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Fertilizer source effects on phosphate and nitrate leaching through simulated golf greens

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"Capsule": *In general, more P than N leached from both field and greenhouse lysimeters.*

Abstract

Phosphorus and nitrogen leached from high-porosity golf greens can adversely affect surface water and groundwater quality. Greenhouse and field lysimeter experiments were carried out to determine the effects of eight fertilizer sources on P and N leaching from simulated golf greens. Phosphorus appeared in the leachate later than nitrate-N, and the highest concentrations were for the soluble 20-20-20 and the 16-25-12 starter fertilizers. The other six sources resulted in lower P concentrations. The soluble 20-20-20 and the 16-25-12 sources each resulted in 43% of the added P eluting in the leachate, whereas the others varied from 15 to 25%. For nitrate-N the lowest cumulative mass was for the controlled-release 13-13-13 and sulfur-coated urea. A higher percentage of applied P than applied N leached from both field and greenhouse lysimeters. However, the amounts of P leached for the field lysimeters were lower than for the greenhouse columns.

Keywords: Water quality; Phosphorus; Nitrate-N; Turfgrass; Leaching

1. Introduction

Fertilizers have dramatically increased agricultural production as well as enhanced the growth of ornamental plants and turfgrass. Under certain circumstances nutrients can run off the soil surface or be carried in subsurface drains to surface waters and degrade water quality. Nitrate-N and phosphate cause algal blooms that can produce toxins and lower the oxygen content of waters, both of which adversely affect aquatic organisms. This eutrophication is a widespread problem that is persistent and slow to recover (Carpenter et al., 1998). Until recently the source of nutrients being transported to surface waters has been attributed mostly to agricultural production. However, there is growing evidence that urban areas contribute to water pollution. High soil P resulting from frequent and high applications of P fertilizer can contribute to P loss in sub-surface runoff via drains (McDowell et al., 2001).

Golf course greens are especially vulnerable to P and N losses via sub-surface drains which empty into creeks and ponds, because greens are designed to have high porosity and drainage rates. Sandy soils, such as used in golf greens, have been shown to result in higher movement of nitrate-N to subsurface waters than finer textured soils (Marshall et al., 2001). Nitrate-N concentrations were >10 mg l^{-1} in leachate from greens, but the leachate from fairways contained <5 mg l^{-1} nitrate-N (Wong et al., 1998). Heavy irrigation of greens (38 mm/week) resulted in 46% of the applied water being found as leachate that contained more than 10 mg l^{-1} nitrate-N (Mancino and Troll, 1990). Starrett et al. (1995) showed that a high irrigation rate (25 mm) increased N leaching through soil columns five times higher than a low irrigation rate (1.5 mm). Irrigating near the evapotranspiration rate minimized losses of N in leachates from golf greens (Brown et al., 1977). Nitrate-N concentrations leaching from newly established greens that were not covered by turf were as high as 200 mg l^{-1}, but decreased to <10 mg l^{-1} after the turf was well established (Snyder and Cisar, 2000). Likewise for grassed areas, it was found that drainage losses for N were very high for fallow areas, but much lower for established turf (Allen et al., 1978; Knappe et al., 2002). On the other hand, Hesketh et al., (1995)

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found that N losses increased after long periods of intensive fertility management for established turfgrass. So even though turfgrass often decreases nitrate-N leaching due to plant uptake, under some circumstances it is not effective in ameliorating nitrate-N losses.

Although some reports indicate that fertilizer source did not affect nitrate-N losses from turfgrass (Geron et al., 1993), generally, the more soluble the source, the greater the leaching potential (Brown et al., 1982; Shuman, 2001). In a greenhouse study with columns under bermudagrass with high N rates (100 and 200 kg ha^{-1} every 20 and 40 days), the nitrate-N exceeded the 10 mg l^{-1} drinking water standard by 10–19 times for high rates of sulfur coated urea and urea (Quiroga-Garza et al., 2001). However, a controlled-release source, hydroform, resulted in decreased N leaching losses. In a similar experiment at lower N rates (up to 49 kg/ha applied every other week), poly- and sulfur-coated controlled-release source resulted in significantly less nitrate-N leached (concentration and mass) than a water-soluble fertilizer source (Shuman, 2001). On sand-based greens leachate concentrations of nitrate-N exceeded 10 mg l^{-1} for as long as 30 days after application for soluble sources but controlled-release sources resulted in lower concentrations (Brown et al., 1982). The latter study found the following order in nitrate-N leaching losses according to source: ammonium nitrate > 12-12-12 > Milorganite > isobutylenediurea > ureaformaldehyde. Therefore, fertilizer source usually has a significant influence on the amounts of nitrate-N leached through golf greens.

