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Researchers at Oklahoma State University conducted field studies to measure both nutrient (N and P) and pesticide (flutolanil, 2,4-D + mecoprop + dicamba, and chlorpyrifos) runoff from plots receiving both sprinkler irrigation and simulated rainfall. Runoff samples were collected from bermudagrass turf managed as golf course fairway for two years, 2006 and 2007. Runoff concentrations detected varied primarily by solubility, but pesiticide and nutrient losses from simulated rainfall did not differ from runoff losses caused by sprinkler irrigation.

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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 450 projects at a cost of $31 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 and Pesticide Losses Caused by Simulated Rainfall and Sprinkler Irrigation

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SUMMARY

Researchers at Oklahoma State University conducted field studies to measure both nutrient (N and P) and pesticide (flutolanil, 2,4-D + mecoprop + dicamba, and chlorpyrifos) runoff from plots irrigated from plots receiving both sprinkler irrigation and simulated rainfall. Runoff samples were collected from bermudagrass turf managed as a golf course fairway for two years, 2006 and 2007. Samples were collected in 5-minute intervals during runoff from four simulated rainfall and irrigation events and tested for nutrient and pesticide losses. Results include:

- Approximately 2.5% of the N applied was lost in irrigation runoff and the same amount (2.4%) was lost to simulation runoff.
- Total P lost was approximately 20.1% of that applied to the irrigated plots and 16.6% of that applied to simulated rainfall plots.
- The concentrations of 2,4-D collected in irrigation runoff accounted for 1.1% of that applied and accounted for 0.8% in simulation runoff.
- Approximately 3.5% and 3.1% of the mecoprop applied and 12.3% and 15.7% of the dicamba applied (analyzed for only one event) were lost to irrigation and simulation runoff, respectively.
- Chlorpyrifos was lost to irrigation runoff at 0.28% of that applied and lost to simulation at 0.14% of that applied.
- 15.1% and 15.7% of the flutolanil applied was lost to irrigation and simulation, respectively.
- Pesiticide and nutrient losses from simulated rainfall did not differ from runoff losses caused by sprinkler irrigation.

Research in crop production and turfgrass has identified grasslands, turfgrass stands, and grass buffer strips as impediments to nutrient and pesticide transport in runoff (7, 12, 13, 27). Dense grass stands have unique characteristics that encourage water to infiltrate soil and impede and filter runoff (10, 19). However, research has also demonstrated that the runoff-reduction characteristics that naturally occur in a dense turfgrass stand are not sufficient to prevent the substantial runoff caused by major storm events (2).

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Urban turfgrasses are usually managed to provide relatively high aesthetic and functional value. Maintenance applications of fertilizers and pesticides required to satisfy consumer expectations followed by major storm events can result in unsatisfactory product transport to surface water features. Normally, surface runoff from turf has little environmental impact (6). However, because maintenance applications of nutrients and pesticides are required to maintain color and density at commercially or socially acceptable levels, there is a danger that some portion of a recent nutrient or pesticide application may combine with surface water runoff and flow into adjacent water features.

Nutrient Runoff

An important environmental hazard caused by nutrient runoff is eutrophication (9). Low levels of nitrogen (N), mostly in the form of nitrate (NO_3^-), and dissolved reactive phosphorus (DRP), including $H_2PO_4^-$, HPO_4^{-2}, and PO_4^{-3}, can cause algal blooms resulting in a loss of oxy-

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gen in surface water. Eutrophication is responsible for the "dead zones" in the Mississippi Delta and the Chesapeake Bay, as well as numerous lakes and other water features throughout the world. At least one state, Minnesota, has passed legislation that restricts the application of phosphorus fertilizer to turfgrass (22). Nitrate in surface water at concentrations as low as 1 ppm (part per million) may lead to eutrophication (26). High NO_3^- levels in drinking water are also a human health hazard. The United States Environmental Protection Agency (USEPA) has established a drinking water standard of 10 ppm for NO_3-nitrogen (27).

