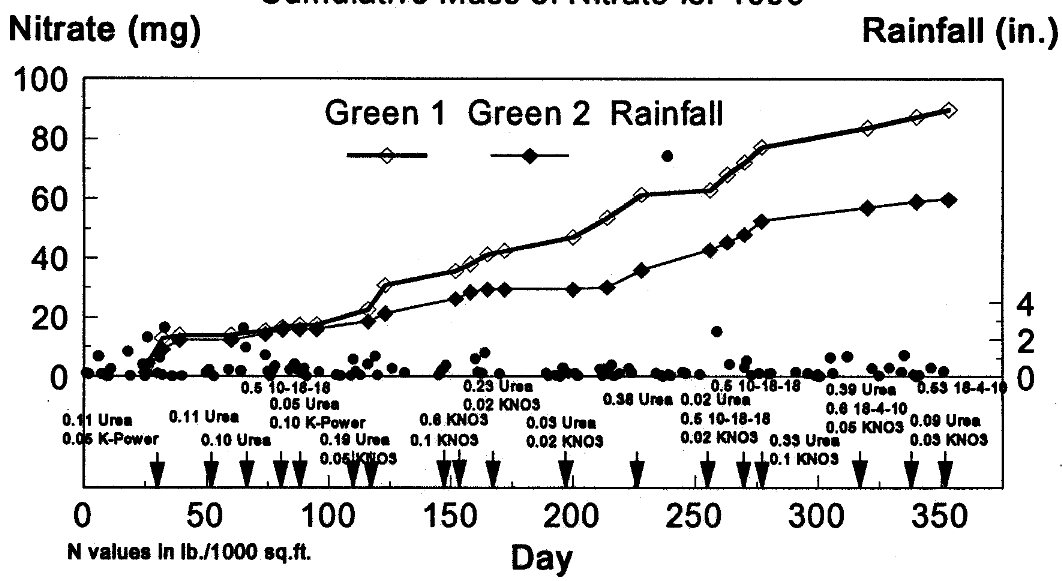
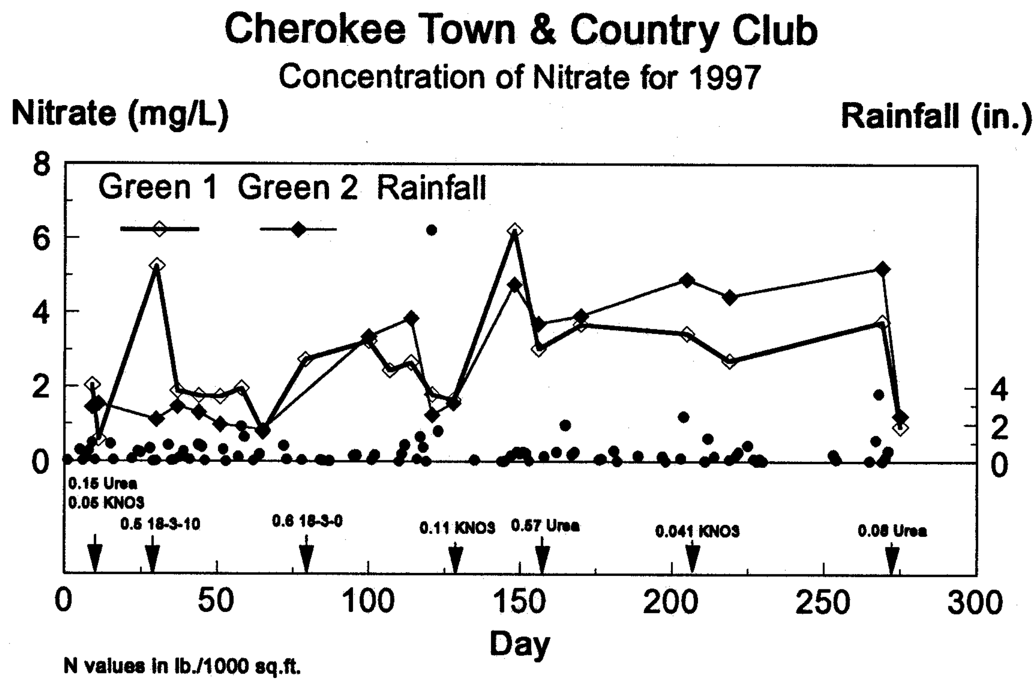


Fig. 9. Nitrate concentration and cumulative mass for 1996 for two putting greens at the Cherokee Town and Country Club.