Although P is usually considered to be immobile in soils, recent research indicates P moves downward under certain circumstances. Phosphorus concentrations in subsurface flow for grassland exceeded 3 mg l^{-1} (Preedy et al., 2001) and over 1 mg l^{-1} for a sandy soil (Elrashidi et al., 2001). Leachate from bermudagrass golf greens had P concentrations above the 0.3 mg l^{-1} surface water standard (Wong et al., 1998). In a greenhouse study with columns built to USGA specifications covered with bermudagrass, peak P concentrations in the leachate exceeded 20 mg l^{-1} (Shuman, 2001). Golf greens develop an organic layer just below the surface, which could help to adsorb P (Atalay, 2001; Harris et al., 1996). However, all soils have a critical point where P load exceeds the adsorption capacity, and it is then transported downward (Heckrath et al., 1995; Kleinman et al., 2000). Phosphorus in runoff water from grasslands is mostly in the soluble form which is immediately available to algae (Sharpley and Menzel, 1987). The P in leachate from four grassland soils was found to be mostly in soluble form (Turner and Haygarth, 2000) as was the leachate P from pastures in Australia (Nash and Halliwell, 2000).

Very little information exists on the effects of P fertilizer source on P leaching through soils. For undisturbed soil columns it was found that there was little difference in P leaching between natural rock phosphate and synthetic phosphate in sandy loam soil (Allinson et al., 2000). However, in a greenhouse experiment with columns built to US Golf Association specifications, a soluble source leached to a greater extent than a granular controlled-release source (Shuman, 2001). Because of the lack of information on fertilizer sources versus leaching losses, especially of P, greenhouse and field lysimeter experiments were carried out to determine the effect of fertilizer source on drainage losses of both nitrate-N and phosphorus.

2. Materials and methods

2.1. Greenhouse study

Lysimeters (36) were constructed to include turfgrass growth boxes (40×40×15 cm deep) on top of bases (Smith et al., 1993). The bottoms of the wooden growth boxes were perforated steel and at the inside-center of the growth boxes a 13-cm length of polyvinyl chloride (PVC) tube (15 cm diameter) was fastened to the bottom with acrylic caulk. The base of the lysimeter consisted of a 52 cm length of PVC tubing (15 cm diameter) capped at the bottom. The cap had a drain tube for the collection of leachate in 4-l bottles. The PVC bases contained three equally spaced rings of acrylic caulk on the inside to help prevent flow along the edge of the columns. The lysimeters were housed in a greenhouse covered with LEXAN thermoclear sheet glazing. This covering had about 90% of the light transmission of glass.

The rooting mixture (sand:sphagnum peat moss) had proportions of 80:20 sand:peat by volume (96.8:3.2 by mass) to give a final percolation rate of 33 cm h^{-1}. This mixture has been prescribed by the USGA for bermudagrass greens (USGA Green Section Staff, 1989). Lysimeter bases were 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. 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^{-1} and produced a flow rate of 1.82 ml s^{-1} at 138 kPa. The boxes were irrigated daily at 6.3 mm resulting in a leachate level of about 1 l per week per column. This results in a flow of about 40 mm per week.

The turf was mowed twice a week at a height of 10 mm using a hand clipper to simulate a reel-type mower.

The fertilizer source experiment consisted of eight sources at one P rate plus a zero-P control. The sources were poly- and sulfur-coated micro-granular 13-13-13, an agricultural 10-10-10, soluble 20-20-20, 16-25-12, 19-25-5, 9-18-18, sulfur-coated urea with super phosphate, and a liquid controlled-release N with super phosphate. Each treatment was replicated four times in a completely randomized block design. The rate was based on P at 11 kg P ha^{-1}. Where N was added separately, it was added at 24 kg N ha^{-1} to be compared with the balanced sources (13-13-13, 10-10-10 and 20-20-20). Fertilizer treatments were added on weeks 3, 5, 7, and 9 with the experiment terminating at week 26. Samples were refrigerated at 4 °C prior to analysis.

