Nitrate and Phosphorus Leaching and Runoff from Golf Greens and Fairways

1999 Annual Report to the United States Golf Association

Dr. Larry M. Shuman

University of Georgia, Griffin, GA

Executive Summary

This project was initiated in 1998 to determine the potential transport of nitrogen and phosphorus by runoff of surface water from fairways and by leaching through golf greens. Experiments on leaching are being carried out at two venues (one greenhouse and one field) and runoff experiments at one field site on campus. A fourth site involves monitoring leachate from two greens at an Atlanta golf course. Highlights of results for this year are reported for each of the four venues.

Two runoff experiments were carried out in 1999 on bermudagrass plots with a 5% slope. The first tested a granular 16-25-12 starter fertilizer and the second a combination of ammonium nitrate and treble superphosphate. Both P sources resulted in the greatest transport at the first simulated rainfall event decreasing dramatically in the three subsequent events. Step-wise increases in P concentration and mass were found for the first event for the 11 and 21 kg ha^{-1} rates. The total mass of P transported combining all rainfall events were 21% for the superphosphate for each rate and 14 and 29% for the two rates, respectively, for the 16-25-12.

The greenhouse experiment carried out this year was for four rates of ammonium nitrate-superphosphate and a water soluble 20-20-20 on columns made to USGA specifications for greens and sodded with bermudagrass. The rates were added twice. A peak for transport was seen at weeks 18-19 for P and week 17 for N. Phosphate concentrations in the leachate were higher for the soluble source at the peak than for the superphosphate (Fig. I). There were little, if any, differences in N leaching found between the ammonium nitrate and the soluble source.

Four treatments at three rates were made to field lysimeters in 1999 with the sources being a granular sulfur and poly coated 13-13-13 and a water soluble 20-20-20. Phosphorus showed little transport for any source or rate giving a slight response to treatments only once. The tendency was for the concentration and mass of transported P to decrease during the course of the year despite repeated fertilizer applications as high as 11 kg ha^{-1}. Nitrogen applications showed transport responses for each application and the soluble source gave much higher transport than did the granular coated source. In fact, the granular source only showed peaks slightly above control for two of the four treatments.

Phosphorus concentrations and mass continued to decrease in the leachates from the two putting greens located at an Atlanta country club as they have been for the four years we have been monitoring (Table 1). The bentgrass greens were constructed in the fall of 1994 and were fitted with three lysimeters each. Nitrate levels were generally low (below the 10 mg L^{-1} drinking water standard) for most of the year, but did increase to 20-25 mg L^{-1} late in the year in response to a high N application (0.88 lb. N/1000 sq. ft. as KNO_3). In 1999 one of these greens was removed and two new playing greens were equipped with three lysimeters each.

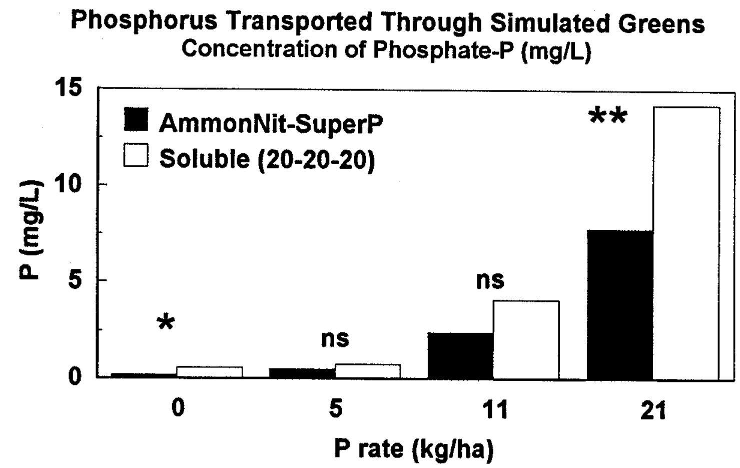


Fig. I. Concentration of P transported through simulated green columns at week 18. Rates applied at weeks 2 and 14. *, ** indicate significance at the 5 and 1 % levels, respectively.

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

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 second 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 two working putting greens on a golf course in Atlanta. This 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, 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 two fertilizer rate experiments were completed on the runoff plots with two sources, a source-rate leaching experiment was completed in the greenhouse, a leaching experiment was carried out 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.

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 tested a Scotts 16-25-12 granular fertilizer at rates to give 0, 0.22, and 0.44 lb. P/1000 sq. ft. (0, 11 and 21 kg P/ha) which gave N rates of 0, 0.32 and 0.64 lb. N/1000 sq.ft. Treatments were made from the beginning of May to the end of June, 1999. 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 tested a combination of ammonium nitrate and treble super phosphate (46% P_2O_5) to give rates of 0, 0.5 and 1.0 lb N/1000 sq.ft. (0, 24, and 49 kg N/ha) and 0, 0.22, and 0.44 lb P/1000 sq. ft. (0, 11, and 21 kg P/ha). Treatments were made from the beginning of July to mid August, 1999. The irrigation and sample collection were as for the first experiment.

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 in May of 1998 and held on a separate bench until placing on the columns at the end of November, 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 0.50 in. (1.25 cm.). The initial leaching period produced small and variable amounts of leachate. It was determined that the boxes were not properly sealed against the medium in the columns. This was corrected in March, 1999, and thereafter the columns drained properly. The turf was mowed twice a week at a height of 1.0 cm. using a hand clipper to simulate a reel-type mower. Fungicide was added as needed 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 combination of ammonium nitrate and treble superphosphate (46% P_2O_5). 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 ammonium phosphate/superphosphate (AN-SP) 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 sources were spread over the surface by hand. Treatments were placed on the turf December 18, 1998 (week 2), and the same rates repeated on March 22, 1999 (week 15). Leachate samples were taken weekly for 34 weeks. The second treatment was made after the boxes were reset to seal the columns. Samples were refrigerated at 4° C prior to analysis for nitrate-N and phosphate-P. Total P and biologically available P were also analyzed. 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.

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. This spring 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. Data will be reported here starting on week 26 and ending on week 56. The experiment is continuing with the expectation of changing sources starting next year. 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. Total P and biologically available P are also being determined.

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 include one old green and two new playing greens with the first leachate from the new greens being collected on March 30, 1999.

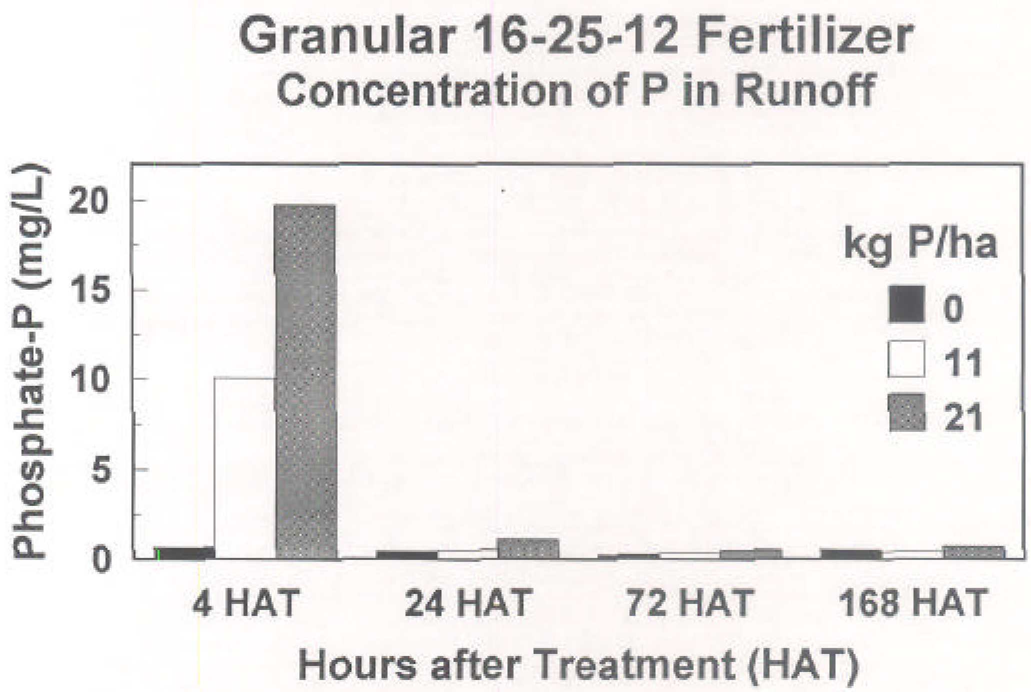
SUMMARY OF RESULTS

Determination of Nitrate and Phosphate Transport from Simulated Fairways

Six runoff experiments were carried out which included 3 rates of two fertilizer sources. The P rates were 0, 11, and 21 kg P/ha and the P sources were a Scotts 16-25-12 and superphosphate, both granular. As was found last year, the greatest runoff was at the first simulated rainfall event (4 HAT) in all cases and was decidedly less at the 3 subsequent times (Figs. 1 and 2). Evenly spaced, step-wise increases in P runoff were found at the 4 HAT runoff event for both sources for the P concentration, but the distribution for rates at that event was a bit different for the sources for the mass (mg P) at the 4 HAT event (Figs. 1 and 2). The mass of P in the runoff at 4 HAT for the 16-25-12 for the 11 kg P/ha rate was lower than that for the superphosphate whereas the mass for the 16-25-12 for the 21 kg P/ha rate was considerably higher than for the superphosphate (Figs 1 and 2). These differences were most likely due to some differences in the volume of runoff for the different experiments (Fig. 3). 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. The nitrogen data has not yet been evaluated.

The concentrations and masses of P in the runoff at the 24 HAT treatments showed some step-wise increase with rate, both sources, but were probably not statistically significant. The concentrations of P in the runoff for the superphosphate were somewhat higher in the 24, 72 and 168 HAT events that for the 16-25-12 (Figs. 1 and 2). The runoff water volumes recorded show that the most water came off the plots at the 4 and 24 HAT events and that the variation between the two source experiments was not great (Fig. 3). These two events are expected to give high volumes, because the simulated rainfall was at 2 in. there, but only at 1 in. at the 72 and 168 HAT events.

The experiments planned for next year will include management practices and effects of soil moisture at the beginning of the experiment. Management will be light watering after fertilizer application to wash the fertilizer into the soil surface and delaying the simulated rainfall for several hours or a day after fertilizer application. Since soil moisture at the time of the simulated rainfall is the major determining factor in the volume of runoff, this too will be varied to study the effects of soil moisture on both runoff volume and concentration of nutrients in the runoff.



