Turfgrass and Environmental Research Online

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University of Georgia researchers used simulated rainfall plots to quantify the amount of nitrate-nitrogen and phosphate contained in leachate from putting greens and runoff from golf course fairways.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 215 projects at a cost of $21 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Nutrient Leaching and Runoff from Golf Courses

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SUMMARY

Researchers at the University of Georgia are using different fertilizer sources at varying rates to determine the potential for leaching of plant nutrients from golf greens and nutrient runoff from fairways. Their findings include:

- Nitrogen was found to leach at a faster rate than phosphorus, and at low rates, leaching of phosphorus was not different than control.
- Controlled-release fertilizers do not appreciably retard phosphorus leaching, but nitrogen leaching can be reduced by using controlled-release sources.
- Nitrogen may be sequestered in the organic layer of greens during the first years after building. Subsequently an equilibrium is established in the layer between sequestering nitrogen and mineralization of nitrogen by microbes.
- The first rain event after a fertilizer application will produce the great majority of the transport by runoff water both of phosphate and of whatever form of nitrogen was applied.
- "Watering-in" should help reduce transport as should applying fertilizer when significant rainfall is not expected for several days.
- Runoff from fairways is a greater threat to water quality than drain outlets from greens and tees because of higher fairway acreage, higher slopes of fairways, and higher application rates for fairways.
- The quantity of nitrogen and phosphate transported from turf is linearly related to the rate of application, and runoff volume is linearly related to soil moisture before a rainfall event.

Environmental quality is being taken more seriously today than in the past. We hear much more about environmental issues in the media. Thus, the materials that are placed on soils such as fertilizers and pesticides are under more scrutiny, both by the public and governmental agencies. The common perception is that the rates for those materials are very high for the lush golf courses that the public sees both as they play and see on television.

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To address this matter the USGA has funded research to determine the extent of possible water pollution coming from golf courses. Research at the University of Georgia is using different fertilizer sources at varying rates to determine the potential for leaching of plant nutrients from golf greens and nutrient runoff from fairways.

Initially we looked at nutrients in lysimeters (devices to sample leachate) from golf greens at a course in north Atlanta. Having found some significant concentrations there, we went on to carry out greenhouse column experiments studying leaching through the same rooting media as is recommended for use for USGA putting greens.

We also determined leaching from larger field lysimeters. Since runoff from fairway could be a problem, we sampled runoff from a golf course fairway during storm events. Although the concentrations of nitrogen and phosphorus were usually low, a large storm soon after a fertilizer

Practice green at a country club in Atlanta, GA. Three lysimeters were installed here to determine nitrate-N and phosphate leached into the drainage water.

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Lysimeters were constructed using stainless steel kitchen sinks (shown here inverted before installation) that collected the putting green leachate and allowed it to be collected in collections bottles at the edge of the greens.

application yielded significant nutrient concentrations in the runoff water. We carried out experiments using simulated fairways with overhead sprinklers that simulate rainfall to determine the potential for this type of water contamination by runoff.

Leaching of nutrients found for golf greens

Three lysimeters were installed in each of two practice greens during construction at a country club in Atlanta, GA, in the fall of 1994. They consisted of common stainless steel kitchen sinks with the tops about three inches below the green surface. A pipe attached to the drain led to the side of the green underground to a collection bottle in a pit. Leachate was sampled after each major rainfall event and was analyzed for phosphorus and nitrate-N. The second green was removed at the end of 1998, so after that date there are only data for Green 1.

Phosphorus was high initially in the leachate, but decreased thereafter to low levels (Fig. 1). There was phosphorus applied just after sodding in order to promote good root growth. There was very little or none applied thereafter until 1999, when P increased again in the leachate for Green 1. Thus, the amounts of P in the leachate were related directly to applied amounts of P.

The pattern for nitrate-N was much different than that for P (Fig. 1). The nitrate-N values were low the first two years, increased the next two years and then seemed to level off for Green 1. We are not certain about the cause of this pattern, but it may be due to sequestering of nitrogen in the organic layer during the first few years. Thereafter the nitrogen started to mineralize (transform from organic to inorganic forms) and thus leached to a greater extent until it reached a steady state. Lysimeters were also installed on two playing greens (12 and 15) at the same course during a renovation in 1998. Leachate concentrations of P followed the same pattern being high at first and then lower thereafter (Fig. 2). Nitrate-N was low for Green 15 the first year and increased the second year as it had for the practice greens.