Generally, about 99% of the phosphorus (P) in soils is unavailable for plant growth (3). Fertilizers are thus important as a source of plant-available P. Most inorganic fertilizers, however, are highly soluble, and if not properly applied, increase the risk of P loss to surface runoff (11). Dissolved reactive phosphorus can contribute to eutrophication at concentrations as low as 25 ppb (parts per billion) (4) and is typically the limiting factor for eutrophication of surface water (23).

Nutrient transport in surface runoff is affected by factors including rainfall or irrigation amount, intensity and duration of rainfall or irrigation, soil moisture, soil texture, slope, fertilizer application rate, and fertilizer formulation (10).

Pesticide Runoff

Pesticide loss from turf depends on factors such as pesticide chemical properties, soil type, turf species, thatch, application timing, and weather conditions (10, 21). Pesticides may be transported to surface water through runoff or eroded sediment. Cohen et al. (6) analyzed water quality data from eighteen studies on golf courses in the United States and one study in Canada. Thirty-one pesticide chemicals were detected in surface waters, nine exceeded maximum allowable concentrations for aquatic organisms, and five exceeded maximum contaminant levels for drinking water. The average concentration of the pesticides ranged from 0.07 to 6.8 ppb.

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Transport of pesticides such as 2,4-D [(2,4-dichlorophenoxy) acetic acid], dicamba (3,6-dichloro-2-methylphenoxy-benzoic acid), and mecoprop [(±)-2-(4-chloro-2-methylphenoxy)-propanoic acid] in runoff from turfgrass can be significant if the soil is saturated and rainfall duration and intensity is high. Smith and Bridges (25) for instance, found that 9%, 14%, and 13% of the applied 2,4-D, dicamba, and mecoprop, respectively, from hybrid bermudagrass [*Cynodon dactylon* (L.) x C. *transvaalensis* Burtt-Davy] during four simulated rainfall events over an 8-day period, was lost to runoff. Researchers have concluded that the greatest mass and concentration of pesticides in runoff from a turf area occurs during the first significant runoff event after pesticide application (7, 18, 25), and the amount of pesticide loss is primarily related to its solubility (24).

Turf as a Deterrent to Runoff

Krenitsky et al. (16) compared natural and man-made erosion control materials and turfgrass. They found that tall fescue (*Festuca arundinacea* Schreb.) sod was an effective material for delaying the start of runoff and decreasing total runoff volume. Gross et al. (12, 13) studied nutrient and sediment losses from turf and found that turfgrass alone (without buffers) effectively reduced nutrient and sediment losses compared with bare or sparsely vegetated soil. Linde and Watschke (17) found that sediments in runoff were low even after vertical mowing of creeping bentgrass (*Agrostis stolonifera* L.) and perennial ryegrass (*Lolium perenne* L.) turf. Wauchope et al. (28) investigated pesticide runoff from bare soil plots compared with grassed plots and determined that the bare plots required one-third less precipitation to produce the same amount of runoff and yielded twice as much sediment as the grassed plots.

Harrison et al. (14) determined nutrient and pesticide concentrations in runoff from sodded Kentucky bluegrass (*Poa pratensis* L.). Plots were fertilized with N, P, and K in a maintenance program typical of golf course turf in the northeast United States. Irrigation at rates of 3 inches per hour and 6 inches per hour for one hour was applied one week prior to and two days following fertilizer applications. The researchers reported that nutrient concentrations in runoff remained low throughout the experiment and generally were no higher than the concentrations found in the irrigation water. However, the N concentrations in runoff were as high as 5 ppm, and dissolved P concentrations were as high as 6 ppm. Both N and P nutrient concentrations were above those that can cause eutrophication of surface waters. The researchers concluded that under the conditions studied, nutrient runoff from established turfgrass areas was low due to low runoff water volume and was not affected by establishment method.