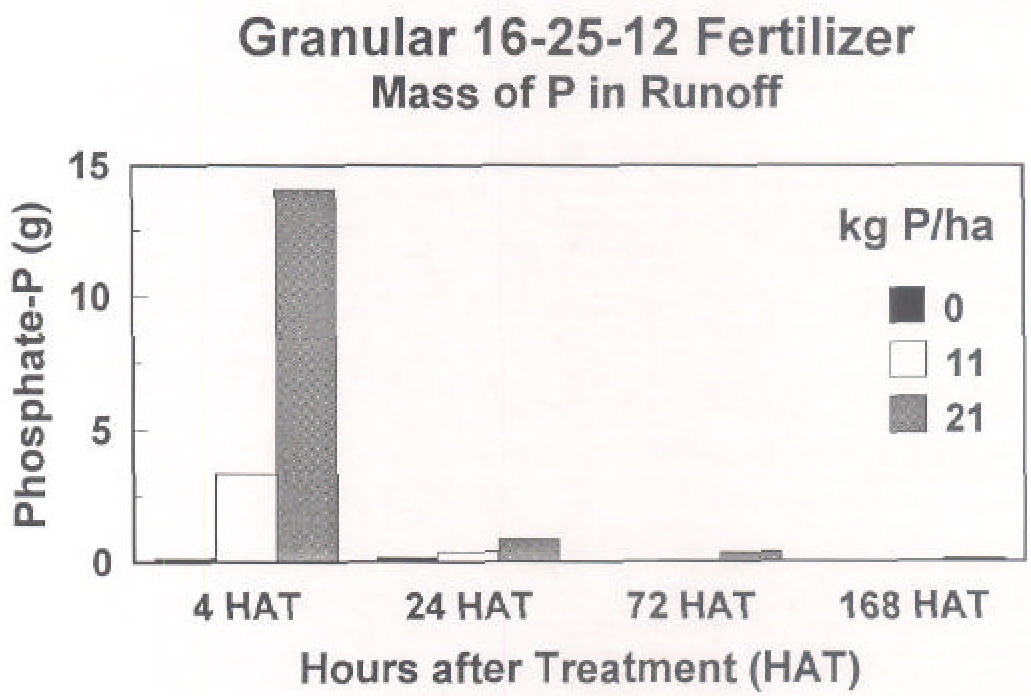
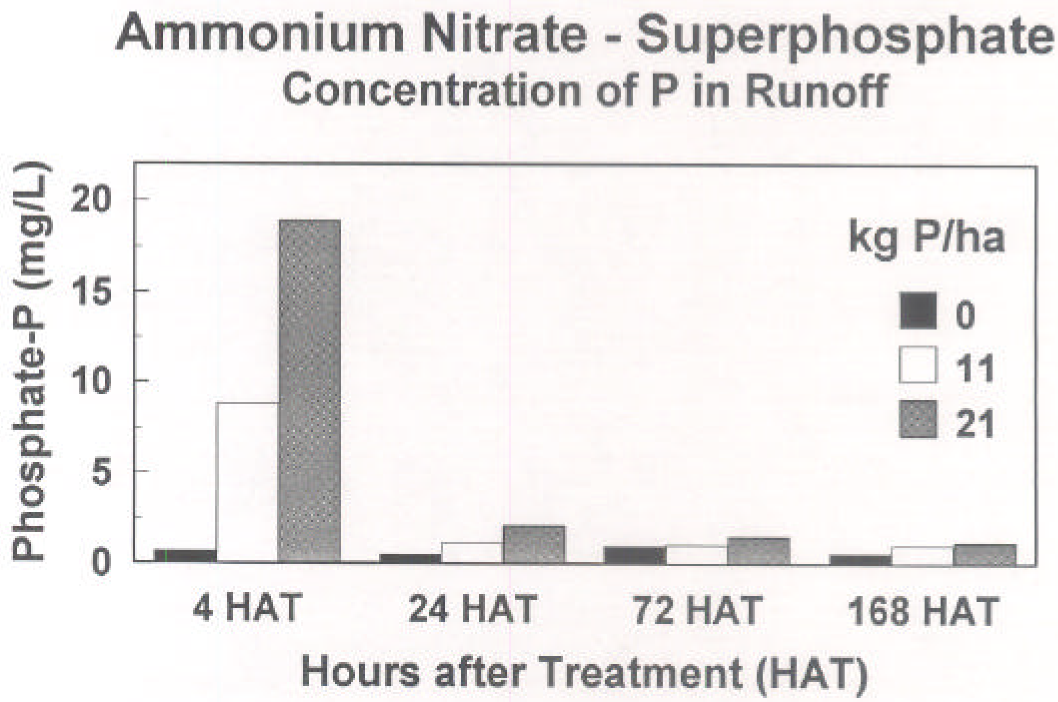


Fig. 1. Concentration and mass of P in runoff for 3 rates of 16-25-12 fertilizer and 4 simulated rainfall events



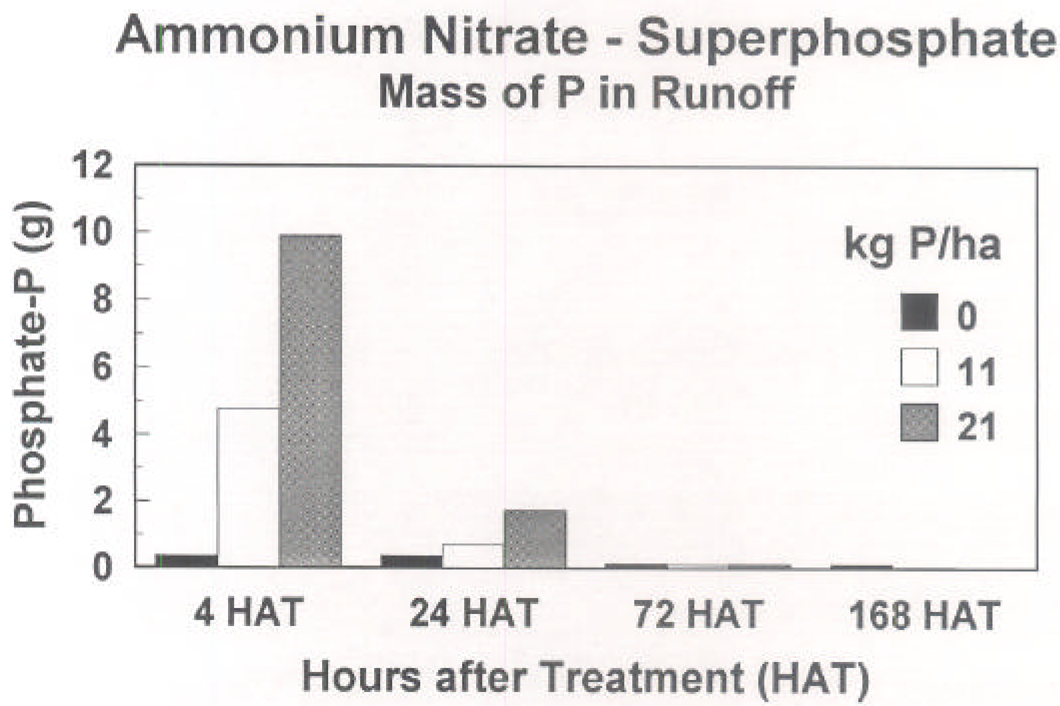


Fig. 2. Concentration and mass of P in runoff for 3 rates of ammonium nitrate and superphosphate fertilizer and 4 simulated rainfall events

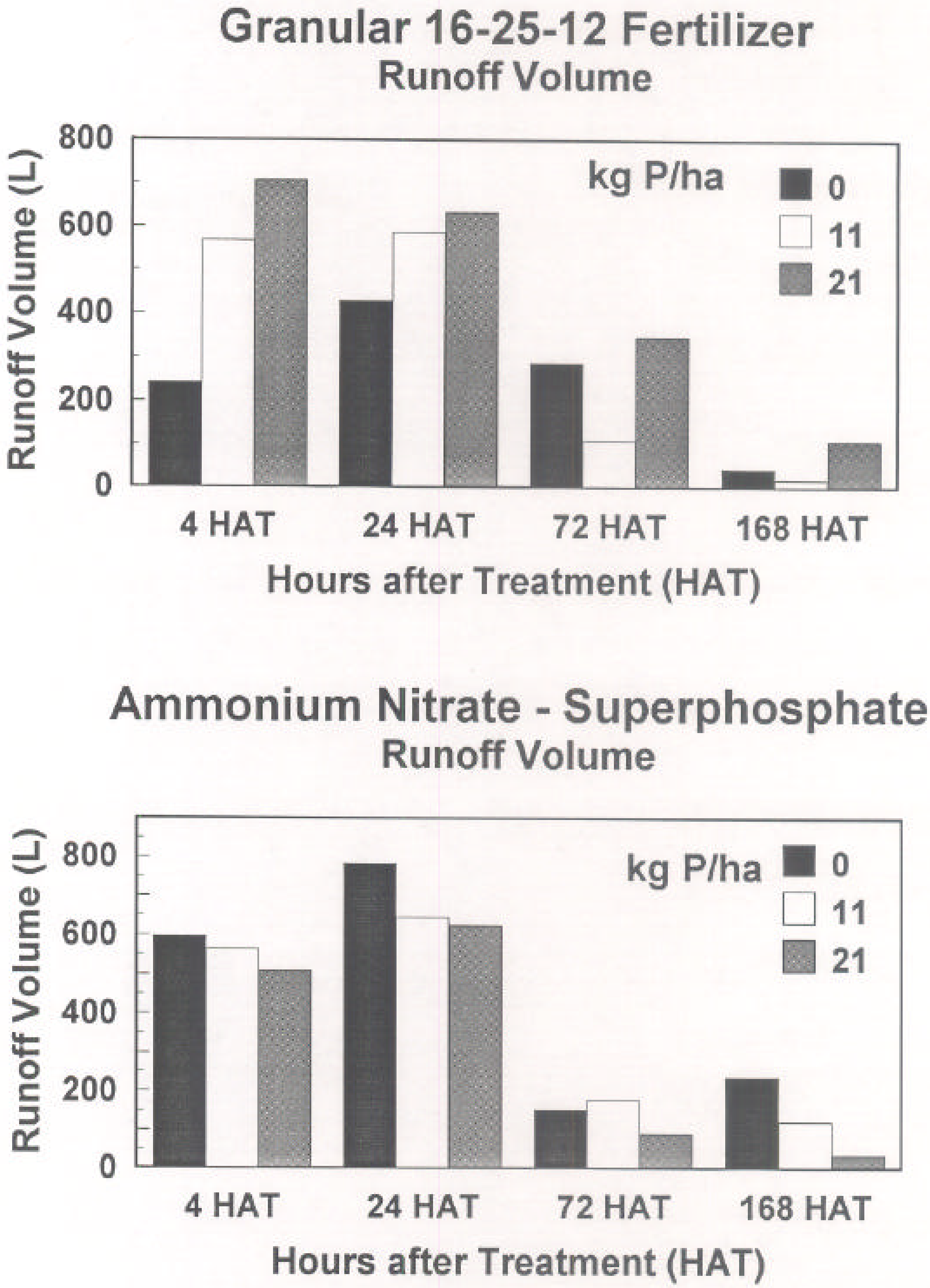


Fig. 3. Volume of runoff water for 3 rates of two fertilizers and 4 simulated rainfall events

Determination of Nitrate and Phosphate movement through Simulated Greens

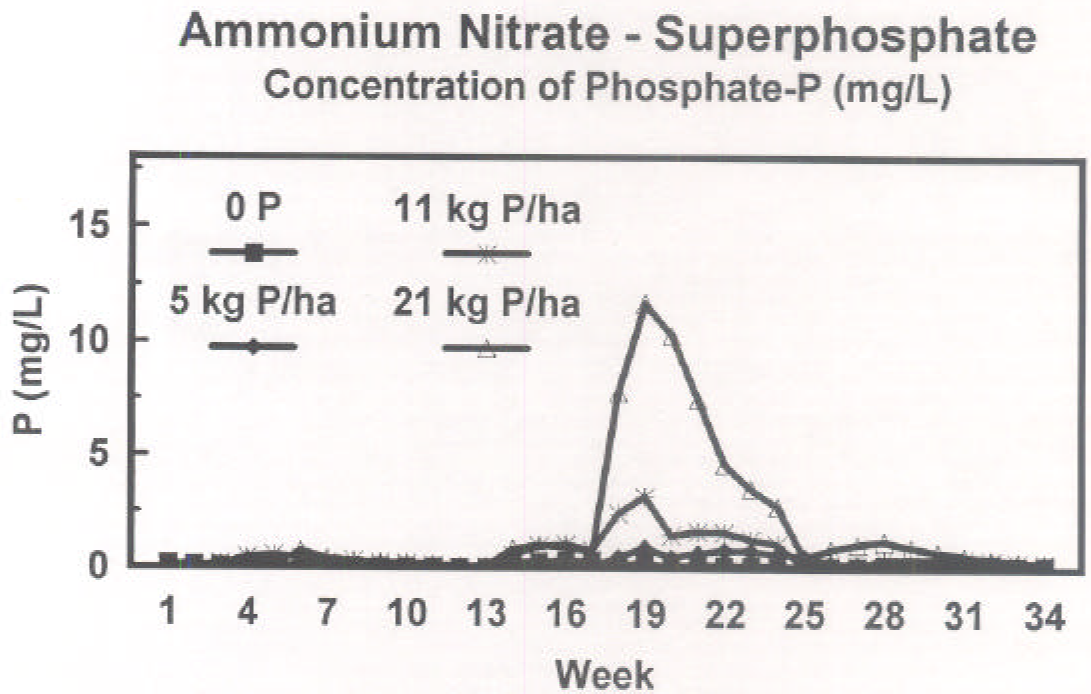
Greenhouse Lysimeters

This year a source-rate experiment tested 4 rates of ammonium nitrate-superphosphate (AN-SP) and a water soluble source. The columns were initially not operating properly and were repaired at week 14 of the trial, the effect of which can easily be seen in the P concentration data where peaks came at week 18-19 (Fig. 4). The two sources were somewhat similar in the concentration pattern, but the peak was sharper and higher for the soluble source with the concentrations tailing more for the AN-SP (Fig. 4). The same pattern was observed in the mass data with the peak for AN-SP being lower and more mass being spread out after the peak than for the soluble source (Fig. 5). The cumulative mass data were different at the low P rate (5 kg P/ha) in that the AN-SP was lower than the soluble source (Fig. 6).

The peaks in the N concentration data came at week 17, one week earlier than for the P data (Fig. 7). The sources were fairly similar in N concentration except that the soluble source showed higher concentrations before the columns were repaired (weeks 4 to 14). The mass of N transported was similar for the two sources, with the exception that AN-SP mg N was a bit higher than for the soluble source. The cumulative mass data are very similar and show that the N was essentially all leached out by week 19 (Fig. 9).