2.2. Field lysimeter study

Field lysimeters consist of two narrow strips of simulated green each subtended with 10 lysimeters with a collection area in a covered walkway between the strips (Smith and Bridges, 1996). The rooting medium was according to USGA specifications for bermudagrass greens (sand: sphagnum peat moss, 80:20, v/v). The areas were sodded to Tifdwarf bermudagrass. The interior diameter of each lysimeter was 55 cm and the depth was 52.5 cm with the tops 5 cm below the base of the sod. The lysimeters were filled with layers of gravel, course sand, and the rooting medium as with the greenhouse lysimeters. A horizontal moving irrigation system and an automatic moving rain shelter controlled the amount of water the turf received at 6.3 mm per day. The turf was mowed twice weekly at a height of 10 mm and the clippings removed. Two sources (soluble 20-20-20 and poly- and sulfur-coated granular 13-13-13) of fertilizer at three rates (0, 12, and 24 kg N ha^{-1} and 0, 5, and 11 kg P ha^{-1}) were replicated three times. Leachate samples were collected once a week and analysed.

2.3. Analytical precedures

Nitrate-N and phosphate-P were determined for samples filtered through 0.45-μm filters to give the soluble form (Sharpley and Menzel, 1987). 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. Phosphate was also determined colorimetrically. The LACHAT instrument uses an ammonium molybdate–ascorbic acid method. Some samples were analyzed directly in test tubes using a spectrophotometer at a wavelength of 880 nm.

The rooting media for the greenhouse experiment was sampled at the end of the experiment. Cores were taken for the top box and the columns were sampled in increments dividing the column into thirds. Samples were air dried and ground to pass a 2-mm sieve. Phosphorus was extracted using the Mehlich 1 procedure (Southern Cooperative Series, 1965) and P analysed as for the leachate samples.

Statistical analysis was used to separate means by analysis of variance and/or LSD tests.

3. Results and discussion

3.1. Greenhouse lysimeter experiment

Phosphorus breakthrough occurred at week 6 for the soluble 20-20-20 source and at week 8 for most of the other sources tested (Fig. 1). The highest concentrations of P in the leachates were for the soluble 20-20-20 fertilizer and the 16-25-12 starter fertilizer. The others were lower, but there were no discernable trends. The results show that most fertilizers are the same as far as leaching of P with only the very soluble sources resulting in significantly more leaching. Similar results have been found for other leaching experiments (Shuman, 2001). Nitrate-N concentrations in the leachates followed patterns different than those for P concentrations (Fig. 2). The Nitrate-N breakthrough for all sources came at week 3, which was considerably earlier than for P concentrations at weeks 6 and 8. The highest peak for nitrate-N came for the soluble 20-20-20 source and the next highest was for the liquid source. The lower nitrate-N concentrations were for the sulfur-coated urea and the sulfur and poly-coated 13-13-13. None of the concentrations were above the 10 mg kg^{-1} nitrate-N drinking water standard.

The highest cumulative P leached for the entire 26-seek experiment was for the 20-20-20 soluble source and the 16-25-12 starter fertilizer with both of them resulting in 43% of that added leaching through the columns (Fig. 3). The others varied from 15 to 25% of added that leached through, but none was significantly different because of variations within the replications. The results show rather dramatically that only the most soluble P sources result in higher leaching losses. The other sources based on ammonium phosphate and the coated sources were about the same in their propensity to leach through these porous golf green profiles. These results are similar to that found for two commercial phosphate fertilizers on a sandy loam soil (Allinson et al., 2000).

For nitrate-N the highest cumulative mass leached was for the soluble 20-20-20, the agricultural grade granular 10-10-10, and the liquid N source (Fig. 3). The coated materials decreased nitrate-N leaching losses, unlike that for P. The 13-13-13 and sulfur-coated urea resulted in significantly lower nitrate-N losses (1.4 and

0.7%, respectively) than the sources which were uncoated. In another column study, less nitrate-N leached from controlled release Hydroform than urea and sulfur-coated urea (Quiroga-Garza et al., 2001). Organic and other controlled-release sources decreased nitrate-N in the leachate from golf greens over that for ammonium nitrate (Brown et al., 1982). The results show that nitrate-N leaching losses were low on a percent of added basis compared to P leaching losses, even though the nitrate-N leached through more rapidly than P. The most likely explanation of this result is that N is more efficiently utilized by the plants than P, and the coated sources tend to keep the nitrate-N in the root zone for a longer time than the uncoated granular and liquid sources. Brown et al. (1982) found 23% of the N added was lost from sand-based greens, and Bowman et al. (1998) found up to 38% of the N added was lost from columns simulating greens. However, others report percent nitrate-N lost in the leachate to be in a similar range as found here (Allen et al., 1978; Hesketh et al.,1995; Vianden and Franken, 1995).