Leaching of nutrients in a greenhouse test

Simulated golf greens were set up in the greenhouse to examine leaching of nitrate-N and phosphorus. There were growth boxes (40 X 40 X 15 cm deep) set on top of polyvinyl chloride columns that were 15 cm in diameter and 53 cm long. Columns were filled with rooting medium mixed according to USGA green recommendations. Sodded "Tifdwarf" bermudagrass was placed on the rooting medium.

The fertilizer source used to compare rates

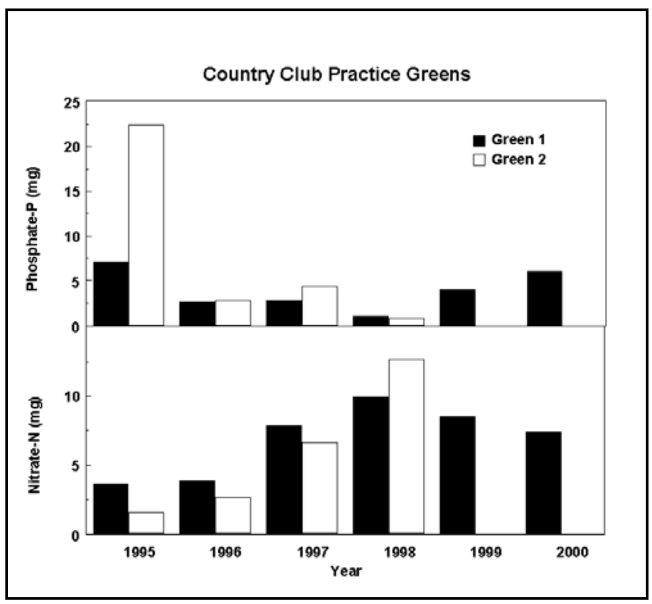

Figure 1. Phosphate and nitrate leached from two practice greens at a country club in Atlanta, GA, as the average of individual rainfall events for each year from 1995 to 2000. Greens were built in the fall of 1994, and Green 2 was removed in the winter of 1998-1999.

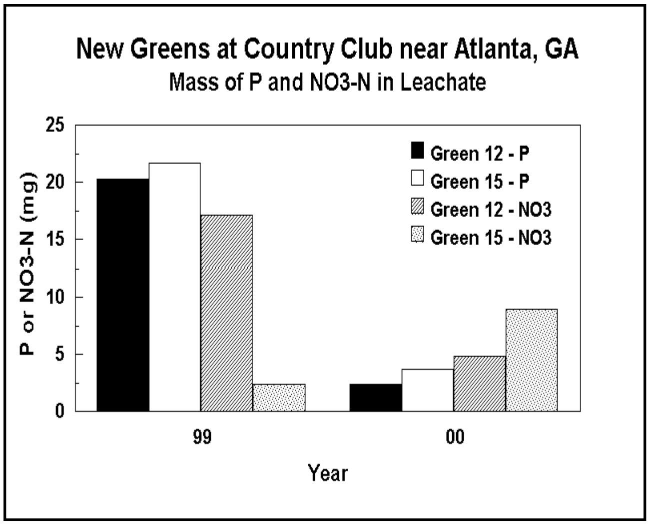

Figure 2. Mass of phosphate and nitrate-N in leachate for two new greens at a country club in Atlanta, GA. Greens were built in 1998.

in Figure 3 was a soluble 20-20-20. The rates were 0, 0.11, and 0.22 lb. P/1000 sq. ft. and 0, 0.25, and 0.50 lb. N/1000 sq. ft., which were replicated three times, and added every other week for a total of six treatments for Experiment 1 and seven treatments for Experiment 5 . This experiment was carried out twice with different irrigation schemes. The first was with the 0.25 and 0.5 in./day throughout the experiment with one large simulated rain, and the second with a lower irrigation rate with no simulated rainfall. Leachate samples were taken weekly and analyzed for nitrate-N and soluble P.

Simulated greens in a greenhouse to determine leaching of nitrate-N and phosphorus. The turf boxes shown have columns underneath built to U.S. Golf Association recommendations.