Volumes of leachate increased dramatically after the columns were repaired (Fig. 10). A large peak at week 14 was due both to the repair and an error in irrigation. This peak probably accounts for the fact that much of the added nutrients were transported through the columns and not used by the turfgrass. The increase in volumes after week 27 was due to turning off the supplemental lighting that was used during the winter to extend the day length. Turning off these lights decreased temperatures and evapo-transpiration by the turf.

The concentrations of P and N at the peaks were placed in a bar graph so that comparisons can be made (Fig. 11). The P concentrations at peak were higher for the soluble source than for the AN-SP, especially at the higher two rates. The N concentrations at the peak were very similar with the AN-SP being somewhat higher than the soluble source. The percent P transported of the total added was 0 for the AN-SP for the low rate but the percents for the other rates for both sources were from about 50 to 80% indicating a high rate of transport (Fig. 12). These are preliminary calculations. The percent N leached were similar for all sources and rates and were also high at around 80 to 90%. As mentioned above, these high transport rates are most likely due to the large volume of leachate that came through the columns just after the second treatments were applied. Attempts will be made in future experiments to control the leachate volume. It is easy to control the amounts of irrigation water, but we are finding that it does not always translate into consistent leachate volumes.



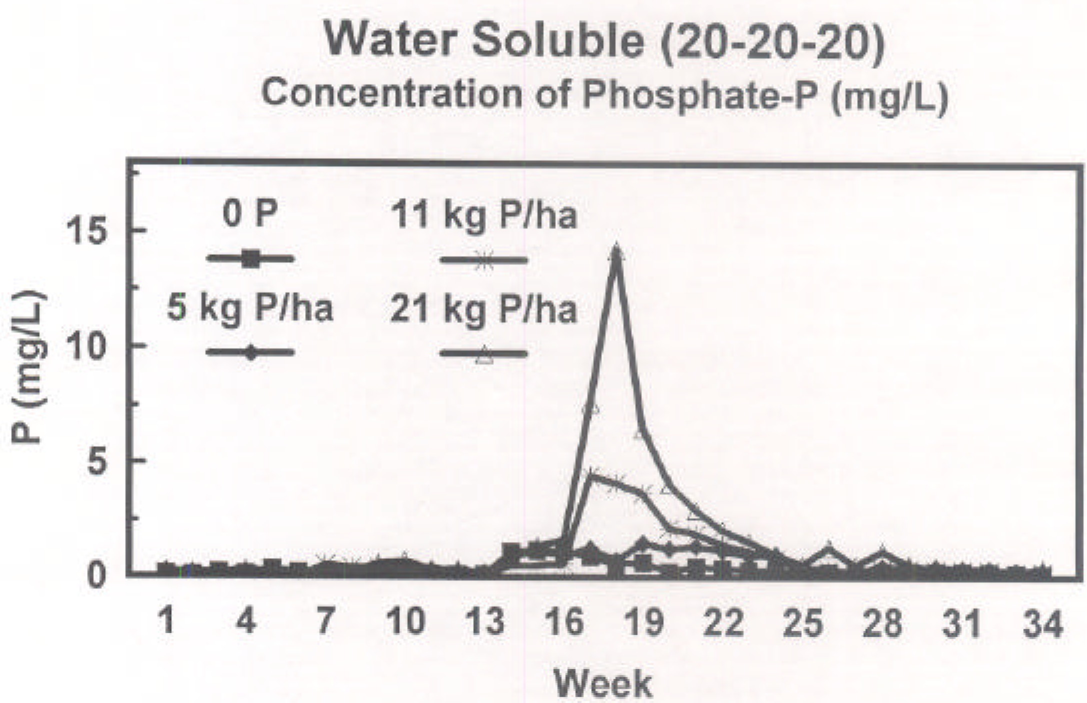


Fig. 4. Concentration of P in leachate transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.

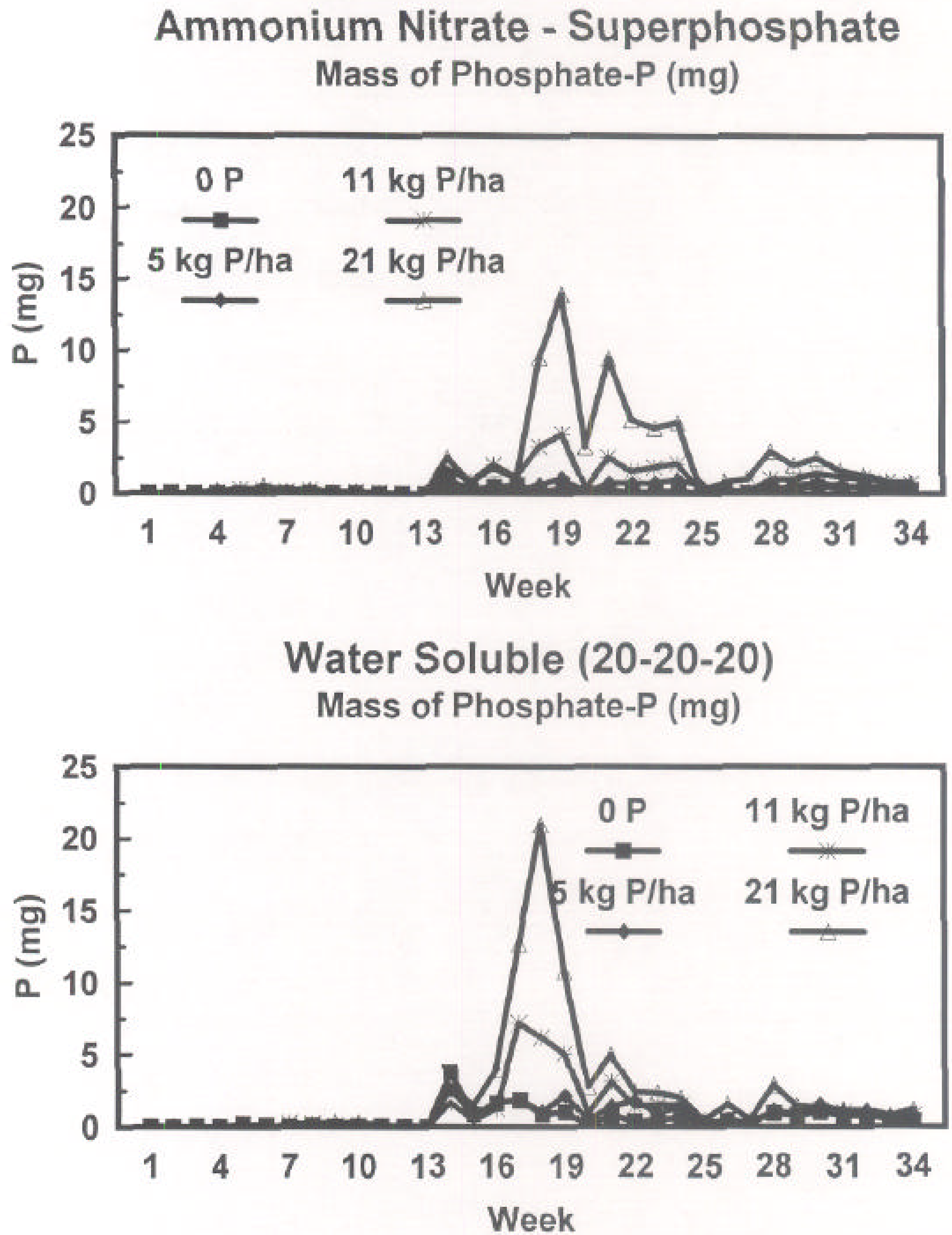


Fig. 5. Mass of P transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.

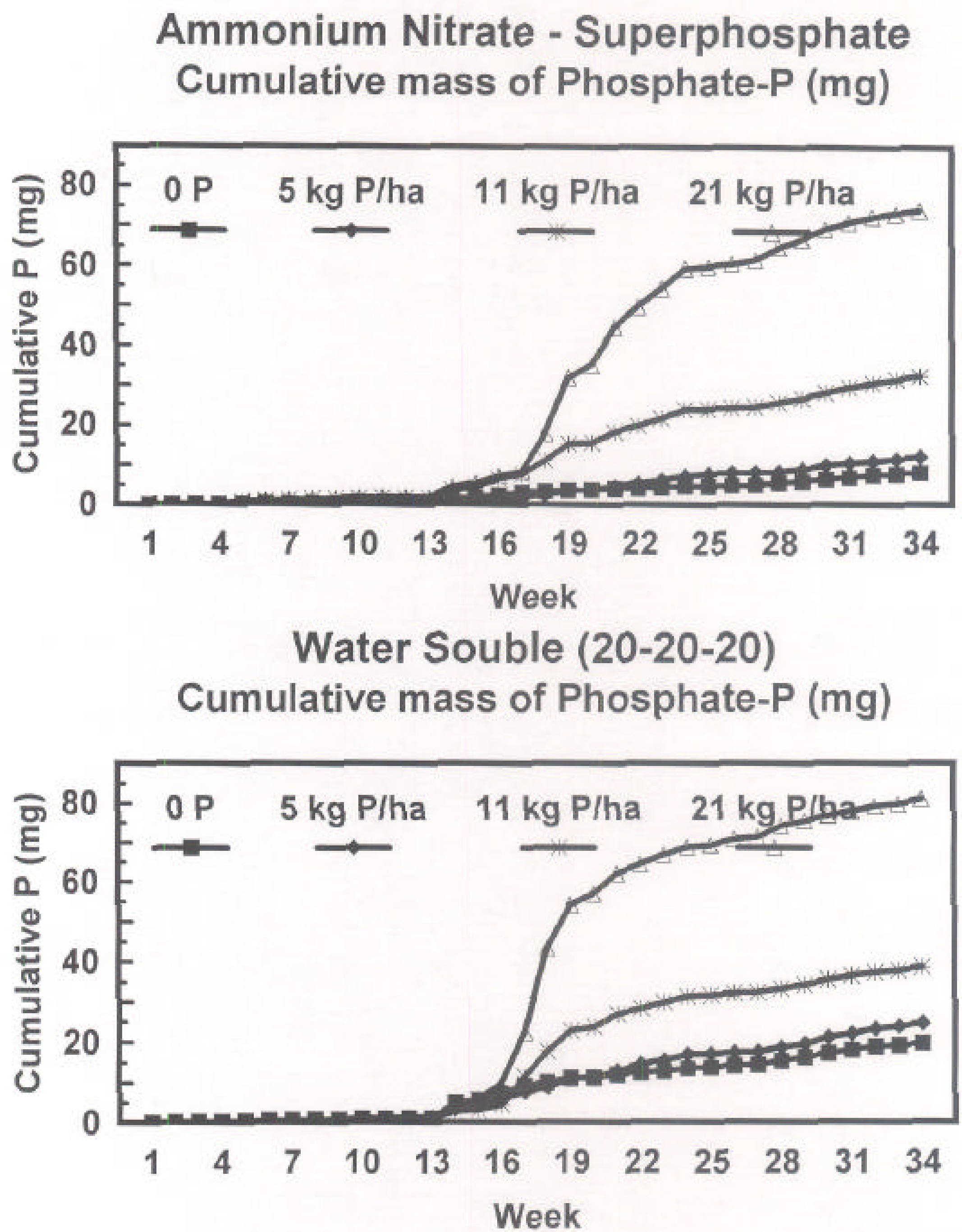
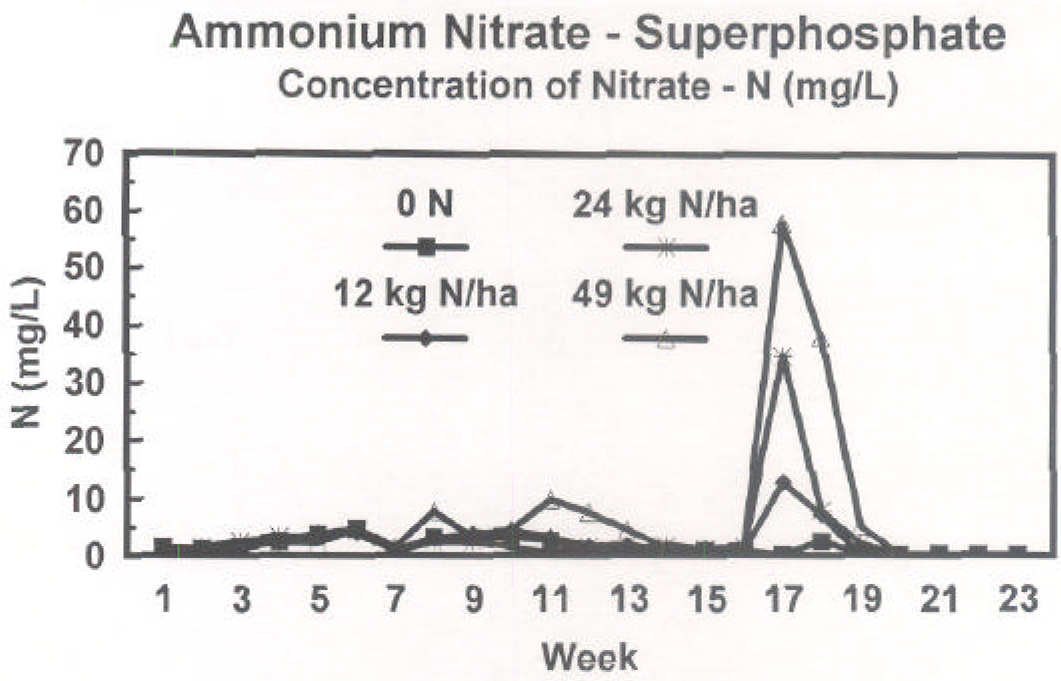


Fig. 6. Cumulative mass of P transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.