Gross et al. (12) studied nutrient and sediment loss from sodded tall fescue and Kentucky bluegrass plots. The plots were sodded on land that was previously cropped to tobacco (*Nicotiana tabacum* L.). Slope at the site was 5% to 7%. Plots were fertilized with either urea dissolved in water as a liquid application or urea as a granular application at a rate of 4.5 pounds N per 1000 square feet per year. Control plots were not fertilized. Nutrient and sediment losses were low for all replications. The researchers concluded that nutrient and sediment runoff from turfgrass areas is low, especially when compared with a previously cropped tobacco runoff study (12).

Gross et al. (13) studied runoff and sediment losses from tall fescue stands of various densities under simulated rainfall conditions. Plots were established at seeding rates of 0, 2, 5, 8, and 10 pounds per 1000 square feet in September 1986. Simulated rainfall was applied at intensities of 3, 4, and 5 inches per hour in June 1987. The highest runoff volume was observed from the non-seeded plots at each of the rainfall intensities applied. Runoff volume was not statistically different among the seeding rates. The researchers also recorded visual quality, density, and tiller counts. They concluded that even low-density turfgrass stands can significantly reduce surface water runoff from well-maintained turfgrass areas.

Kauffman III and Watschke (15) studied phosphorus and sediment runoff from creeping bentgrass and perennial ryegrass following core

Nutrient or Product	2006 June 8 target	2006 June 8 actual	2006 August 18 target	2006 August 18 actual	2007 July 7 target	2007 July 7 actual	2007 September 22 target	2007 September 22 actual
	pounds active ingredient per acre							
nitrogen	N/A*	36.60	N/A	35.50	N/A	21.90	N/A	30.50
phosphorus	N/A	16.50	N/A	7.10	N/A	16.90	N/A	11.70
flutolanil	8.60	5.66	10.75	8.73	1.90	1.28	4.30	1.84
2,4D	0.24	0.18	0.24	0.22	0.24	0.18	0.24	0.11
mecoprop	0.12	0.09	0.12	0.12	0.12	0.09	0.12	0.06
dicamba	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
chlorpyrifos	1.00	0.81	1.00	1.00	1.00	0.82	1.00	0.53

*nutrient rates were determined by a random selection of spreader settings

Table 1. The target application rates and actual measured nutrient and pesticide application rates by event. Calibration of a CO_2-powered bicycle sprayer equipped with a speedometer and handled by two different experienced operators did not guarantee that the rate desired was the same as the rate applied.

aeration. They concluded that the DRP concentrations found in the runoff and the minimal soil erosion that occurred should not be considered a serious threat to surface waters. When turfgrass is healthy and dense it is an effective deterrent to off-site transport of nutrients and pesticides in runoff. Easton et al. (10) reported that the establishment of turfgrass on bare soil increased soil infiltration by more than 65% over a two-year period. As shoot density increased, infiltration rate increased and runoff decreased.

Nonetheless, turfgrass sites can contribute to nutrient and pesticide losses to surface water in concentrations greater than recommended. It is the turfgrass manager's responsibility as environmental steward to practice management techniques that limit runoff transport of potentially dangerous nutrients and pesticides. We used a rainfall simulator and typical sprinkler-type irrigation system for turf to create runoff and measured runoff losses of nutrients and pesticides to determine how much product was lost to runoff during a severe precipitation event. We also wanted to determine if the two precipitation systems differed in the amount of nutrients and pesticides lost to runoff, and whether or not the application rate of the products caused a significant difference in the amount product lost.

Methods

The research was conducted on the Oklahoma State University Turfgrass Runoff Research Site, Stillwater, OK on a Norge silt loam (fine-silty, mixed, active, thermic Udic Paleustolls) with an infiltration rate of less than 0.5 inch per hour. The runoff site was divided into whole plots of event containing subplots of simulated rainfall and sprinkler irrigation replicated twice. The subplots (simulation and irrigation blocks) consisted of two experimental units each that measured 20 ft (6 m) wide with a uniform 5% slope that measured 80 ft (24 m) long.