The effect of irrigation rate is evident in the leaching of both P and nitrate-N (Fig. 3). The data are for the percent of applied P or nitrogen applied that was found in the leachate as a total for the entire experiment. Higher amounts of P were leached than nitrate-N, which is somewhat surprising. Nitrogen is more soluble than phosphorus and thus is thought to move to a lesser extent in soil. However, these were USGA greens intended to give a high percolation rate. As it turned out, the nitrogen evidently was used by the plants to a greater extent than the P, resulting in less mass of N in the leachate. High irrigation resulted in about 20 % of the P moving through, whereas low irrigation rates just above evapotranspiration resulted in about 2 to 6 % moving through. For nitrate-N the higher irrigation resulted in about 8

Column like those under turf boxes to simulate golf greens in the greenhouse to determine leaching of nitrate-N and phosphorus.

to 13 % moving through, but at low irrigation the treated columns resulted in mass of nitrate-N in the leachate that was at or below the control. The values in Fig. 3 have had the control mg of P or nitrate-N subtracted before calculating the percent of the applied that passed through the columns.

Comparing eight fertilizer sources in the greenhouse

In another greenhouse experiment we

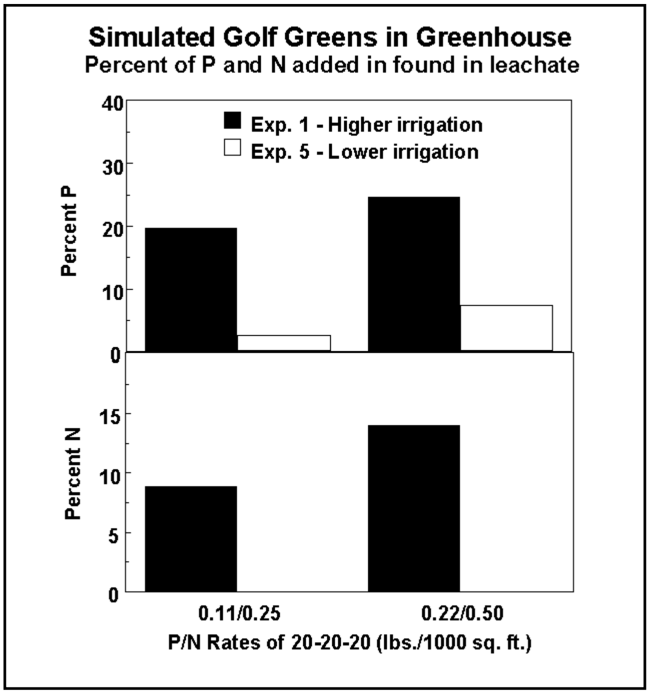

Figure 3. Effect of irrigation on percent of nitrogen and phosphate applied that was found in the leachate for simulated golf greens in the greenhouse.

compared eight fertilizer sources all applied at 0.22 lb. P/1000 sq. ft., and where applicable, 0.5 lb. N/1000 sq. ft.. The 20-20-20 soluble source was included along with 2 balanced granular fertilizers (10-10-10, 13-13-13). Other sources were granular 16-25-12, 9-18-18, and 19-25-5. Superphosphate (SP) was used in two treatments with two N sources (a liquid controlled-release source [NS] and a granular sulfur-coated urea [SCU]). These were added every other week for a total of 4 treatments. Sample collection and analyses were as previously described.

The 20-20-20 soluble source and the 16-25-12 starter fertilizer produced the most leaching of phosphorus (Fig. 4). The lowest leaching came from the super phosphate and 9-18-18 materials. The others were intermediate, but not much higher in total mass of P leached than the lowest sources. These results indicate that the more soluble the source, the less should be applied, since the more soluble sources are prone to leach. Superphosphate and less soluble granulars do not leach as readily, but certainly low rates should be used.

The nitrate results indicate less leaching similar to that found in the above experiments. Only five nitrogen sources can be compared, which are the balanced sources and those put on as separate treatments with the superphosphate. Here the 20-20-20 certainly resulted in the highest total mass of N leached. The 10-10-10 and the liquid source were intermediate and the coated granules were lowest. The 13-13-13 is poly- and sulfur-coated and the other coated N source was sulfur-coated urea. These both produced favorable leaching characteristics by presumably increasing N use efficiency by the turfgrass.