Soil tests were performed on the growth boxes to determine differences among the treatments and to relate the soil test results to fertilizer recommendations.

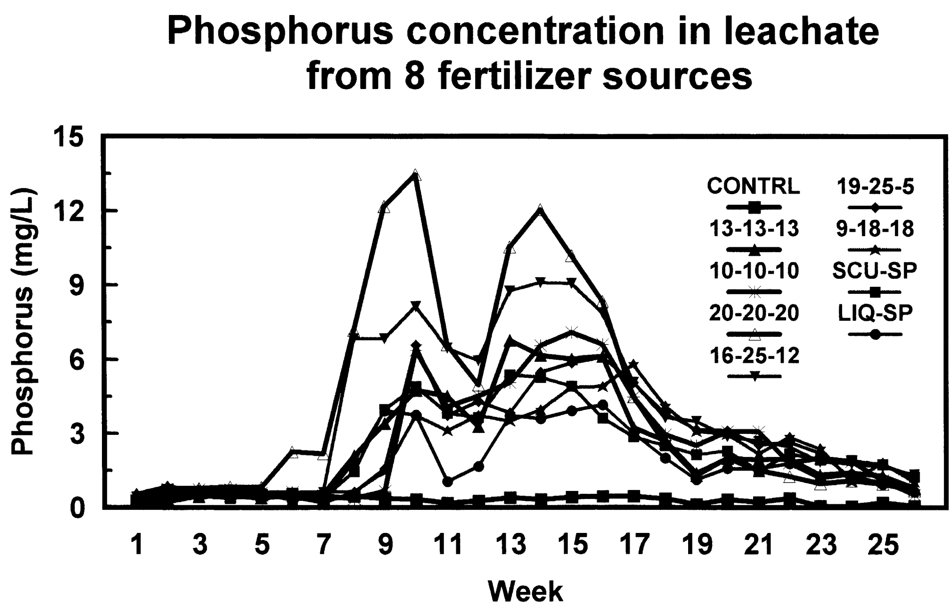

Fig. 1. Phosphorus concentrations in leachate from eight fertilizer sources for simulated golf greens in the greenhouse.

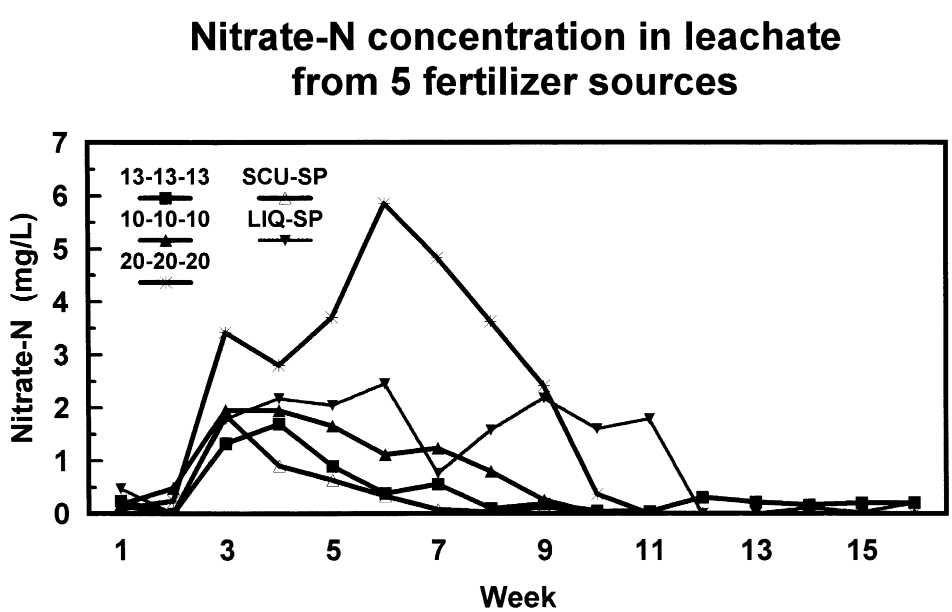

Fig. 2. Nitrate-N concentrations in leachate from five fertilizer sources for simulated golf greens in the greenhouse.