The site was graded and sodded with 'U-3' bermudagrass in the summer of 1998 and has been used for runoff research since 2000. An in-ground sprinkler-type irrigation system that delivered a precipitation event of 1.61 inches per hour (41 mm h^{-1}) was used to force runoff on the irrigation plots. A rainfall simulator designed after the Coody-Lawrence patented system and adjusted for peak sprinkler performance by Mark Carroll at the University of Maryland (5) was used to supply simulated rainfall at 1.51 inches per hour (38 mm h^{-1}).

Our irrigation system could not supply

sufficient water to operate the irrigation system on two plots and the simulator system on two plots simultaneously, so the simulator was supplied with water through a fire hydrant fed from a reservoir by gravity flow. The Christiansen's coefficient of uniformity (1) for the simulator averaged 78% compared with 80% for the irrigation system. To maintain experimental precision, the two plots that generated precipitation using the simulator system in 2005 were exchanged to receive irrigation in 2006, and the two plots that received irrigation in 2005 received simulation in 2006. The turf was mowed at 0.5 inches (13 mm) three times per week to simulate a golf course fairway.

Rain events were simulated on June 8 and August 18, 2006, and July 17 and July 22, 2007. The site was irrigated to runoff 24 hours before fertilizers and pesticides were applied to help maintain consistent antecedent soil moisture for each event. Samples were collected at this time to test for residual pesticides, but none were detected.

Simulated rainfall and irrigation were applied 24 hours after fertilizer and pesticide application to create runoff and sustained for 90 minutes after runoff began. Runoff samples were collected until runoff stopped which consistently occurred 15 minutes after irrigation or simulation ceased. Isco 6700 portable samplers (Isco, Lincoln, NE) with ultrasonic modules (Isco 710) mounted over each Parshall flume were programmed to collect samples in 5-minute intervals and to measure runoff flow rate in 1-minute intervals.

Nutrient and Pesticide Applications

In addition to N from urea and P from triple superphosphate, a fungicide, flutolanil (Prostar, Bayer Environmental Science, Research Triangle Park, NC), a broadleaf herbicide, 2,4-D plus mecoprop plus dicamba (Trimec Classic, pbi/Gordon, Kansas City, MO), and an insecticide, chlorpyrifos (Dursban, Dow Agrosciences, Indianapolis, IN) were applied prior to each event. The 2,4-D was applied at 0.24 pound (lb) active ingredient (ai) per acre, mecoprop at 0.12 lb ai/acre, and dicamba at 0.02 lb ai/acre.

These herbicide application rates were very low to allow for comparison with trials at