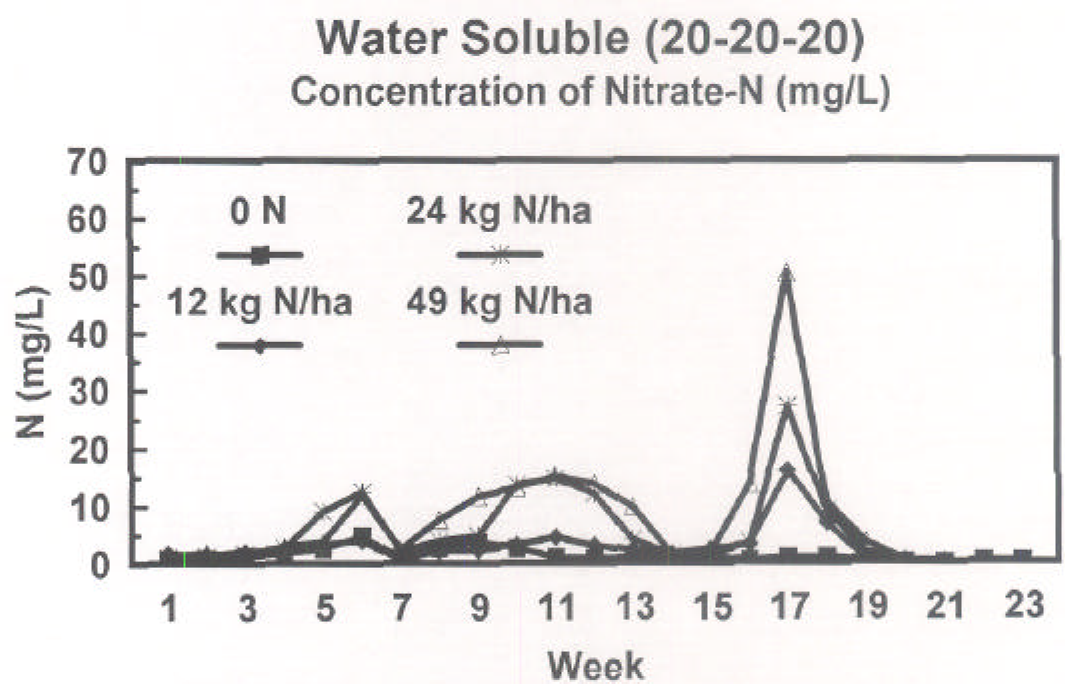


Fig. 7. Concentration of N in leachate transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.

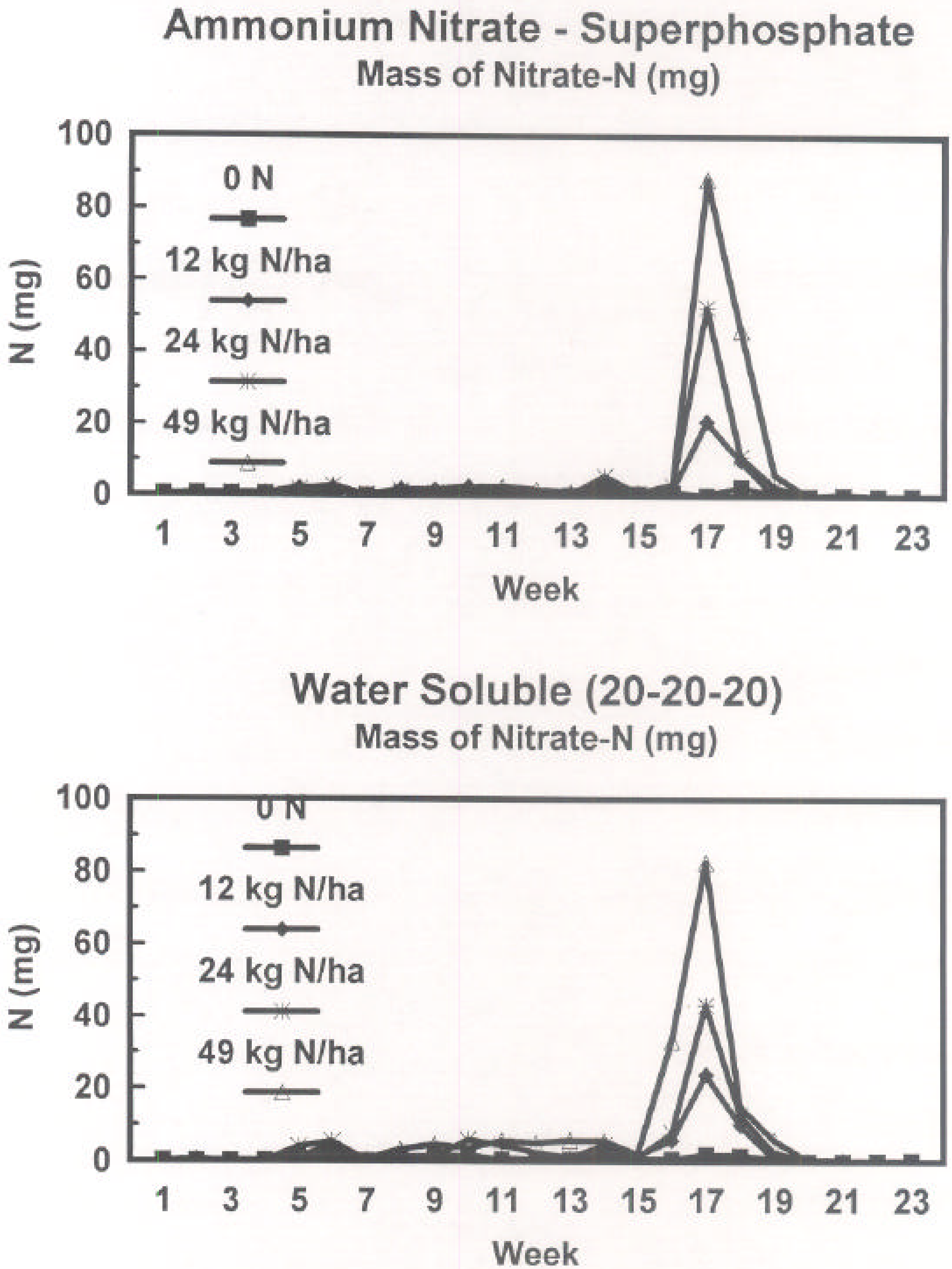
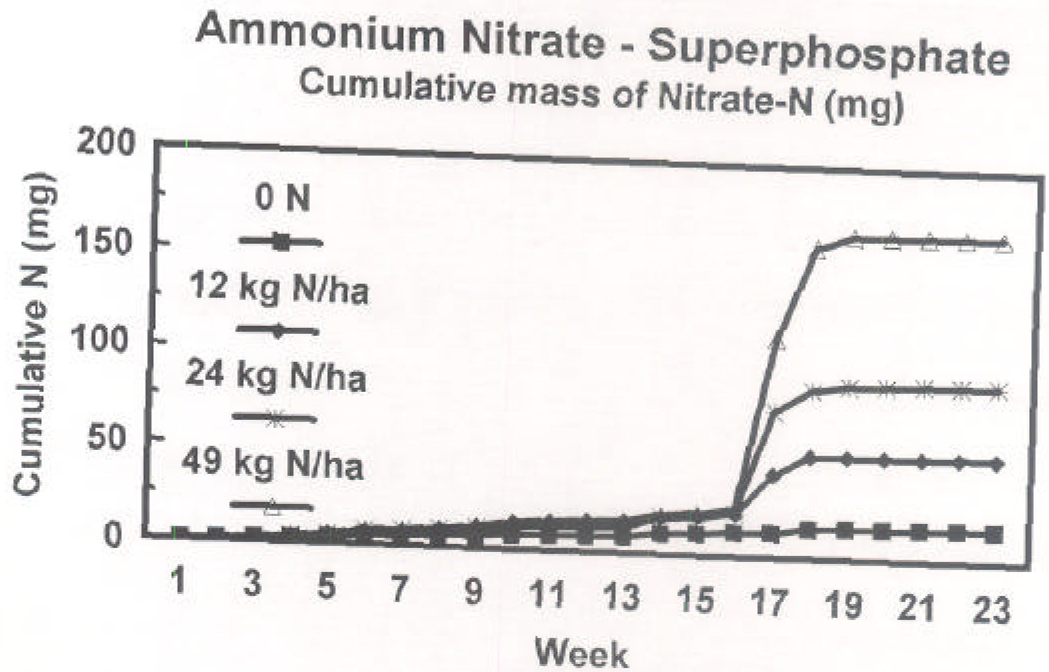


Fig. 8. Mass of N transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.



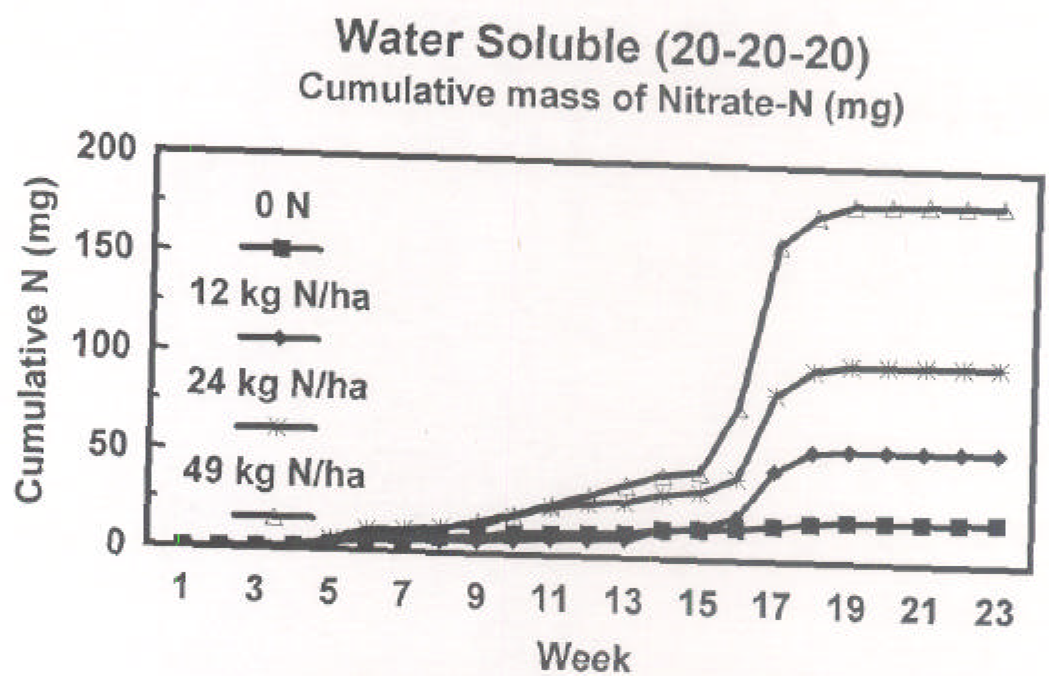


Fig. 9. Cumulative mass of N transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.

