retardation factors (R) based on our laboratory measured thatch and soil sorption coefficients with model fitted R's to predict carbaryl transport.

Modeling of bromide transport presented strong evidence of significant two-domain flow in all columns except the zoysiagrass soil columns. In columns exhibiting two-domain flow, use of retardation factors based on laboratory measured adsorption coefficients accounted for 74 to 94 percent of the variability in carbaryl transport. Slightly improved estimates of carbaryl transport were obtained when R was kept as a fitting parameter. In columns where two-domain flow was not apparent, the LEM model satisfactorily described carbaryl transport only when R was curve-fitted. Use of R's based on laboratory derived adsorption coefficients resulted in poor LEM estimates of carbaryl transport. The 2SNE model gave reasonable estimates of carbaryl transport when R was calculated using the adsorption coefficients determined in our sorption studies.

Nitrogen and Phosphorus Leaching and Runoff from Golf Greens and Fairways

University of Georgia

Larry M. Shuman

Start Date: 1998
Number of Years: 3
Total Funding: $75,000

Objectives:

1. *Quantify the amounts of nitrogen and phosphorous that leach from USGA greens under various management practices.*
2. *Determine the amounts of nitrogen and phosphorous that runoff from a Southeastern piedmont soil under various management practices including the effect of buffer zone width and irrigation scheduling with respect to fertilizer application.*
3. *Determine the effects of forms of phosphorous, dissolved organic carbon (DOC), soil compaction and crusting, and climatic variables on phosphorous leaching and runoff. This information will be incorporated existing fate prediction models.*
4. *Develop best management practices to limit leaching and runoff on nitrogen and phosphorous form golf course greens and fairways.*

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. 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 was greatest at the first simulated rainfall event from bermudagrass plots with a 5 percent slope and receiving three rates of a 10-10-10 fertilizer (Figure 9). The runoff decreased dramatically during subsequent rainfall events. Step-wise increases in phosphorous concentrations in the runoff were found for the 5 and 11 kg ha^{-1} rates for the first runoff event. The total mass of phosphorous transported for all four events was 10.6 and 11.5 percent 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.

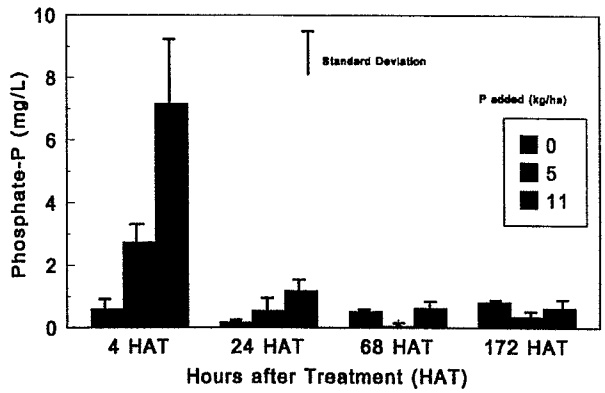

Figure 9. Phosphate concentration in runoff for three rates of 10-10-10 fertilizer. Simulated rainfall at two inches for 4 hours after treatment (HAT), two inches at 24 HAT, and one inch at 68 HAT, and one inch at 172 HAT.

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 (Figure 10). The difference is especially great at the lowest phosphorous rate (5 kg ha^{-1}). In fact, phosphorous concentrations in the leachate were not different from the control at the granular source rate.

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 phosphorous applications in 1994 during grow-in.

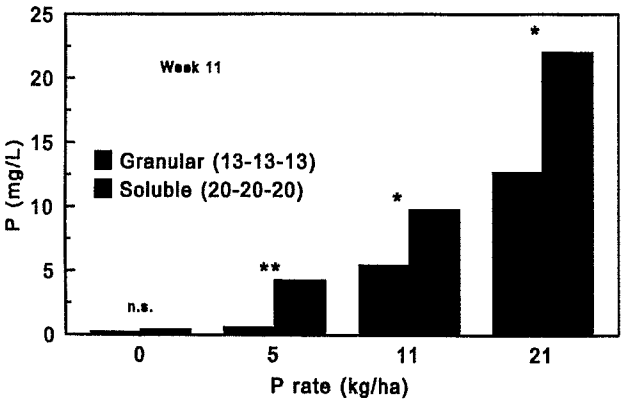

Figure 10. Concentrations of phosphorous through simulated green columns. Rates of applied were applied bi-weekly for a total of six times ceasing on week 11. *, ** indicate significance for sources at each rate (P = 0.05 or 0.01, respectively).

Innovative Water Quality Management Utilizing Wetlands Construction on a Golf Course

Purdue University

Ronald F. Turco

Start Date: 1998
Number of Years: 5
Total Funding: $125,000

Objectives:

Our objective is to evaluate the use of a "closed-loop" water in situ treatment system in terms of:

1. *Use of a golf course wetland to improve residential runoff.*
2. *Protection and improvement of a sensitive wetland environment.*
3. *Regeneration of water supplies for golf course use.*

Previous USGA-funded studies have documented the chemical makeup of water formed during golf course runoff and leaching events. Our work goes beyond monitoring to assess how innovative golf course water quality management, based around a constructed wetland, can reduce pollution from the golf course and from adjacent non-golf course sources. Not only do the wetlands accept water originating from the golf courses but also runoff from a watershed that includes a gas station, retail businesses and parking lots, over 500 residences, and two major city highways. The quality of water will be monitored throughout the system for nutrients, pesticides, salt, automobile fluids, and other possible contaminants.

Earlier results from across the country demonstrated that the quality of water originating from the golf course is expected to be good. We have established an innovative management scheme in which golf course runoff and urban runoff are passed through created wetlands and then used as the primary water source for golf course irrigation. This arrangement is designed to both reduce impacts from the golf course and commercial / residential runoff on an important wetland adjacent to the golf course and to provide a reliable source of water for golf course irrigation. This approach will provide a blueprint that allows for a reduction in golf course nutrient applications and groundwater withdrawals for irrigation.

This project is a model for any location where a golf course interfaces with natural areas or other high value property. The ability of the constructed wetland to remove contamination is being evaluated and documented. The use of the wetland system to clean and remediate roadway water and water from commercial and residential areas is also being followed. For locations where water is expensive or not available, this approach may prove to be an extremely useful way to improve water supply. This approach will add environmental value to the golf course. Roadway water that would have been directly discharged, untreated, to surface water now will be treated in the golf course wetland system before release.

Work to date has concentrated on the integration of the constructed wetland and the golf course. Purdue University's athletic department constructed the Kampen Golf Course that opened in the summer, 1998 adjacent to the new Turfgrass Research and Diagnostic Center. The Kampen Golf Course is a Pete Dye designed facility intended to display state-of-the-art environmentally sensitive golf course management as well as providing an excellent playing surface. In order to meet real and anticipated environmental problems, the Kampen golf course design includes a series of constructed wetlands between the course and the adjacent natural wetland. Moreover, the course is constructed to capture water from the adjacent city highway and residential area. The constructed wetlands will intercept and process runoff, tile water directly