Leaching in field lysimeters not as severe as in greenhouse

Field lysimeters consist of two narrow strips of simulated green each having ten lysimeters under them with a collection area in a covered walkway between the strips (3). The green areas have rooting media that are USGA specification for bermudagrass as in the greenhouse (sand: sphagnum peat moss, 80:20, v:v). The areas were sodded to "Tifdwarf" bermudagrass in July of 1998. The tops of the lysimeters are 5 cm. below the base of the sod.

The facility includes a horizontal moving irrigation system and an automatic moving rain shelter that automatically moves over the area during natural rain events. Irrigation was at 0.625 cm. per day. The turf is mowed twice weekly at a height of 1.0 cm. and the clippings removed. Treatments consisted of two sources (soluble 20-

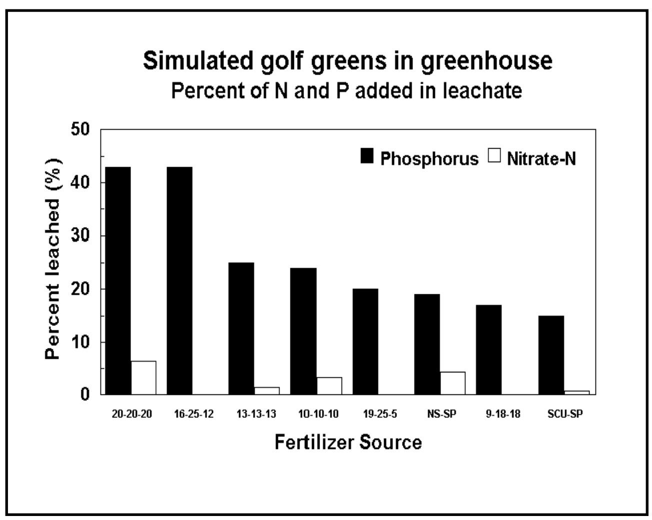

Figure 4. Cumulative phosphorus and nitrate-N as percent of that applied for a leaching experiment for eight fertilizer sources from simulated golf greens in the greenhouse.

Field lysimeter facility to determine leaching of nitrate-N and phosphorus through simulated golf greens. There is a tunnel under the metal area to the left to sample leachate in bottles and a moving cover automatically cover the area during natural rainfall.

20-20 and poly- and sulfur-coated granular 13-13-13) at three rates replicated three times. The rates were 0, 12, and 24 kg N ha^{-1} and 0, 5, and 11 kg P ha^{-1}. Leachate samples were collected once a week and analyzed for nitrate-N and P. Nutrients were determined for samples filtered through 0.45 micrometer filters, which is considered to be the soluble form (2).

Field lysimeters simulate actual greens closer than greenhouse columns in that they are larger and are subjected to weather conditions. The treatments had been applied several times per year since the spring of 1998, but no treatment effects were seen until late 1999 and the first half of 2000 (Fig. 5). Treatments were applied three times before the start of the time period reported for purposes of calculating percent applied found in the leachate. Treatments were also applied two times during the time period.

Treatment effects were evident for P beginning in November 1999 giving several peaks for the high rate. These peaks were related to increases in leachate volume. Volume increased in the winter months peaking in February to March and being lower in summer and fall. The lower application rate of P resulted in P concentrations only slightly above the untreated control. The percent of P applied that leached through the lysimeters ranged from 3.0 to 8.1 % and the percent of nitrate-N was 0.1 to 2.5 %. These values are considerably lower than for the greenhouse experiments. The higher application rates resulted in higher percents for the field lysimeters.

Runoff can also be a problem

Although leaching can be a potential problem for porous greens, for fairways built on native soil, the problem will more likely be runoff. Soils in the Southeast piedmont are typically eroded so that they are high in clay content. Thus, these soils tend to crust and get hard when dry. This factor, along with the high intensity storms that are frequent in the summer, can lead to significant runoff, even from turf areas.