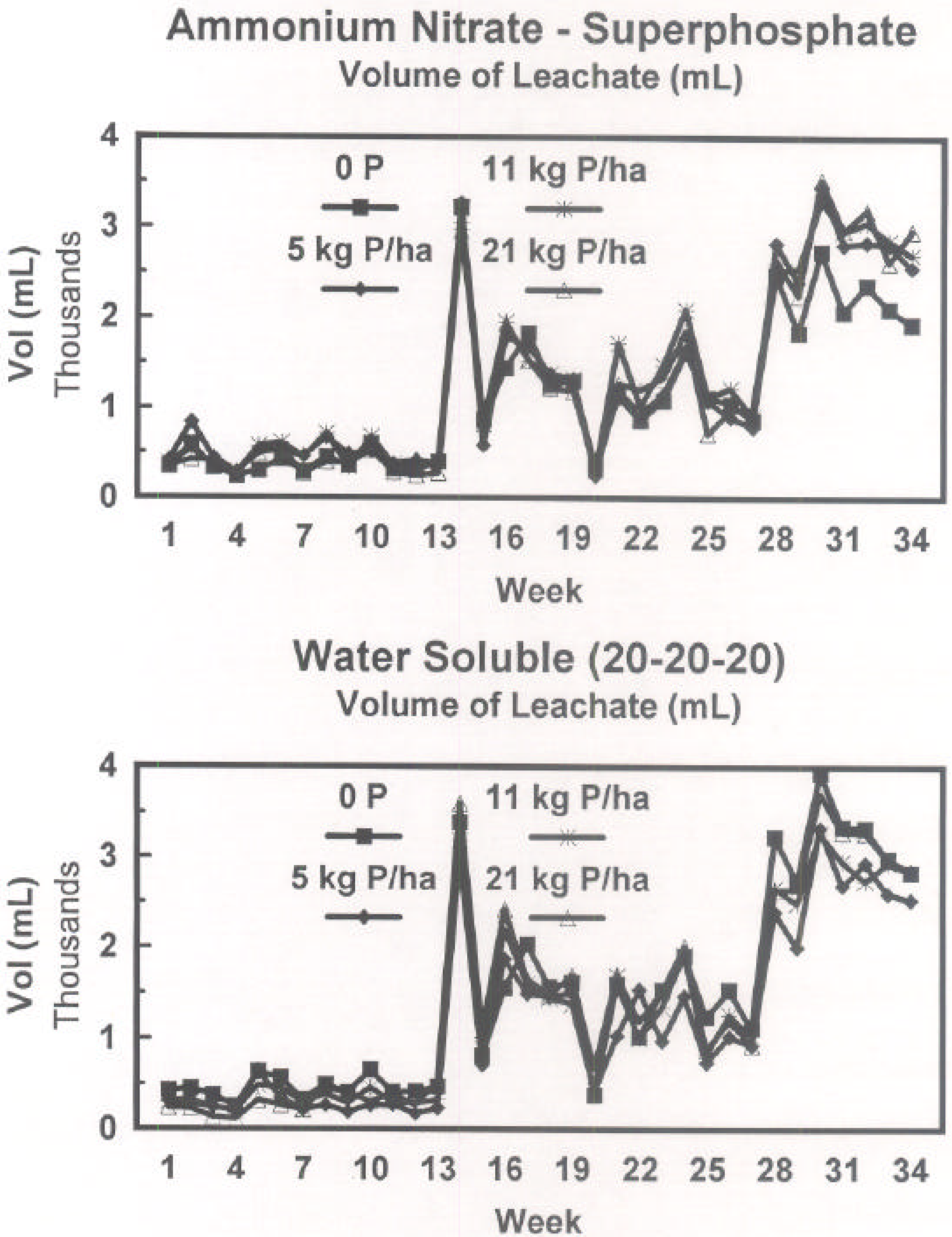


Fig. 10. Volume of leachate transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Rates applied on weeks 2 and 14. Separated columns repaired on week 14.

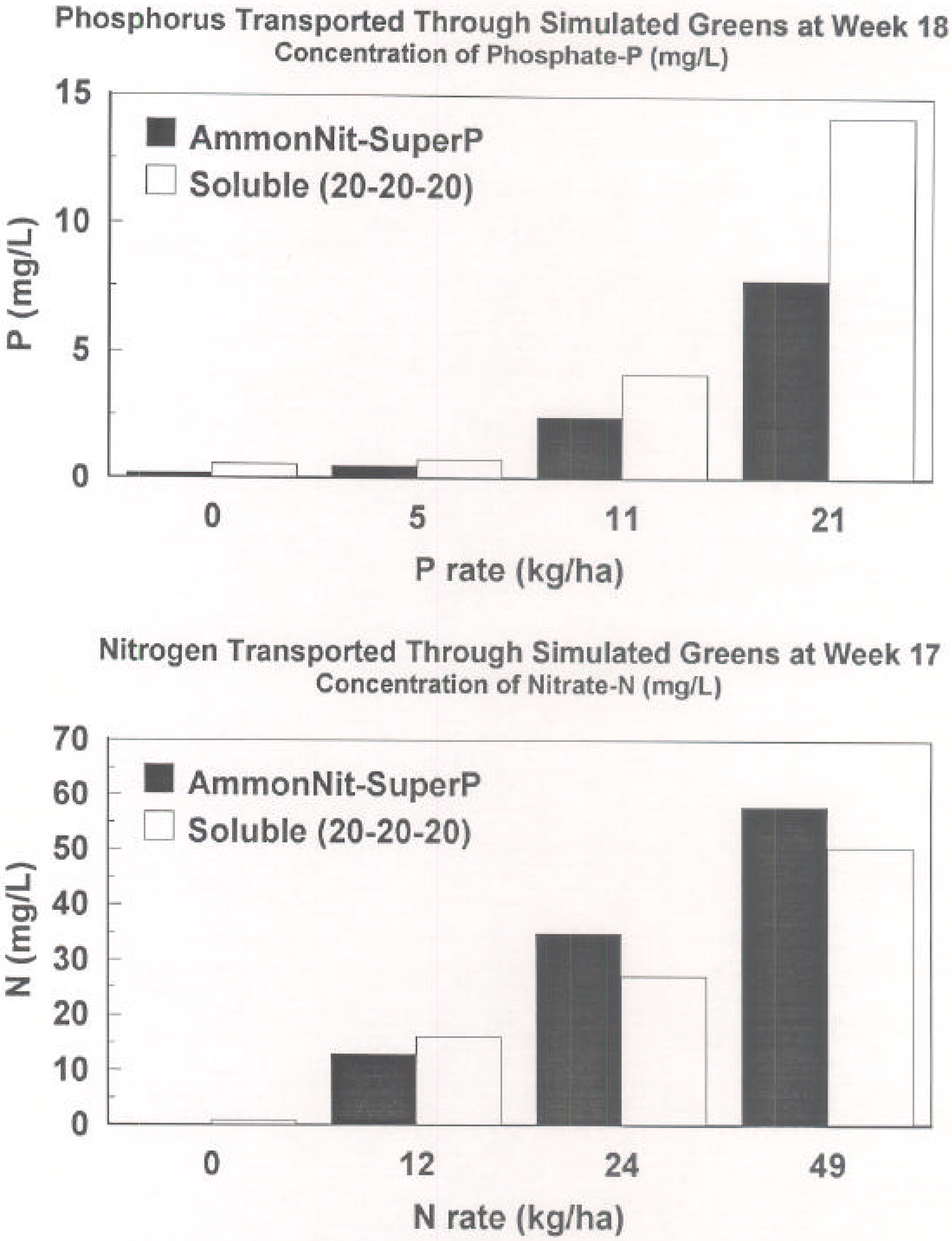
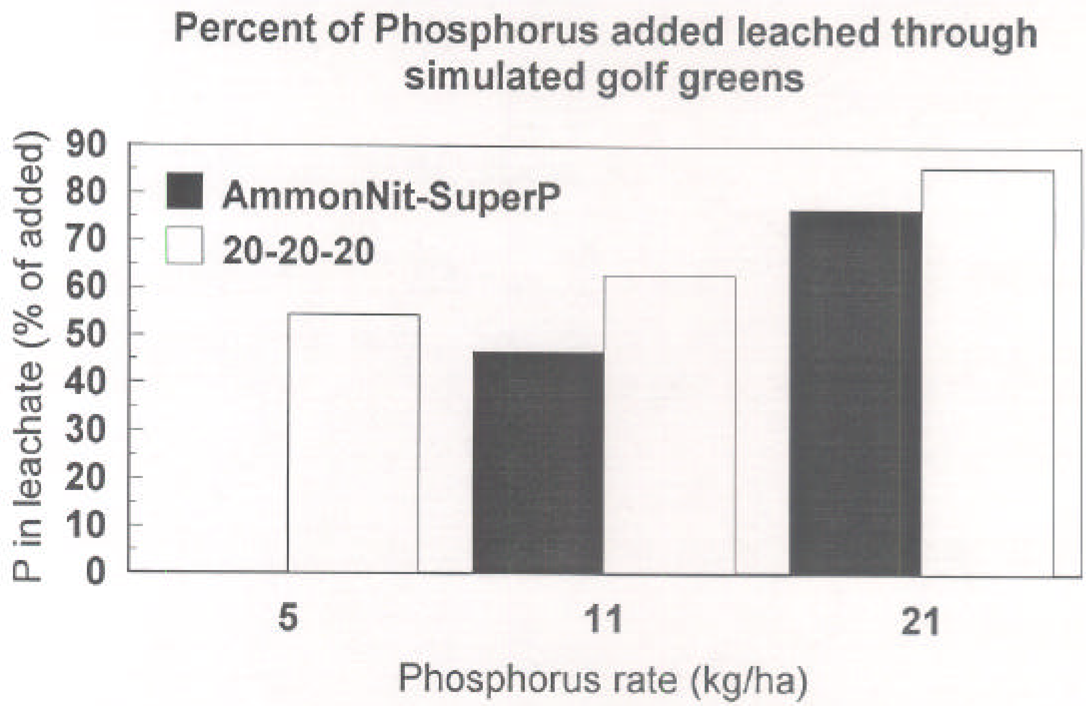


Fig. 11. Phosphorus and Nitrogen transported through simulated golf green columns for 2 fertilizer sources at 4 rates. Comparisons made for the peaks for each element.



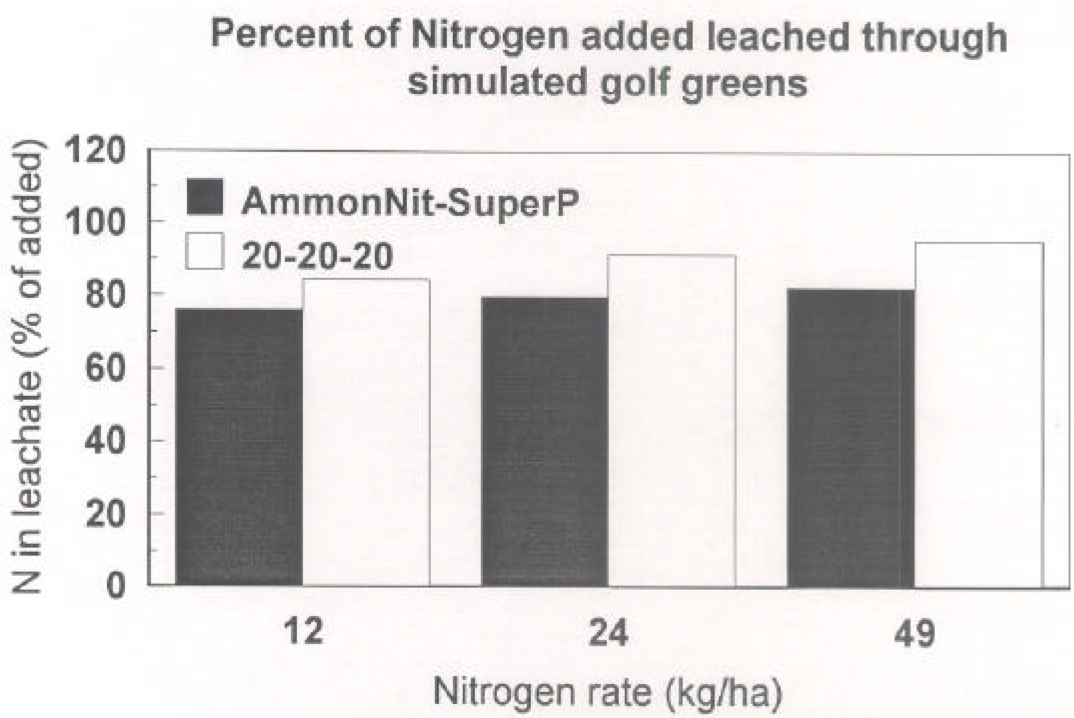


Fig. 12. Phosphorus and Nitrogen transported through simulated golf green columns for 2 fertilizer sources at 4 rates (percent of that added).

Field Lysimeters

Phosphorus transport through the field lysimeters was minimal as the concentrations decreased the entire time of the experiment and showed essentially not treatment effects (Fig. 13.). The concentrations were higher at the start of the experiment for the water soluble treatments than for the granular, but by week 57 they were similar. The mass of P transported showed more variations, but still little treatment effects and were similar at the end of the time period for the sources (Fig. 14). There was a discernable peak for the treatments for both sources at weeks 27-28 for the mass of P, which came from treatments added in the fall of 1998.