The control at 16.6 mg kg^{-1} was in the 'low' range for bermudagrass according to the current University of Georgia soil test recommendations (Plank, 1989; Fig. 4). At that soil test value the recommended P rate is 3.93 lb. P 1000 sq ft^{-1}. The added rate was 0.88 lb P 1000 sq ft^{-1}, or about a quarter of the recommended rates. The fertilizer amendments all increased the soil test values into the 'medium' range for bermudagrass with the exception of the 9-18-18, which resulted in a value just below the 'medium' range. The values for the soil test P for the columns under the boxes were very low (<3 mg kg^{-1}) with little or no treatment effects.

3.2. Field lysimeter experiment

Field lysimeters may give a somewhat more realistic picture of leaching than those in the greenhouse. In this case the column size was different and may account for some differences in results from the two areas. Although treatments of soluble 20-20-20 and controlled-release 13-13-13 had been added since 1998, there were no treatment effects observed in the P concentrations in the leachate until the winter of 1999–2000. The fertilizer treatments considered here for calculating percent of added in the leachate, were applied in April, May, and

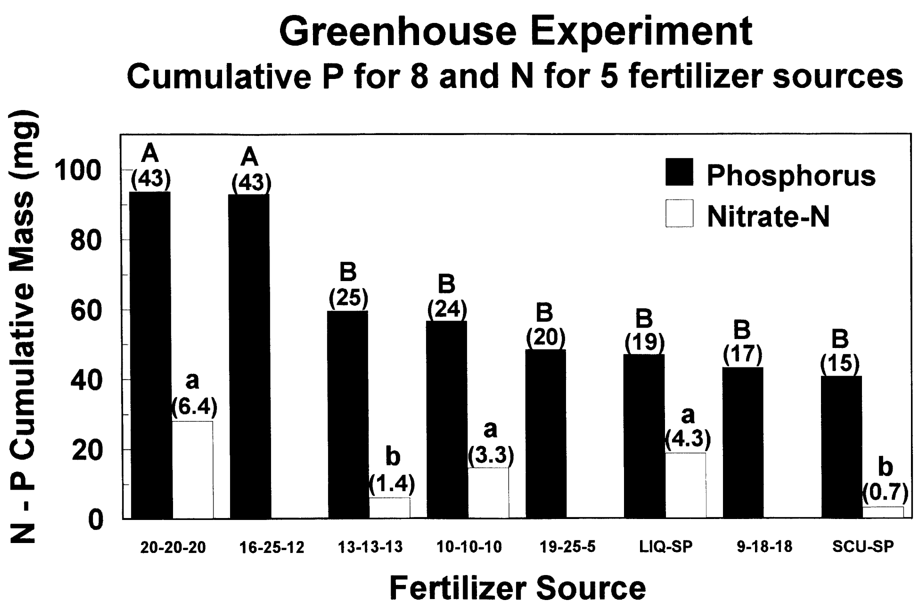

Fig. 3. Phosphorus and nitrate-N cumulative mass and % leached of added (in parentheses) in leachate from fertilizer sources for simulated golf greens in the greenhouse. Bars within an element with the same letters are not different at the 5% level according to an LSD test.