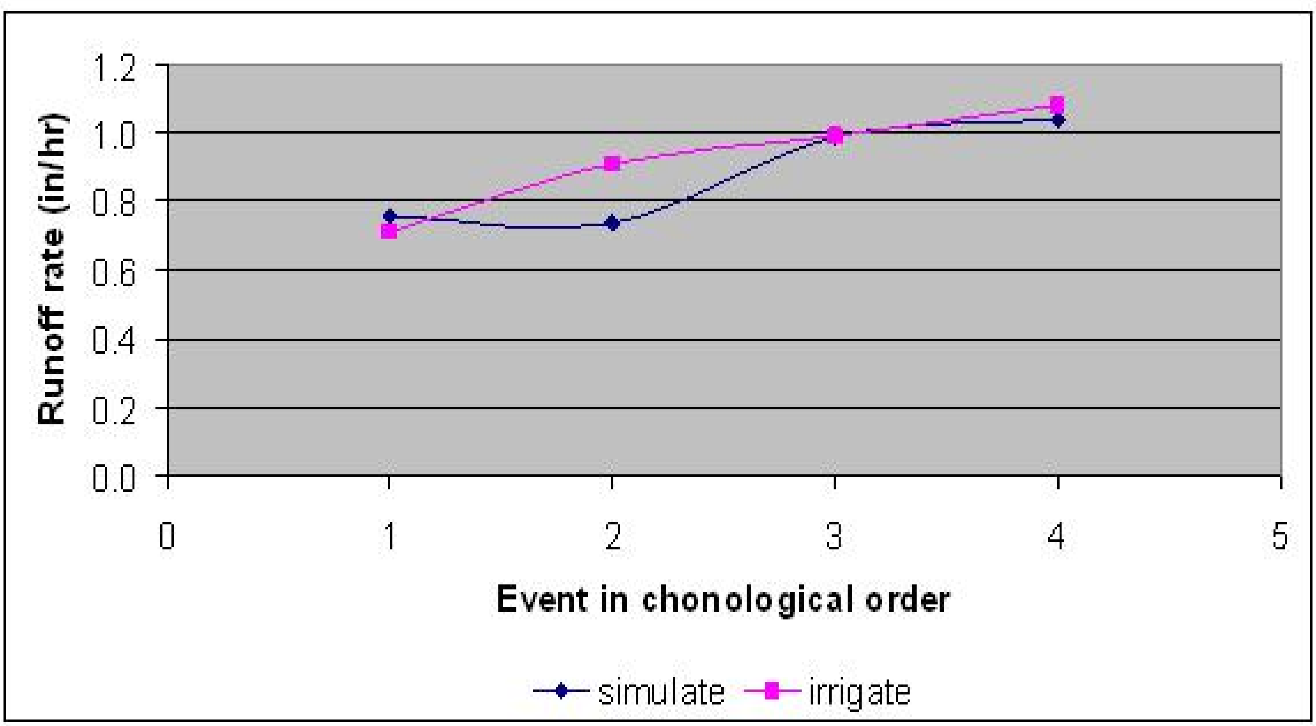

Figure 1. Mean runoff from four simulated rainfall events in 2006 and 2007 produced from a rainfall simulator (n=8) and a turfgrass irrigation system (n=8).