Treatment effects were evident in the nitrate concentration and mass data for the field lysimeters (Figs. 15 and 16). An initial nitrate concentration peak is evident for week 27 for the granular source from the fall application (Fig. 15). That peak for the soluble source was most likely earlier than week 26. The granular source nitrate concentrations were much lower than for the soluble source and only one peak at 51-52 can be seen. For the soluble source the concentration rose to 7 mg/L at week 36 in response to the treatment at week 32. Other peaks in response to treatments were lower. These were in the summer when the turf most likely was more efficient at using the nitrogen applied. The mass data for nitrate was similar to the concentration showing essentially the same peaks and rate effects (Fig. 16.). Note that the nitrate transported through the field lysimeters is much lower than that found in the greenhouse with similar sources, rates, and amounts of irrigation.

Nitrate and Phosphorus Leaching Through Golf Course Putting Greens

Phosphate

Phosphorus concentration and mass in the leachate from the golf course putting greens was generally quite low for 1998 (Fig. 17). These values are averages of the data for the three lysimeters in each green. Only late in the summer did the concentration show a peak and some increases in mass were observed. Note that no P fertilizer was added to these greens in 1998. The cumulative mass of P did rise for both greens after julian date 150 (May 30, 1998), but more so for green 1 (Fig. 19). These data are lower than reported for earlier years. This result can be easily seen in the averages for P concentration and mass for each year shown in Table 1. Thus, the P leached from these putting greens is decreasing dramatically over time.

Nitrate

As for the P data, the nitrate concentration and mass data were low until the end of the summer (Fig. 18). The cause for the increase may be a rather large application of N (0.88 lb N/1000 sq. ft. as KNO_3). The nitrate concentrations did stay below the 10 mg/L drinking water standard until after this application. The cumulative nitrate data

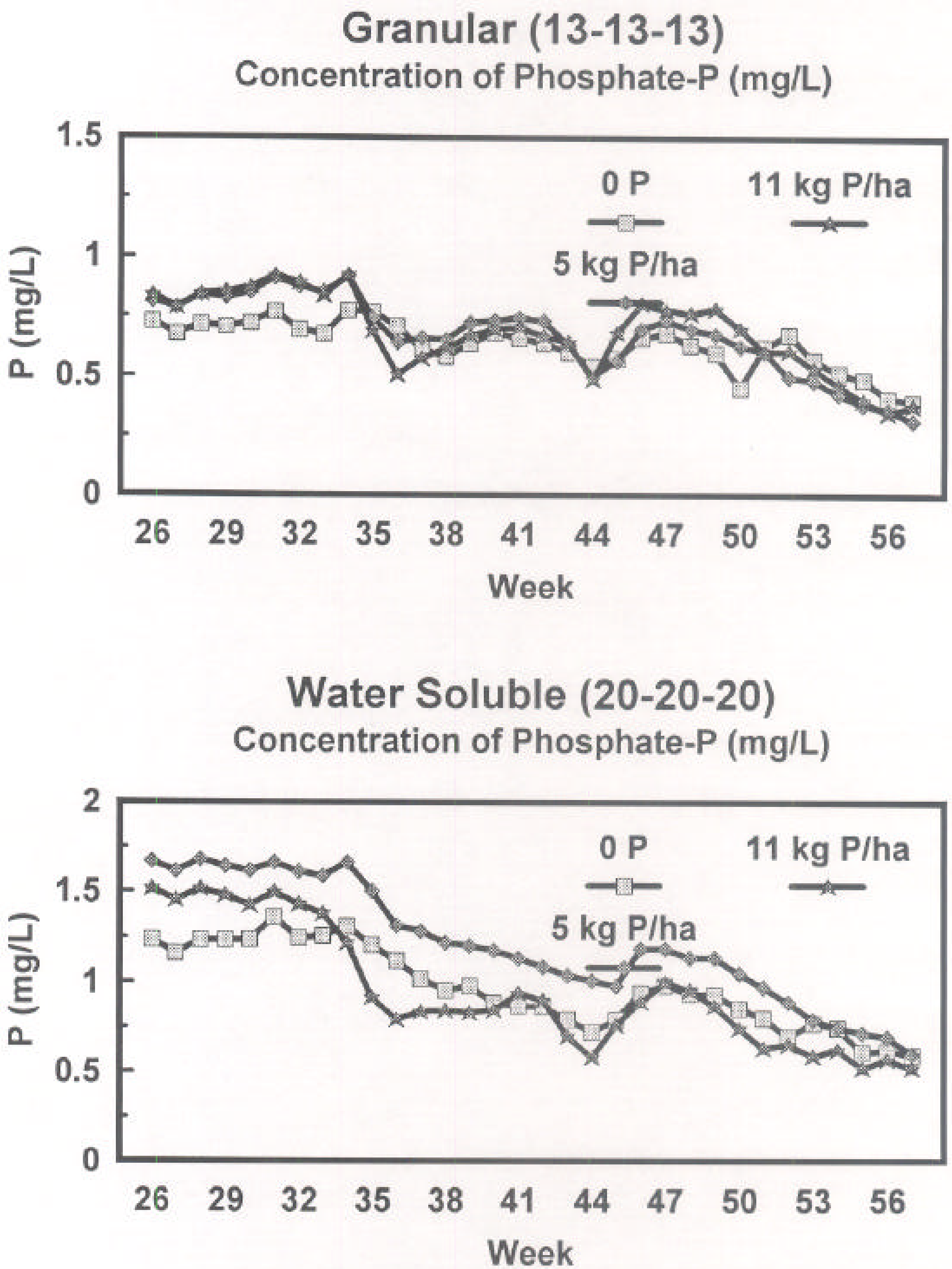


Fig. 13. Phosphorus concentration in leachate transported through field simulated golf greens for 2 fertilizer sources at 3 rates. Rates applied 3 times.

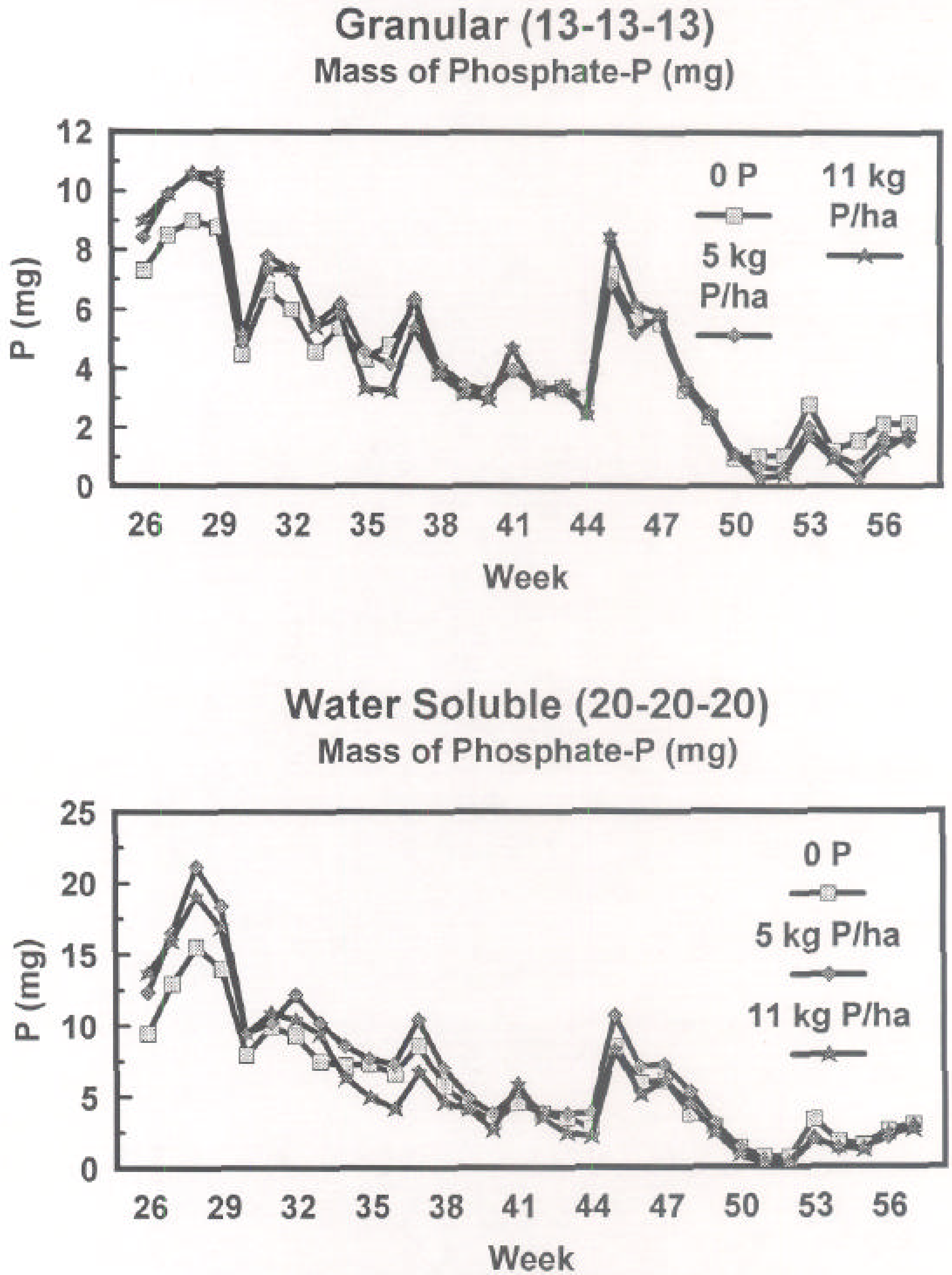
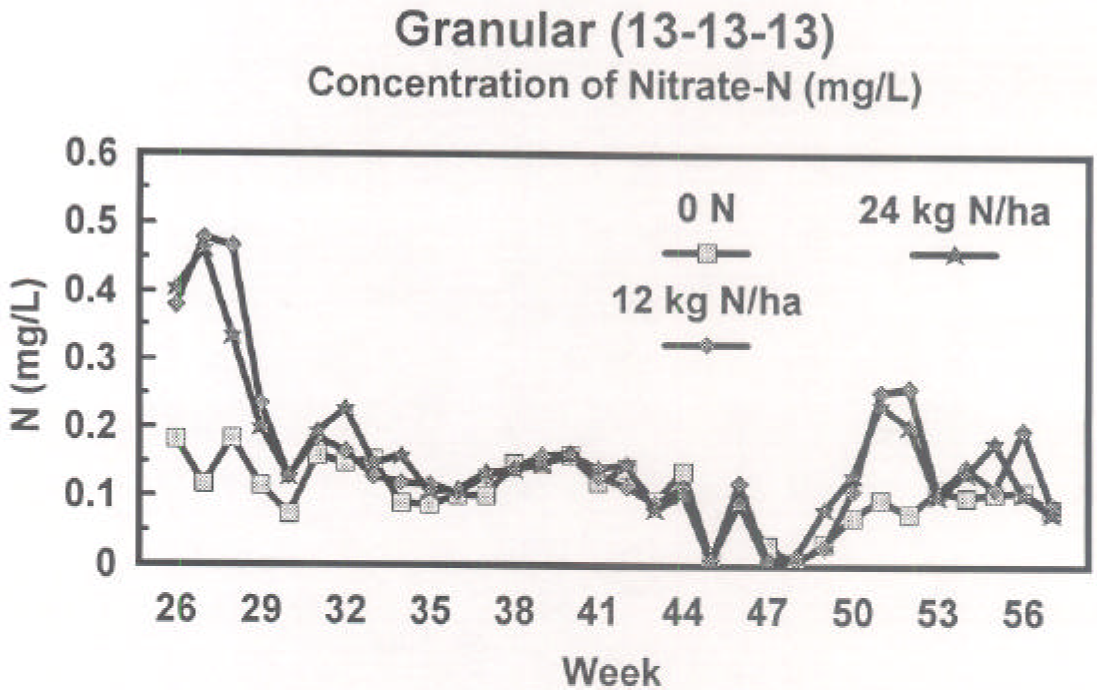


Fig. 14. Mass of Phosphorus transported through field simulated golf greens for 2 fertilizer sources at 3 rates. Rates applied 3 times.