We placed an auto-sampler at the output of a surface drain that drained a portion of a fairway at a golf course in north Atlanta, Georgia. It was designed to start sampling at the beginning of flow and continue taking a sample each hour until either it was out of bottles (24), or flow stopped at the end of the rainfall event. One such sampling

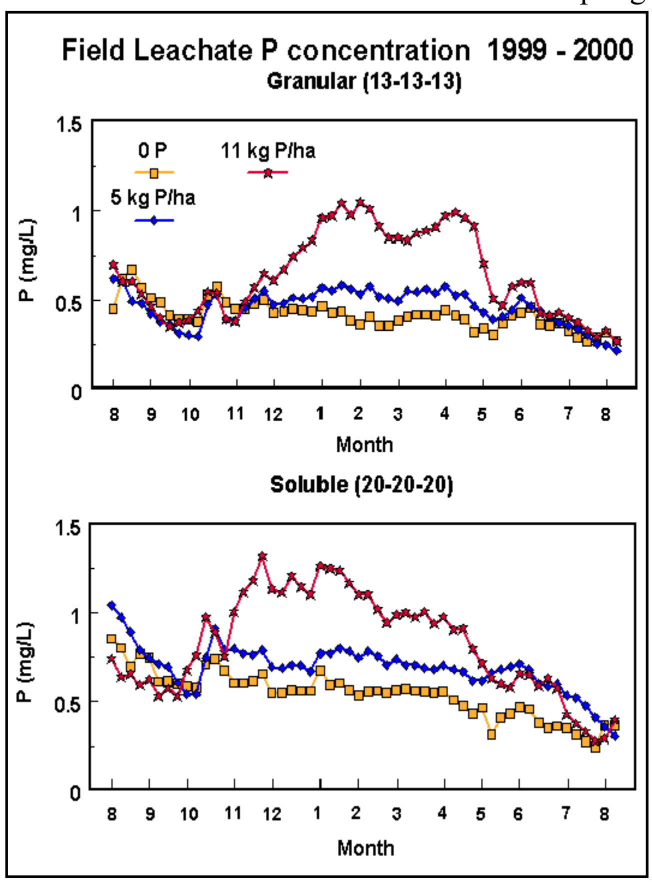

Figure 5. Concentration of phosphorus in the leachate for two fertilizer sources for a field leachate facility that simulates golf greens.

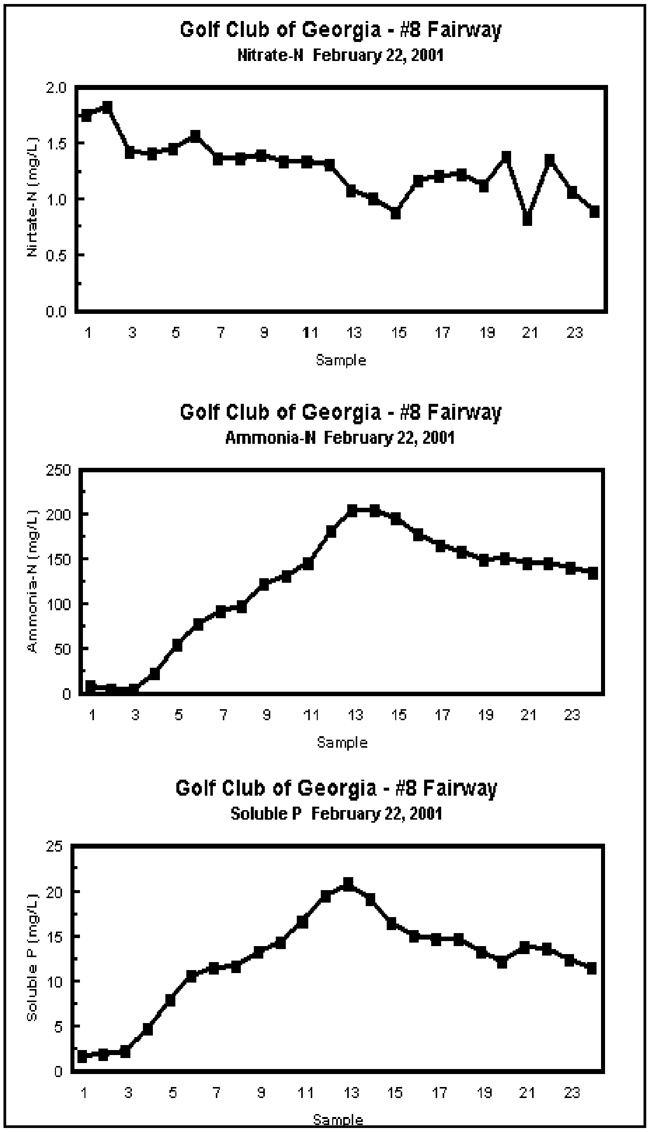

Figure 6. Concentrations of nitrate-N, ammonium-N, and phosphorus in runoff for a golf fairway in a northern suburb of Atlanta, GA. The samples are for one-hour intervals for a 1.5-inch rainfall event after applying ammonium phosphate to the fairway at a rate to give 1 lb. N/1000 sq. ft.