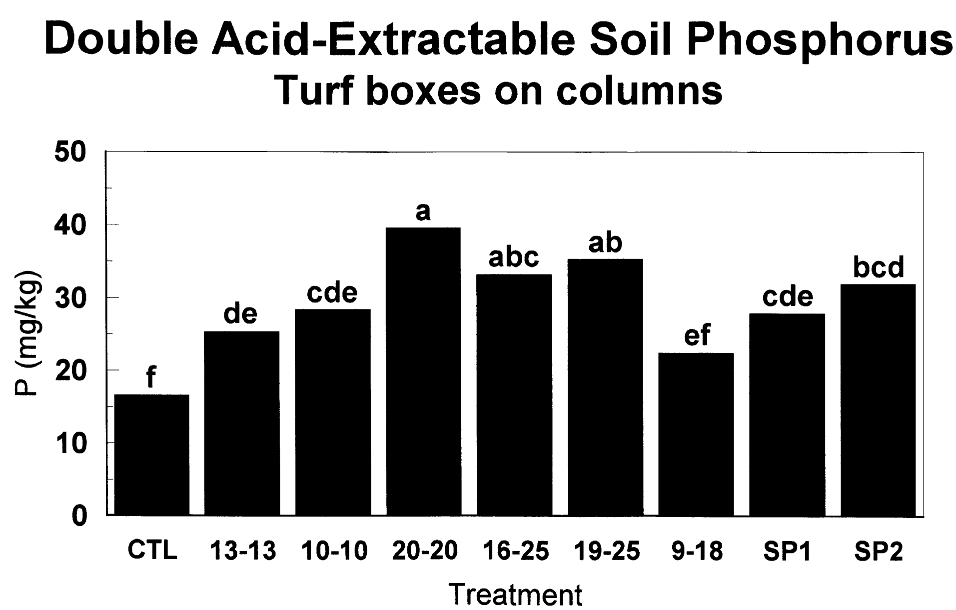

Fig. 4. Double acid-extractable soil P in the turf boxes on the columns for eight fertilizer sources for simulated golf greens in the greenhouse. Bars with the same letters are not different at the 5% level according to an LSD test.

July 1999, before the start, and in October, 1999, and May, 2000, during the time period reported (Fig. 5). Prior to this period the P concentrations in the leachate for both 20-20-20 and 13-13-13 plots had gradually decreased.

Increases in the P concentrations in the leachate for the granular 13-13-13 appeared for the first time in November 1999 (Fig. 5). The lower P rate resulted in P concentrations in the leachate higher than control from November 1999 to June 2000, but there were no discernable peaks. The treatment effects were more a result of increased leachate volume than the timing of fertilizer treatments. Concentrations of nitrate-N in the field lysimeter leachates show a different pattern than for P concentrations (Fig. 6). Very little of the added N leached through these lysimeters. In fact, there were no treatment effects seen for any N rate for the 13-13-13 fertilizer source. For the 20-20-20 fertilizer source there were treatment effects observed in August 1999, and during October and November 1999.

Leachate volumes followed a pattern of increasing in the winter months peaking in February–March and decreasing in the summer months to the lows in June, July, and August (Fig. 7). This pattern was also observed in Canada for seasonal leachate volumes (Roy et al., 2000). The differences found are a result of different evapotranspiration rates in the winter than in the summer.

The percent of N and P added that leached through the field lysimeters was relatively low with P ranging from 3 to 8.1% and N from 0.1 to 2.5% (Table 1). The percent of P that leached from the field lysimeters was much lower than for the greenhouse experiment. Higher rates of P resulted in a higher percent being leached for both sources, but higher rates of N resulted in no statistically different percent leached. The results show the