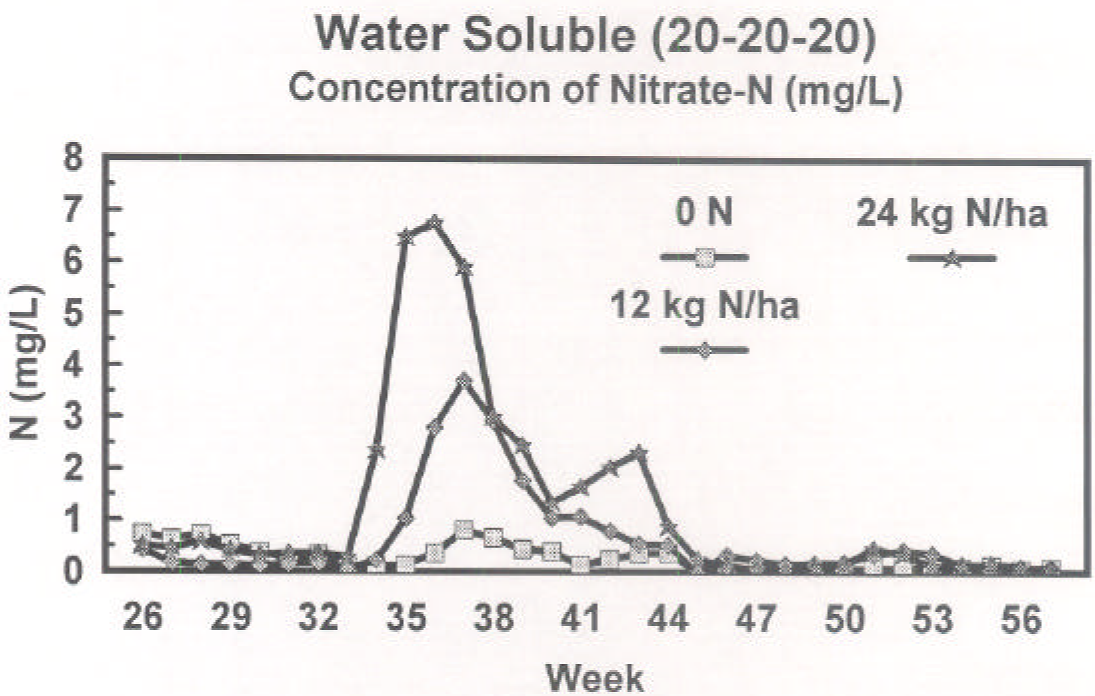


Fig. 15. Nitrogen concentration in leachate transported through field simulated golf greens for 2 fertilizer sources at 3 rates. Rates applied 3 times (weeks 32, 40, and 47).

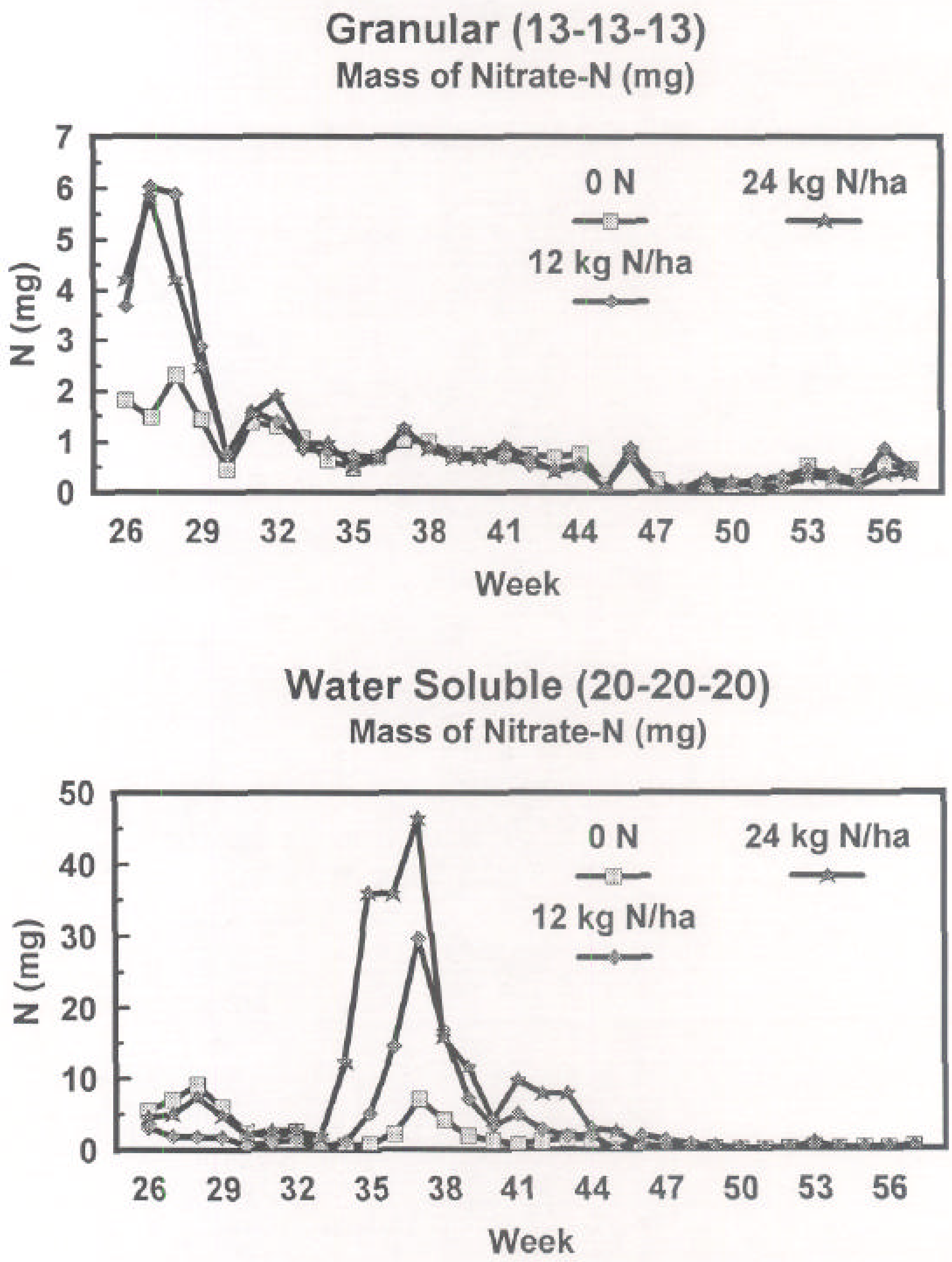
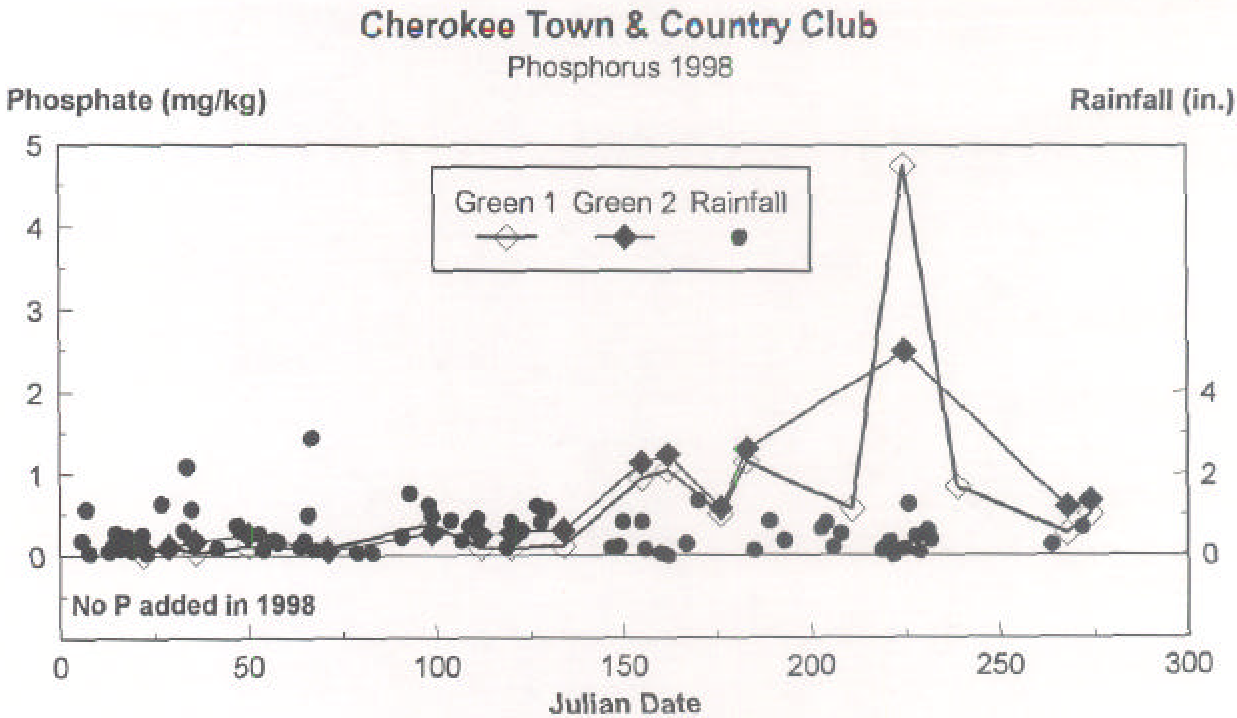


Fig. 16. Mass of Nitrogen transported through field simulated golf greens for 2 fertilizer sources at 3 rates. Rates applied 3 times.



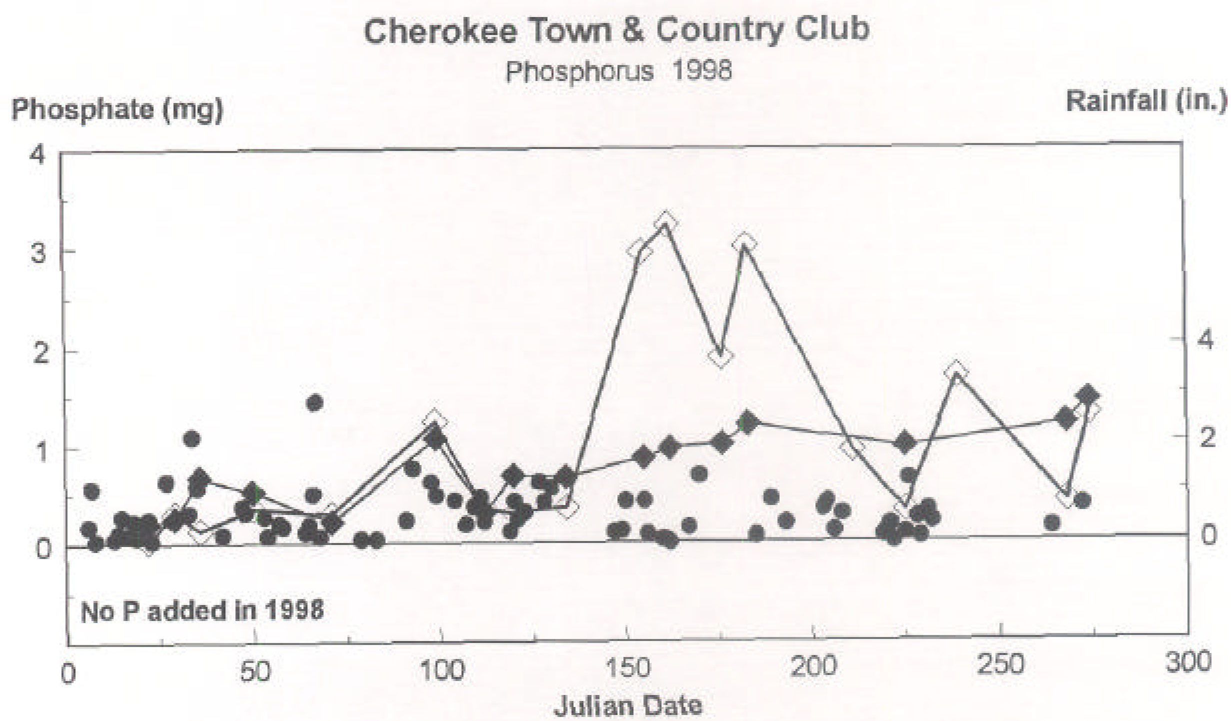
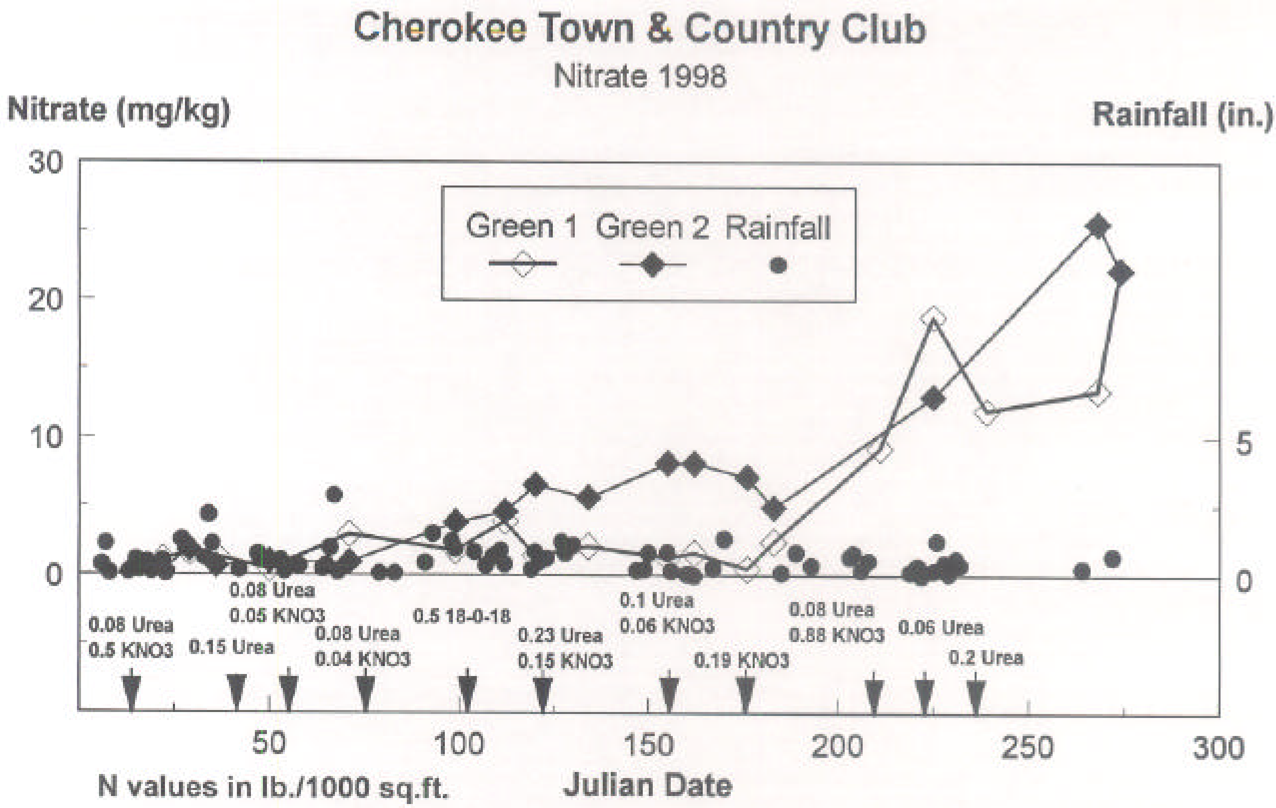