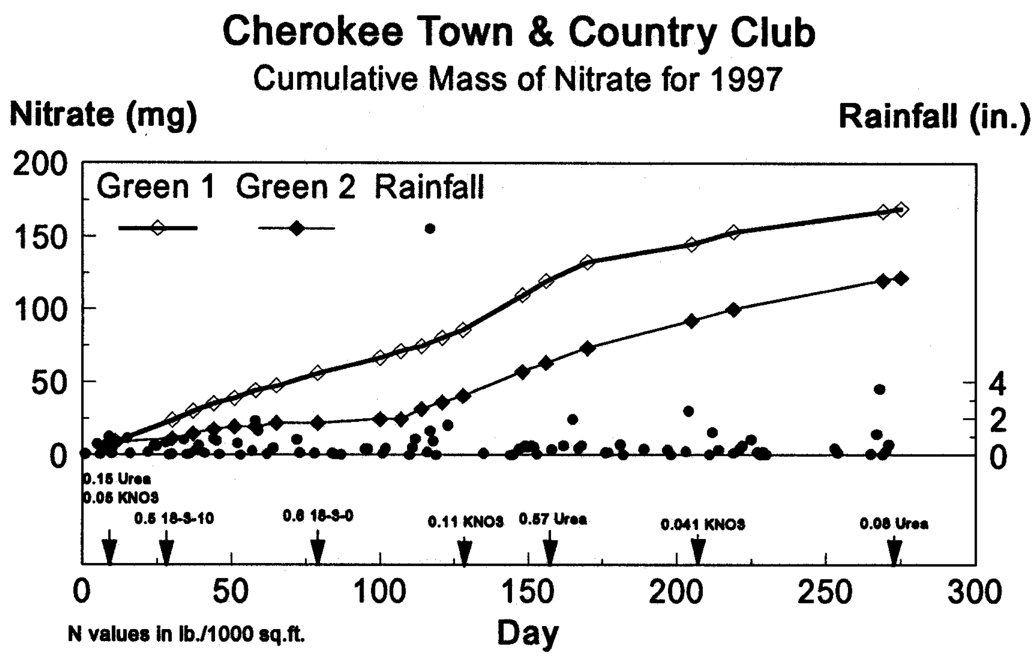


Fig. 10. Nitrate concentration and cumulative mass for 1997 for two putting greens at the Cherokee Town and Country Club.

Phosphorus

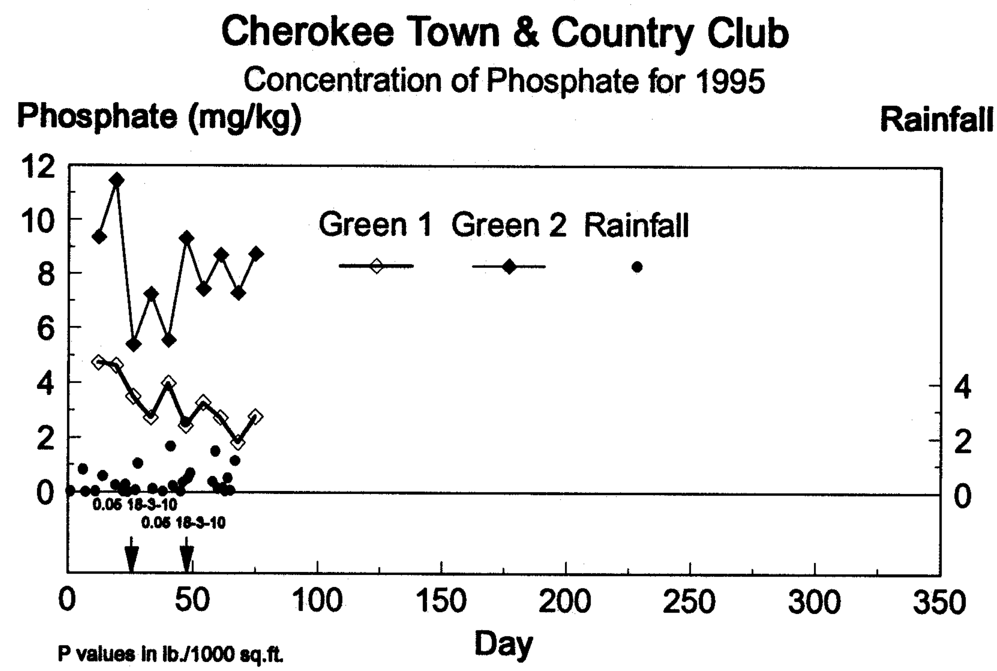
For reasons unknown, P data were only recorded for January to mid-March in 1995 (Fig. 11). This is unfortunate, since that data are the highest data we have and seem to be decreasing with time. The higher concentrations may have been caused by additions of P made in 1994 during grow-in of the greens. Very little P was added to these greens during the three years of monitoring, according to the records supplied to us by the superintendent of the golf course (Figs. 11-13). For 1996 and 1997 the concentrations of P were usually between 1 and 3 mg L^{-1}. The cumulative P was similar for 1996 and 1997 at around 60 mg (Figs. 12 and 13). Some increases in cumulative P correspond with the time of rainfall events. The dramatic decrease in P concentrations and mass are indicated in the data shown in Table 2 as averages for each year.