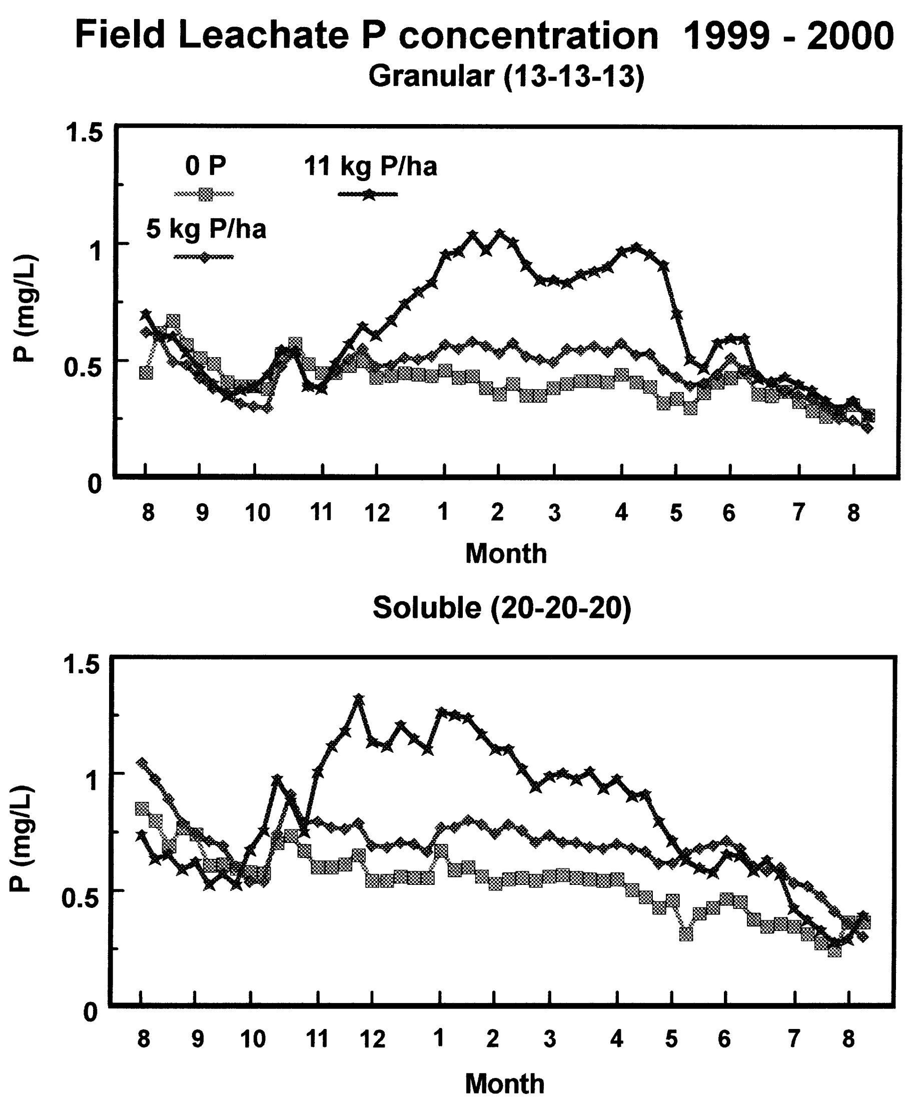

Fig. 5. Phosphorus concentrations in leachate from two fertilizer sources for field lysimeters.

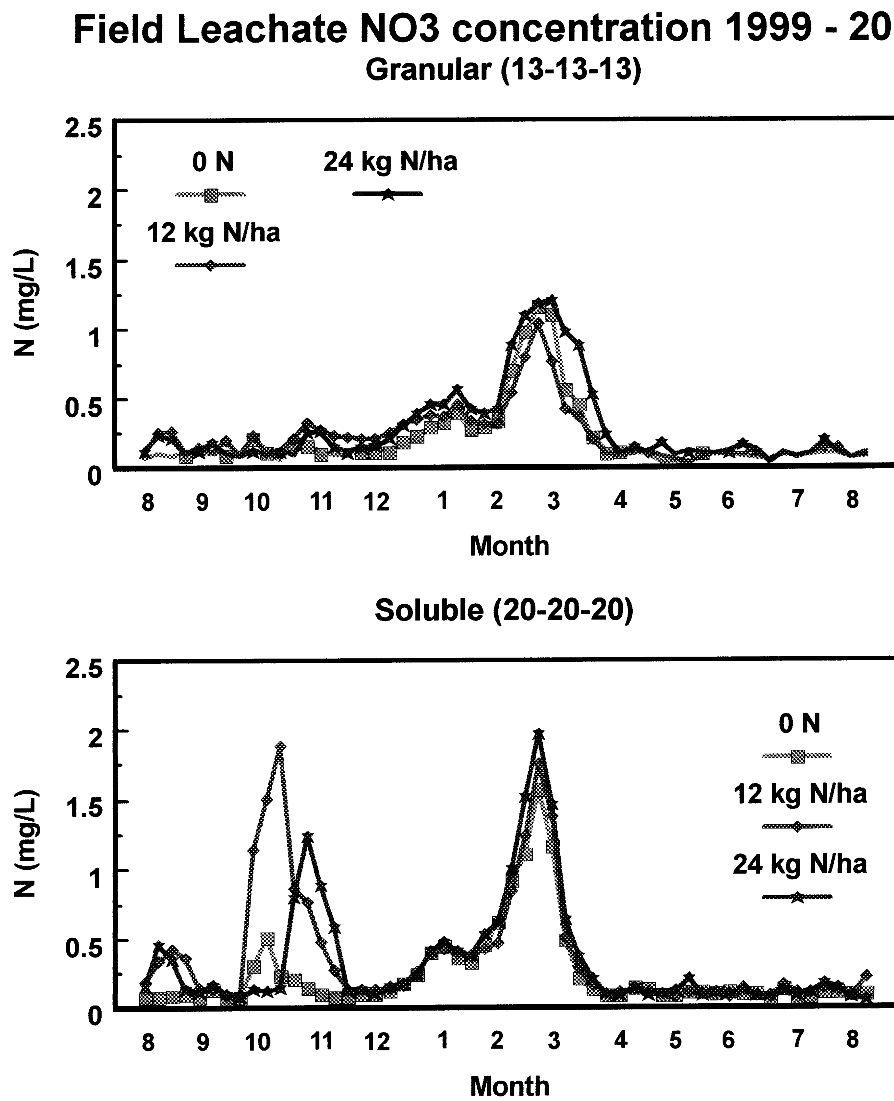

Fig. 6. Nitrate-N concentrations in leachate from two fertilizer sources for field lysimeters.