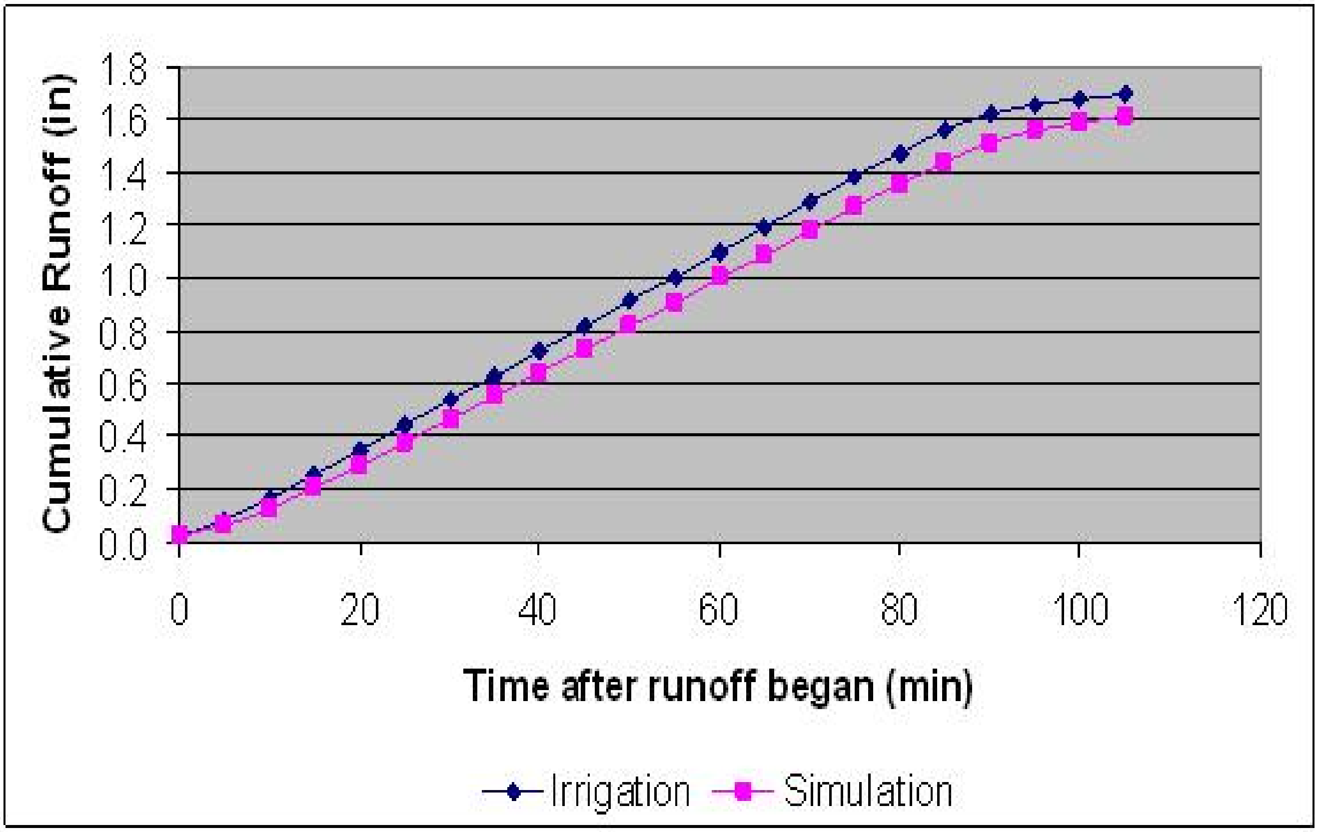

Figure 2. Mean runoff from four precipitation events in 2006 and 2007 produced by a rainfall simulator (n=8) and a turfgrass irrigation system (n=8). The irrigation system produced precipitation at 1.61 in/hr and the simulator produced precipitation at 1.51 in/hr accounting for the slight,but statistically significant, difference in cumulative runoff between irrigation and rainfall simulation.

other sites where creeping bentgrass (*Agrostis stolonifera*) was used as fairway in similar studies instead of bermudagrass. Chlorpyrifos was applied at 1.00 lb ai/acre. Flutolanil applications were made at high rates and varied by event to investigate the relationship between flutolanil applied and flutolanil lost in runoff. Nitrogen and P applications varied by event for the same reason and were determined by random selection of spreader settings.

Analytical Procedures

Water samples were analyzed for NO_3-N and NH_4-N using colorimetric methods by automated flow injection analysis and DRP using the phosphomolybdate colorimetric procedure employed by Murphy and Riley (20). The detection limit was 0.01 ppm for each nutrient in the runoff water samples. The average background levels of nutrients in the irrigation water samples were 2.7 ppm for total N (NO_3-N + NH_4-N) and 5.8 ppm for DRP and 2.5 ppm total N and 7.0 ppm DRP in simulated rainfall samples. The concentration of NO_3-N, NH_4-N, and DRP in the precipitation was measured during each event and subtracted from the measured concentrations in collected runoff before statistical analyses were performed.

Comparison of Runoff Losses During Rainfall Simulation and Irrigation

The irrigation system produced precipitation at 1.61 inches per hour and the simulator produced precipitation at 1.51 inches per hour. This difference in precipitation rate caused a slight difference in runoff rate (Figure 1). Runoff from the irrigated plots averaged 0.93 inches per hour and runoff from the rainfall simulator plots averaged

0.88 inches per hour. However, the differences in runoff flow rate between irrigation and simulation were not statistically significant. The amount of runoff that occurred during individual precipitation events differed in spite of considerations such as uniform plot size and slope, individual flume calibrations, and steps to maintain uniform antecedent soil moisture designed to improve consistency.