was taken for a 1.5 inch rainfall event on February 22, 2001 (Fig. 6). We analyzed the 24 sequential samples for P, nitrate-N, and ammonium-N. There had been an application of ammonium phosphate earlier that month to give 1 lb. N/1000 sq. ft.

As is evident from the data in Fig. 6., the nitrate-N was relatively low, but the ammonium-N and P are very high. The ammonium-N and P were not finished running off after a 24 hour period, so even more than is indicated here actually made its way off the fairway into a riparian area next to a stream. Although in this case, the riparian area may have decreased these concentrations considerably before the water made its way to the stream, in many cases these drains empty directly into streams or ponds. These data show that runoff of nitrogen and phosphorus can be a potential problem for golf courses.

Runoff experiments initiated

Twelve individual plots (7.0 X 3.6 m) separated by landscape timbers were built in a grid with a 5% slope from the back to the front (cover photo). 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 (*Cynondon dactylon* X *C. transvalensis)*.

A trough was installed in a ditch at the front of each plot to collect the runoff water in a tipping bucket sample collection apparatus. The bucket tips each time that 2 liters 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 con-

Detail of tipping bucket apparatus to measure runoff volume and take a sample in the slot between the two sides.

tainer that is analyzed after each simulated rainfall event. We measured a simulated rainfall intensity of 2.7 cm hr-1 (about 1 inch hr^{-1}), which is lower than reported by Smith and Bridges (3) for this same facility.

Fertilizer treatment consisted of 10-10-10 granular at rates to give 0, 12 and 24 kg N/ha (0, 0.25 and 0.5 lb. N/1000 sq. ft.) and rates of 0, 5 and 11kg P/ha (0, 0.11 and 0.22 lb. P/1000 sq. ft.). Treatments were made through the summer months from April to September. 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 (5.0 cm), 24 (5.0 cm), 72 (2.5 cm), and 168 (2.5 cm) hours after treatment (HAT) for the first experiment. In a second experiment the fertilizer was "watered in" with 0.25 in. of irrigation and the sequence of simulated rainfall was not started until three days later.

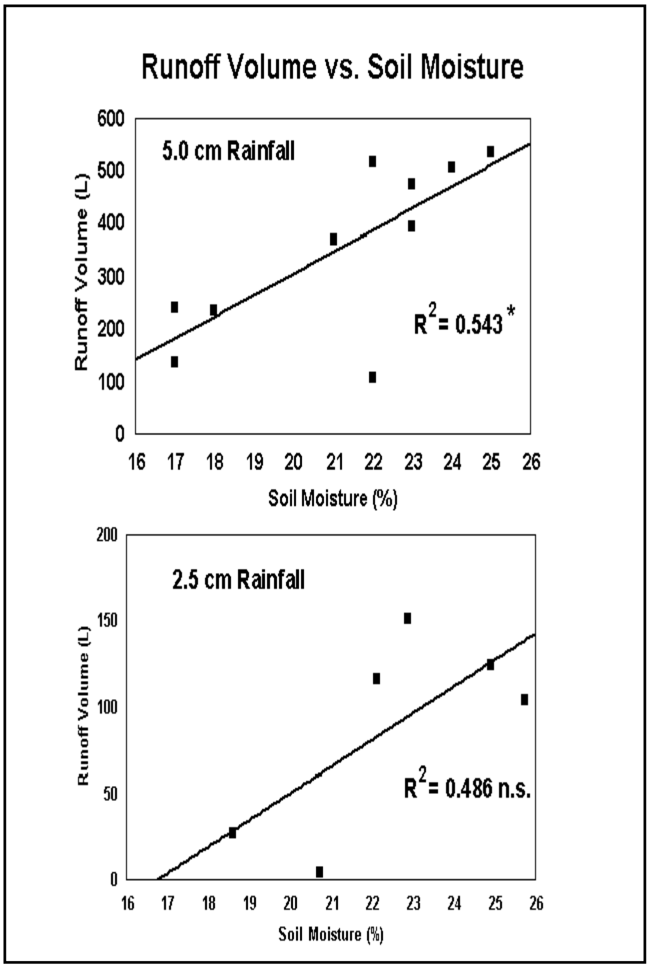

Figure 7. Runoff volume versus soil moisture before the simulated rainfall events. The runoff is for a field experimental site on a 5% slope to simulate a golf fairway.