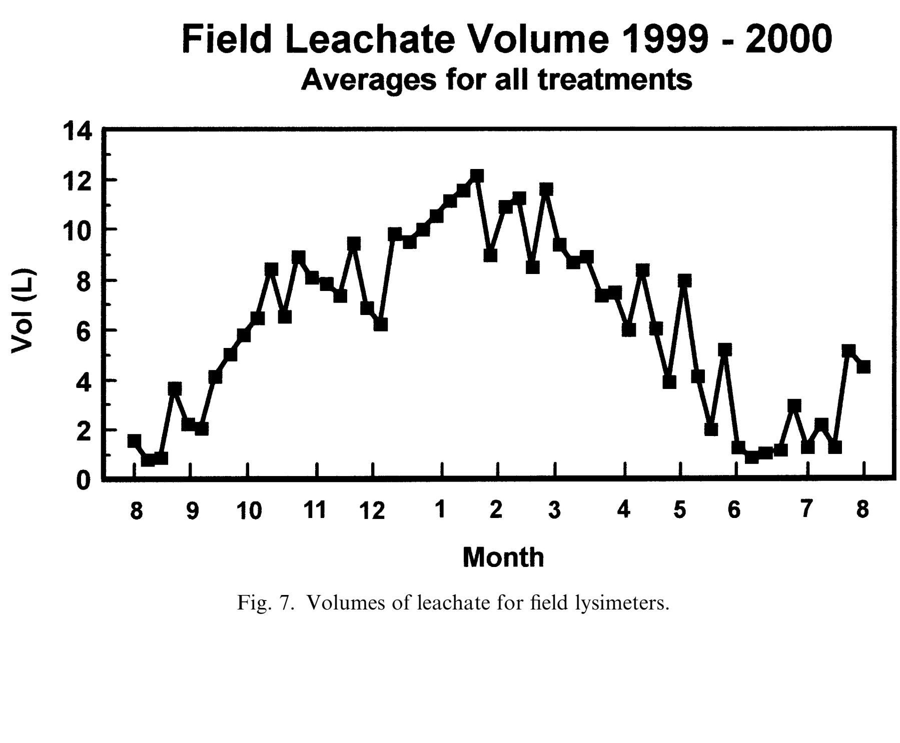

Fig. 7. Volumes of leachate for field lysimeters.

Table 1
Percentages of nitrate-N and phosporus added in fertilizer that was found in the leachates for the field lysimeter experiment

Fertilizer source	Fertilizer rate (kg ha^{-1})	Cumulative mass minus control (mg)	Percent of added
Phosphorus			
20-20-20	5	40.9	5.4 b[a]
20-20-20	11	123.1	8.1 a
13-13-13	5	22.6	3.0 b
13-13-13	11	98.5	6.5 a
Nitrate-N			
20-20-20	12	43.7	2.5 a
20-20-20	24	38.7	1.1 a
13-13-13	12	2.3	0.1 a
13-13-13	24	30.4	0.9 a

[a] Values followed by different letters within a fertilizer element and source are not different at the 5% level according to an ANOVA test.

same pattern for greenhouse versus field data in that the percent leached was much higher for P than for N. However, the field data for P was much lower in percent leached indicating that the greenhouse columns may overestimate the amounts of P leached. A possible explanation may be higher adsorption due to organic matter build-up in the field lysimeters.

4. Conclusions

Results of the greenhouse fertilizer source experiment show that nitrate-N leaches at a faster rate than P, but that more of the applied P leaches through the rooting media than nitrate-N. The reason is that the nitrate-N is more efficiently used by the turf. Coated, controlled-release granular fertilizers did not affect P leaching compared with other granular sources in general, but were effective in decreasing the amounts of nitrate-N that leached through the columns. Less P leached from field compared with greenhouse lysimeters, but approximately the same amount of nitrate-N. Thus, there may be less P leaching from actual golf greens than the greenhouse data indicate. Considering both the greenhouse and field experiment, the results point to the need to use low rates of P on golf greens and to use controlled-release fertilizer sources of nitrate-N to help decrease the amounts of N and P that are discharged from drains to surface waters.

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