FUTURE PLANS

Runoff experiments will continue with other fertilizer sources. The sources will be superphosphate, urea, sulfur-coated urea, and various liquid fertilizers. In the coming year we will make more attempt to have the soil moisture the same before running each experiment, since it is the most important factor in influencing runoff volume. Irrigating 2" at 24 hours before treatment did not give a uniform soil moisture for the start of each experiment. This could be because we had a very hot and dry summer so that soil moisture varied considerably before the initial irrigation. If there is time, we may carry out an experiment where the fertilizer is added and an irrigation done with no runoff before the runoff sequence is initiated. Giving the nutrients time and opportunity to react with the soil should have a major effect on runoff.

Leaching experiments, both in the greenhouse and field, will continue with other fertilizer sources. In the greenhouse we will be using a rate of irrigation to be certain that leaching occurs, unlike our experience early this year. When leachate volumes were very low, it introduced variation in the data, and we did not observe treatment effects. We will also make only one or two fertilizer applications per experiment in order to increase the number of experiments we can complete in a year. Monitoring the nitrate and phosphate in the lysimeters at the country club in Atlanta will continue. The course is undergoing a major renovation, but these two greens will be left intact.

Laboratory procedures are being reviewed to ensure quality control, since we had to rerun samples this year. We are quite confident of the P data at this point and are reviewing the nitrate data to make certain that the data are accurate. Next year we will continue efforts to analyze samples for forms of P, both total and biologically available. Our data for this year indicate that nearly all the P in the runoff samples is soluble P. This winter we will be analyzing selected runoff and leachate samples for dissolved organic carbon to determined if there is any relationship between the DOC content and P concentrations.