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. Soil moisture was determined before each simulated rainfall event by oven drying 7.5-cm-deep soil cores.

Soil moisture influence on amounts of runoff water

Since soil moisture has an effect on runoff volume, we sampled soil moisture just before each runoff event. Regression analyses were carried out on the averages of the 12 replications for each event for each year. The data are presented separately for the 5-cm and 2.5-cm simulated rainfall events separately (Fig. 7).

For the 5-cm simulated rainfalls, there is a good linear relationship with only one outlier. The R-square value is significant. For the 2.5-cm simulated rainfall events, there is a linear pattern, but the points are more scattered. This scatter, and the fact that there are only six points, led to a non-significant R-square value. The longer times between rainfall events allowed more variation in soil drying than for the first two rainfall events.

Cole et al. (1) likewise found that the higher the antecedent soil moisture, the higher were the runoff volumes from simulated rainfall. For the 5-cm simulated rainfall events, there was a high of 43.5 % and a low of 24.3% runoff volumes on soil that was near field capacity. For the 2.5-cm simulated rainfall events, the range was from 17.7 to 27.4 %. These variations had much to do with the moisture status of the soil at the time of the rainfall event.

In a simulated rainfall experiment with bermudagrass, when the soil was relatively dry, runoff was 4 to 16 % of that applied, whereas when the soil was moist, the runoff was 49 to 80% of that added (1). As shown in Fig. 7 there was a direct relation between soil moisture and amount of runoff. Also, the time of year, the temperature, cloud cover, humidity, etc. all play a part in how