Differences in water pressure primarily from the gravity-fed rainfall simulator resulted in variation among runoff flow rates by event (Figure 1), but these differences were not significant nor was there significant interaction between precipitation sources and events. However, the clear difference in precipitation rate between the irrigation system at 1.61 inches of precipitation per hour and the simulator system at 1.51 inches per hour caused a significant difference in cumulative runoff between the two systems (Figure 2). Consequently, the runoff flow rates recorded for irrigation were adjusted downward by a factor of 1.51/1.61 prior to analysis of cumulative nutrient and pesticide losses.

Results

A total accumulation of 1.67 inches of irrigation runoff was lost from a single plot during each event. A total accumulation of 1.59 inches of runoff was lost from each rainfall simulator plot. After adjusting by multiplying irrigation runoff by a factor of 1.51/1.61 total irrigation runoff was reduced to 1.57 inches making total runoff losses from irrigation and rainfall simulator nearly equal.

Approximately 2.5% of the N applied was lost in irrigation runoff and the same amount (2.4%) was lost to simulation runoff. The total P lost was approximately 20.1% of that applied to the irrigated plots and 16.6% of that applied to simulated-rainfall plots. Neither P loss nor N loss from irrigation and simulation were significantly different, nor did losses differ for any pesticide.

The concentrations of 2,4-D collected in irrigation runoff accounted for 1.1% of that applied and accounted for 0.8% in simulation runoff. Approximately 3.5% and 3.1% of the mecoprop applied and 12.3% and 15.7% of the dicamba applied (analyzed for only one event)