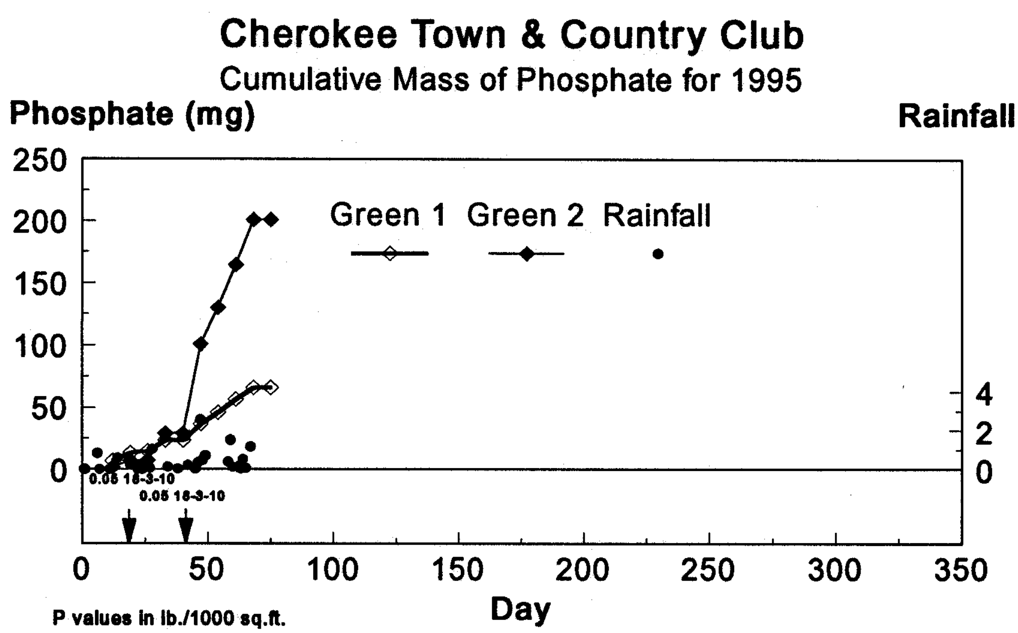
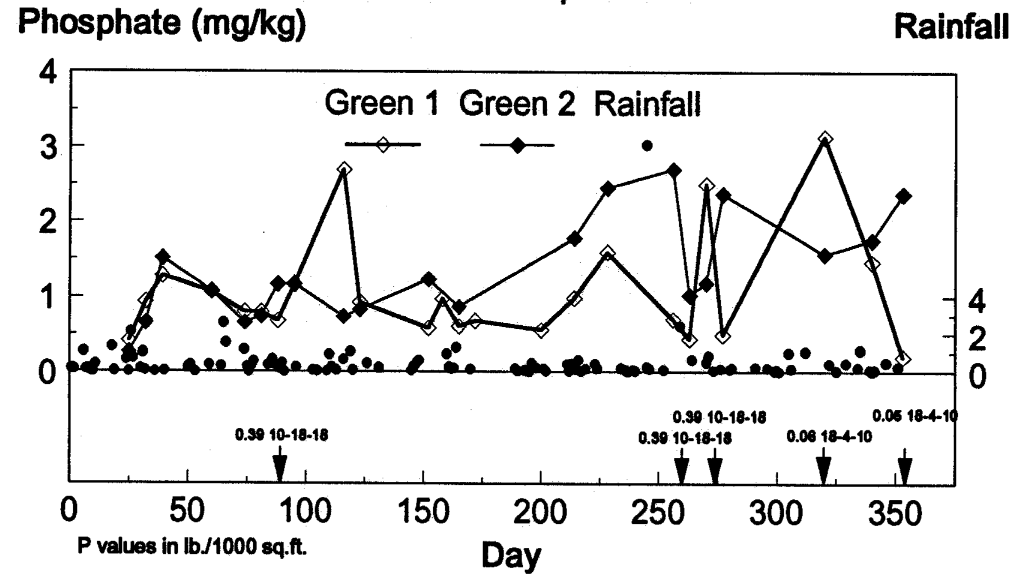


Fig. 11. Phosphorus concentration and cumulative mass for 1995 for two putting greens at the Cherokee Town and Country Club.

Cherokee Town & Country Club

Concentration of Phosphorus for 1996



Cherokee Town & Country Club

Cumulative Mass of Phosphorus for 1996

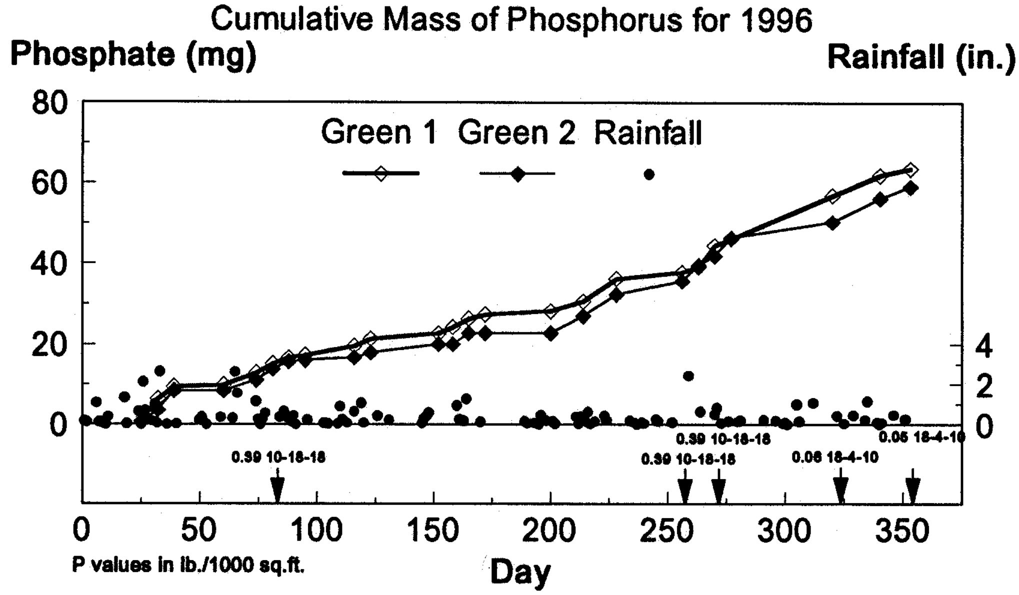


Fig. 12. Phosphorus concentration and cumulative mass for 1996 for two putting greens at the Cherokee Town and Country Club.