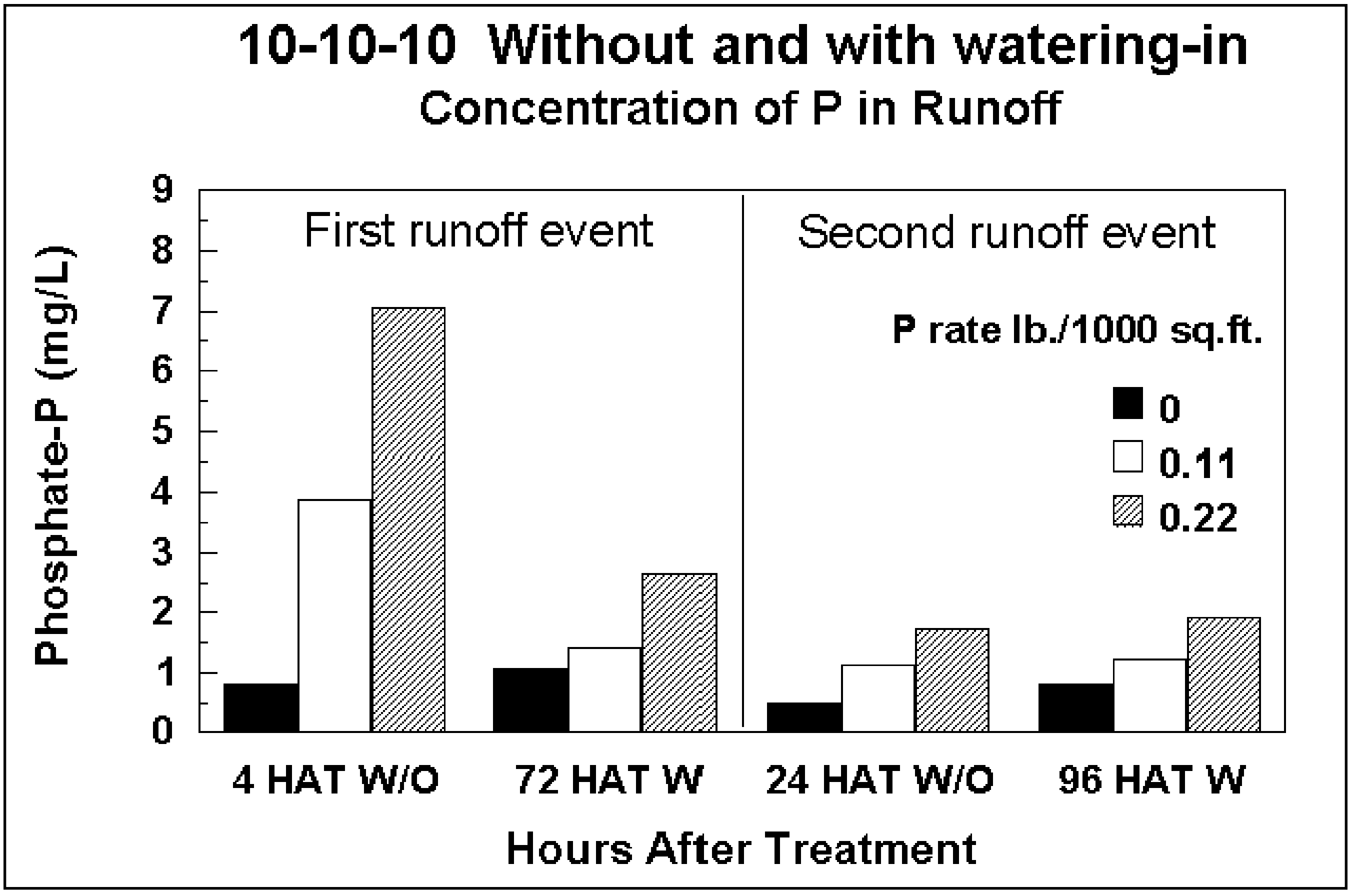

Figure 8. Phosphate concentrations in runoff water for two runoff events and 3 rates of 10-10-10 fertilizer. Two experiments are depicted both with and without "watering-in" the fertilizer. Without watering-in had simulated rainfall events 4 hours after treatment (HAT) and 24 HAT. With watering-in had simulated rain at 72 and 96 HAT.

moist the soil is at the time of the rainfall event. At the 168 HAT simulated rainfall event, the soil was usually dry, and the runoff volume from the 2.5-cm rainfall was very low. These data indicate that dry soil conditions when applying fertilizer is beneficial for reducing runoff volume, and thus reducing transport of nutrients from turf areas.

"Watering-in" helps decrease nutrients in runoff water

Most of our runoff experiments were carried out under the most severe conditions in that the first two-inch rainfall event took place four hours after treatment (HAT) on the same day as the fertilizer was applied. We observed significant P concentrations in the runoff water for that event and much lower for subsequent events as indicated by the 4 HAT and 24 HAT W/O watering-in (Fig. 8).

However, where we watered-in the fertilizer and let it stand for 3 days, before adding the first 2-inch simulated rainfall, the concentration of P was much reduced (72 HAT with watering-in). When we watered-in there was not much difference in the P concentrations in the runoff between the 72 HAT and the second event at 96 HAT. For all the simulated rainfall events, there was a stepwise increase in P concentration with P application rate indicating that low rates of P are preferable from an environmental standpoint.

Recommendations

Since phosphorus has been found to leach through greens, and significant amounts are not taken up by the turfgrass, it is best to add as low rates as possible to greens. Even controlled-release sources are not able to reduce the eventual leaching of phosphorus.

For nitrogen, spoon feeding certainly is encouraged. Use of controlled-release sources as opposed to soluble sources greatly attenuates leaching of nitrogen to the drainage water.

Finally, "flushing" of greens with large amounts of irrigation should only be done when fertilizer nutrients are nearly depleted and not soon after fertilizer application. Lower amounts of irrigation will help to abate leaching of fertilizer nutrients.

Use common sense when applying fertilizers to fairways. Remove all fertilizer off hard surfaces. Do not apply more than needed and do not apply immediately before an expected rainfall. Watering after fertilizer application can be beneficial in order to wash fertilizer off the plants and into the soil. This irrigation should be light so as to not induce runoff. Use of controlled release fertilizer sources does not seem to be as important in controlling transport from fairways as it is for decreasing leaching from greens.

Acknowledgments

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