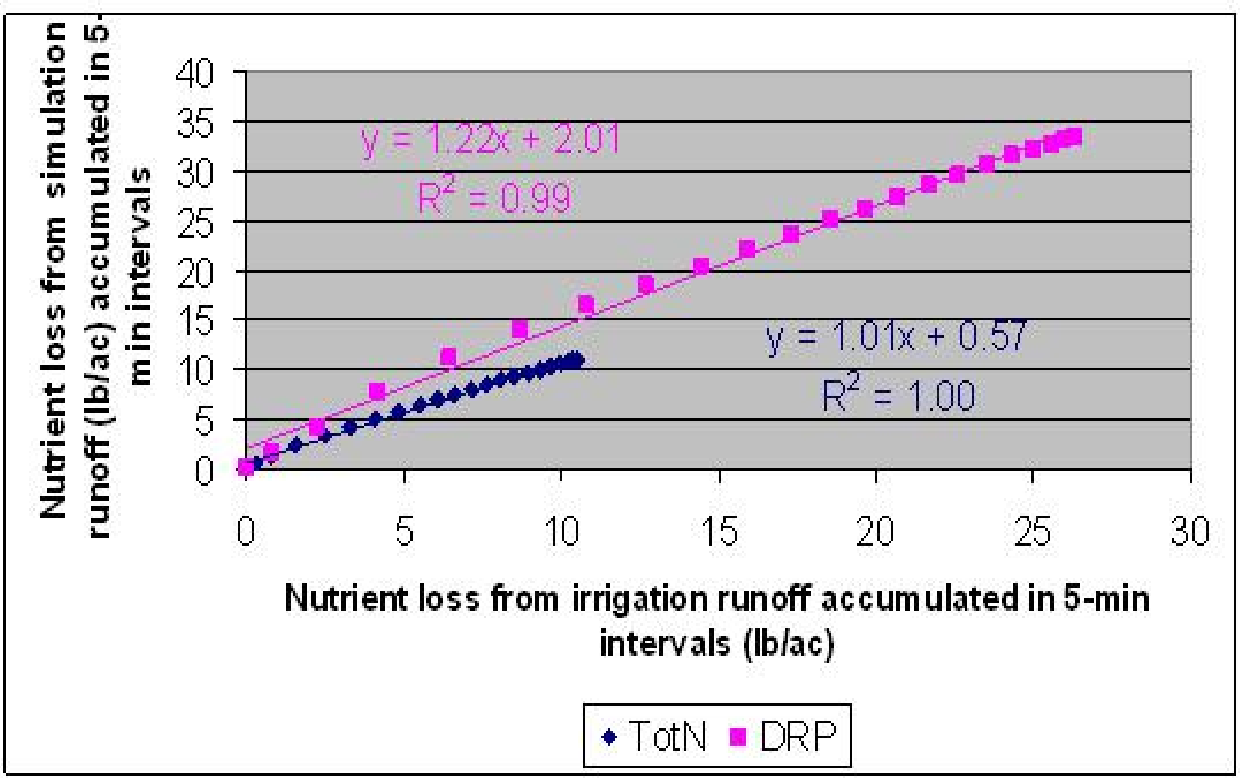

Figure 3. A comparison of nutrients lost to simulation and irrigation runoff accumulated in 5-minute intervals.

were lost to irrigation and simulation runoff, respectively. Chlorpyrifos was lost to irrigation runoff at 0.28% of that applied and lost to simulation at 0.14% of that applied. Approximately 15.1% and 15.7% of the flutolanil applied was lost to irrigation and simulation, respectively. None of these results differed significantly by precipitation type demonstrating that irrigation or simulated rainfall applied to bermudagrass turf did not differ in their influence on runoff or nutrient and pesticide losses.

Comparisons of Product Applied Versus Product Lost in Runoff

The amount of P applied did not significantly affect the amount of P lost to runoff. The amount of N applied also did not significantly affect the amount of N lost, nor did the amount of flutolanil applied significantly affect the amount of flutolanil lost. However, the work does suggest that the amount of nutrient or pesticide applied has some effect on the amount lost. Averaged over all plots and events (n=16) regardless of precipitation type, 0.2% of the chlorpyrifos, 15.4% of the flutolanil, 3.3% of the mecoprop, and 1.0% of the 2,4-D was lost in runoff. Dicamba losses were only assessed for one event (June 18, 2006) and amounted to 14.0% of that applied. Dicamba was the most soluble pesticide applied, and although it was only applied in a very small amount, 14.0% of it was lost in runoff demonstrating how easy it is to lose a highly soluble product to runoff.

Of the remaining pesticides, chlorpyrifos has poor solubility, flutolanil has medium solubility, and mecoprop and 2,4-D have high solubilities. With the exception of flutolanil, pesticide losses in runoff followed what would be expected according to pesticide solubility with chlorpyrifos having very low loss rates and mecoprop and 2,4-D demonstrating higher losses. However, it must be remembered that flutolanil was applied at very high rates (4.4 pounds per acre on average), and mecoprop (0.09 pounds per acre) and 2,4-D (0.17 pounds per acre) were applied at very low rates. In fact, 49 times more flutolanil was applied than mecoprop and 26 times more flutolanil than 2,4-D. It is likely that the large difference in application rates affected the high loss rates of flutolanil and the low loss rates of mecoprop and 2,4-D.

Consequently, the fact that application rates did not significantly affect the cumulative losses of nutrients and pesticide applied does not necessarily indicate that application rate did not influence the amount of product lost. More likely, there are other contributing factors that collectively interfered with a direct relationship between product applied and product lost. Perhaps future research will determine more about additional factors that need to be considered when attempting to determine the amount of product likely to be lost during a measured runoff event.

In the meantime, high application rates should be considered more likely to generate high runoff losses than low application rates. Although runoff research has demonstrated that high losses of nutrients and pesticides from turfgrass systems are unlikely, the relatively huge losses of P (18.4% of applied) and flutolanil (15.4% of applied) in this study demonstrate what can happen when nutrients and pesticides are applied 24 hours after soil saturation and a severe rainfall event occurs 24 hours after application.

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