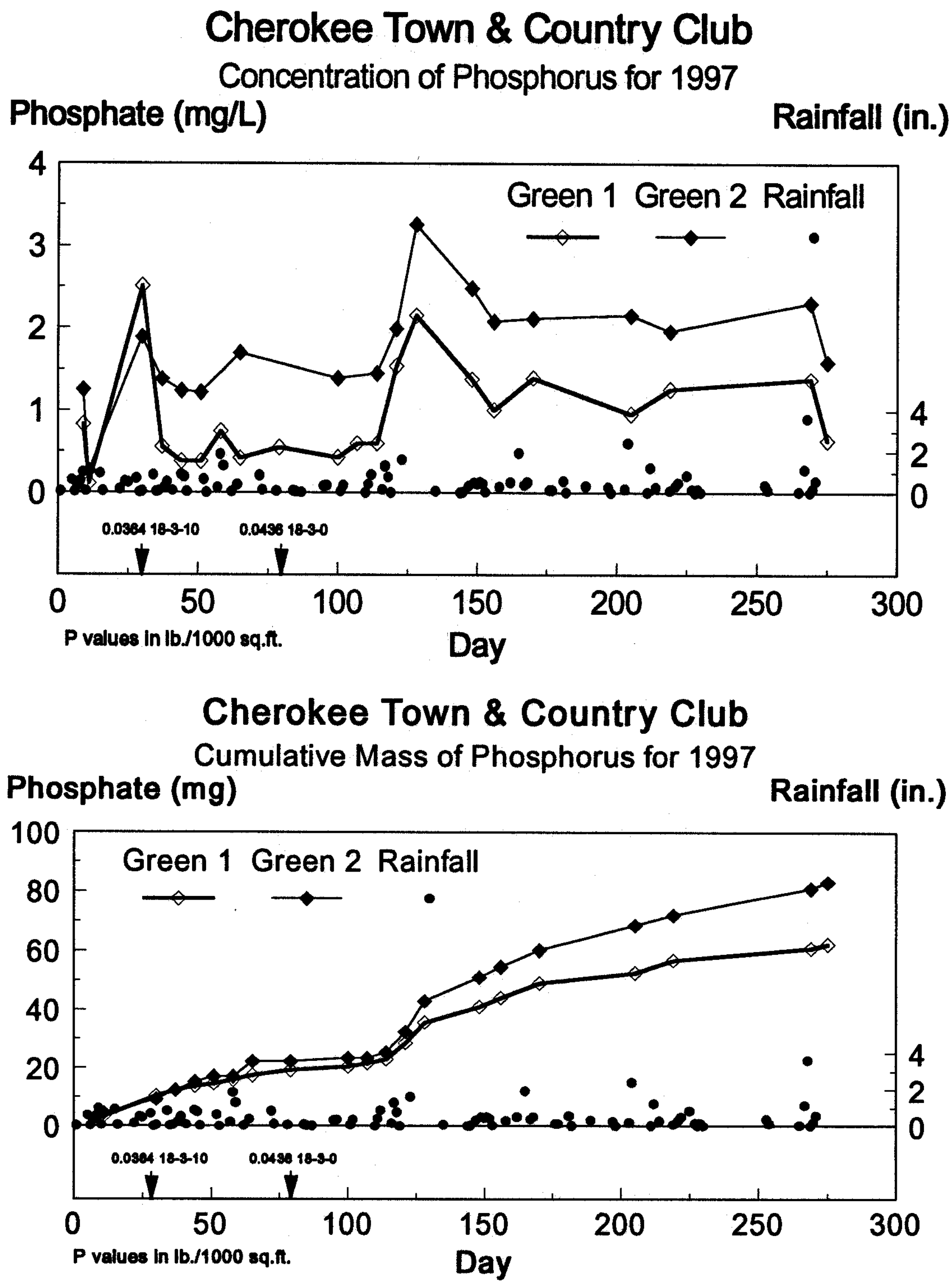


Fig. 13. Phosphorus concentration and cumulative mass for 1997 for two putting greens at the Cherokee Town and Country Club.

Table 1. Nitrogen leaching concentration (mg/kg) and mass (mg) averages for individual collection dates by year for three 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
	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

Table 2. Phosphorus leaching concentration (mg/kg) and mass (mg) averages for individual collection dates by year for three 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
	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