Fig. 17. Phosphate concentration and mass for 1998 for two putting greens at the Cherokee Town and Country Club.



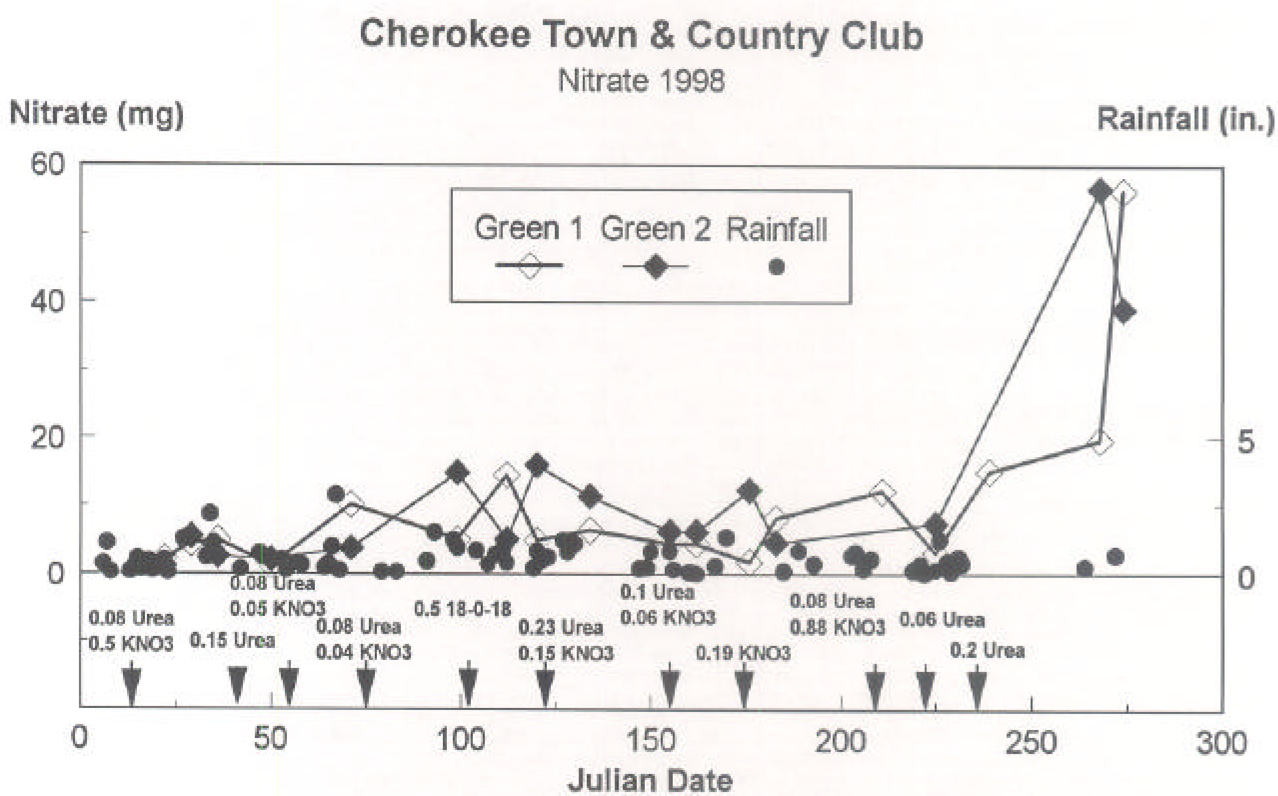


Fig. 18. Nitrate concentration and mass for 1998 for two putting greens at the Cherokee Town and Country Club.

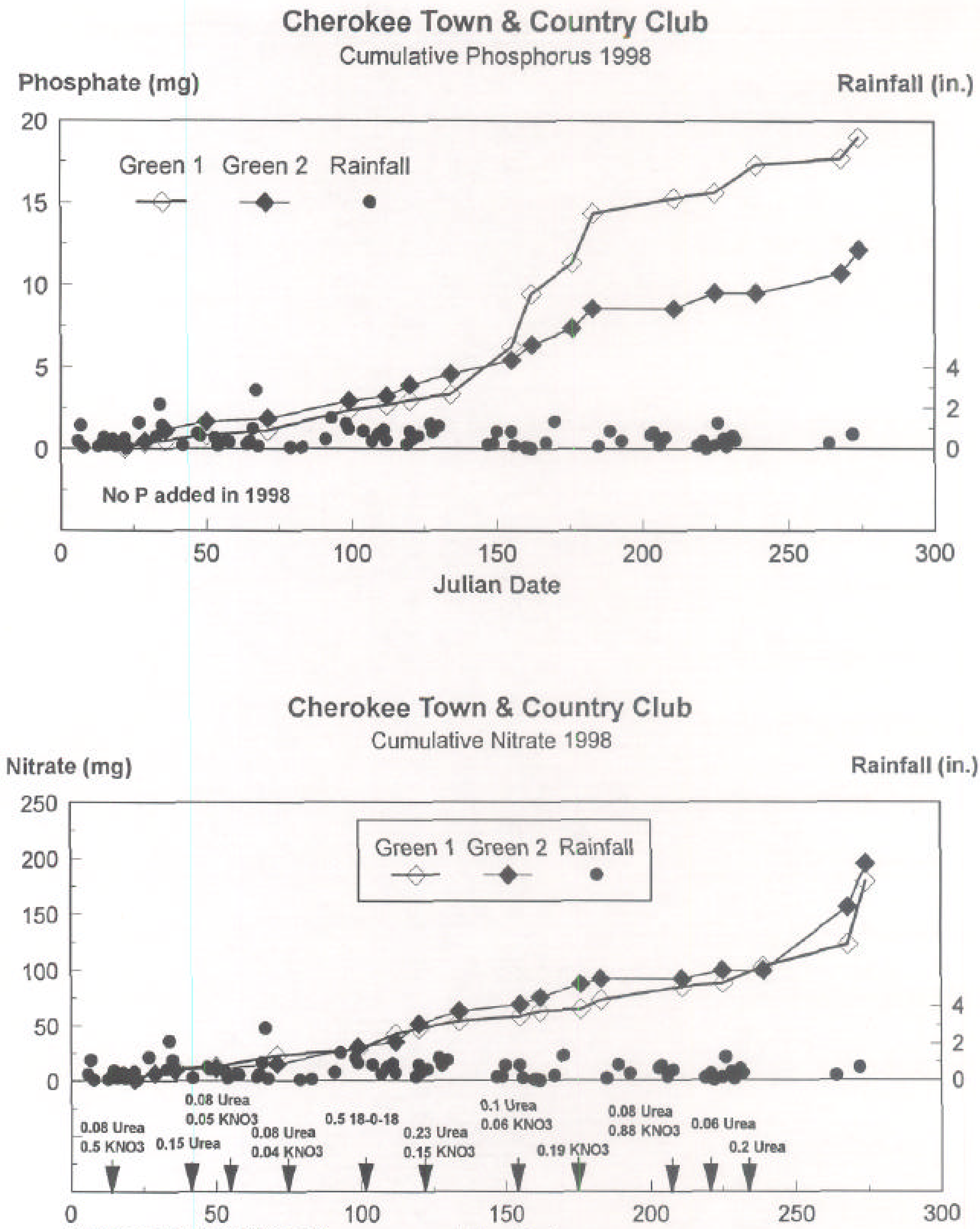


Fig. 19. Phosphate and nitrate cumulative mass for 1998 for two putting greens at the Cherokee Town and Country Club.

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

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

also show an increases both early in the summer and again at the end (Fig. 19). Nitrate amounts leached as averages are increasing over time as indicated in Table 2. However, several high values can skew an average, so one needs to look at the overall data as shown in the figures to get a true picture. The nitrate data for most of the year for 1998 was quite low and only at the end of the time period did it increase.

FUTURE PLANS

Runoff experiments will shift away from source-rate experiments toward addressing management for lowering runoff. One approach will be to study the effects of "watering in" the fertilizer with an irrigation of about 0.25 inches after application. This irrigation should wash fertilizer particles off the leaves and help it react with the soil. The usual simulated rainfall events will follow after a day. The second parameter to vary will be the soil moisture at the beginning of the experiment so as to effect some differences in runoff volumes. The experiments to date included a 2 inch or more irrigation to effectively saturate the soil the day before fertilizer application. Here less water will be applied to reduce the runoff at the initial rainfall event. This procedure would simulate a heavy rain after a relatively dry period.

Experiments for the greenhouse columns will start with a source experiment at one rate. This experiment will differ from the usual source-rate experiment and allow comparison of a number of N and P sources at one time. This experiment will start in early November, 1999. Subsequent experiments will use some of the prior fertilizer sources and use less irrigation so as to simulate low rainfall conditions often found in the Southeast during the summer.

Half of the 20 field lysimeters will be removed this winter, so that we will only have 10 for future experiments. We will continue with source-rate experiments for this site. Likewise, monitoring of nitrate and phosphorus will continue for the lysimeters at the golf course in Atlanta. These include one old putting green and two new playing greens.

We are currently caught up in analyzing all leachates and runoff waters for total P and biologically available P. We will continue to analyze for these forms of P. Also, we still want to analyze selected waters for dissolved organic carbon (DOC) to determine if there is any relation between leaching of nutrients and soluble carbon compounds.

PUBLICATIONS

Shuman, L. M. 1999. Potential leaching and runoff of nutrients from golf greens and fairways. K. J. Hatcher, (Ed.). Proceedings of the 1999 Georgia Water Resources Conference, March 30-31, 1999, University of Georgia, pp. 166-169.

Shuman, L. M. 1999. Phosphate and nitrate movement through simulated golf greens. ABSTR. Amer. Soc. Agron., Salt Lake City, UT. P. 124.

Pending publications

Shuman, L. M., A. E. Smith, and D. C. Bridges. 1999. Potential movement of certain nutrients and pesticides following application to golf courses. In Clark, J. M. and M. Kenna (Eds.) ACS Volume Based on Fate of Turfgrass Chemicals and Pest Management Approaches symposium, Boston, MA, August 23-27, 1998.