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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 350 projects at a cost of $29 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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Turfgrass Runoff Investigations: Does Plot Size Matter ?

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SUMMARY

There is concern about the applicability of results obtained from small-plot turf investigations to larger turf areas such as a golf course fairway. A runoff facility was constructed at the University of Maryland to examine the effect of plot size on pesticide fertilizer runoff. Chemical runoff was examined during a single high-intensity rainfall event that took place one day after applying a three-product pesticide tank mix and granular forms of N and P. The study's findings include:

- Plot size had no effect on the runoff of foliar applied pesticides or on urea total N losses.
- Greater P runoff from the large size plots was attributed to mass transport of triple superphosphate granules in large streams of runoff that developed within the these plots during the rainstorm event.
- The high chemical runoff losses observed in this study were the result of wet soil conditions, not watering granular products in after application, and the short time interval between the application of the chemicals and the rain storm event.
- Scheduling chemical applications around weather conditions that favor near-term runoff generating storm events is one of the most powerful management tools superintendents have at their disposal to minimize chemical transport to surface waters.

In some ways research scientists are no different than individuals in any other profession. We all look for the simplest way to get things done. Take turfgrass runoff research, for instance. Ask a turfgrass researcher if they would they would rather investigate turf chemical runoff from 5000-ft^2 plots or from more modest sized plots, say ones that were 10 to 20 times smaller, most researchers would probably respond by saying they would rather work with the smaller-sized plots.

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Why do turf researchers prefer to work with smaller plots? There are host of reasons. Small plots allow multiple treatments to be examined without utilizing large blocks of land. This makes it relatively easy to develop plots with uniform field conditions (ie., slope, soil type). The use of small plots also avoids the need to apply large volumes of water to generate runoff. This eliminates complications associated with securing adequate water resources in remote locations, sampling large volumes of runoff, and transporting large rainfall simulators around the field. It is also much simpler to shield small plots from undesirable environmental conditions, such as wind and rain, compared to large plots.

This last point is an important consideration when a primary focus of the research is to evaluate how timing of a rainfall event affects chemical runoff. The ability to simulate rainstorms at specific time intervals is one of the primary reasons why researchers use rainfall simulation devices. Rainfall simulation devices are also used because well-designed ones are good at replicating the rainfall droplet size and kinetic energy distribution that occur during high-intensi-

Simulation rainfall events are often conducted at night, or near daybreak, to take advantage of near windless conditions.

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Plot dimensions (m)	Area (m^2)	Area (ft^2)	Source Reference
1 x 10	10	107	Gross et al. (3)
1.2 x 2.4	2.8	31	Wauchope et al. (14)
3.7 x 7.4	27.3	295	Smith and Bridges (9)
1.8 x 9.8	17.6	190	Cole et al. (2)
6.5 x 19	123	1,329	Linde and Watschke (5)
3.7 x 7.4	27.3	295	Hong and Smith (4)
3.7 x 7.4	27.3	295	Ma et al. (6)
3.7 x 7.4	27.3	295	Armbrust and Peeler (1)
3.7 x 7.4	27.3	295	Shuman (11)
3.7 x 7.4	27.3	295	Shuman (12)
12.2 X 24.4	198	3,203	Moss et al. (7)
12.2 X 24.4	198	3,203	Moss et al. (8)

Table 1. Plot dimensions used in turf simulation rainfall chemical runoff investigations

ty storm events. They do this by delivering simulated rainfall from a height of at least 9 feet. A breeze that is barely perceptible to someone standing on the ground can drastically alter the performance of a rainfall simulator that operates from this height. The only way to deal with unexpected wind when using a "high elevation" simulator is to surround the plot with a barrier that blocks the wind. This is only practical for small plots. In temperate humid climates, windless conditions frequently prevail late at night. As a result, simulation rainfall events are often conducted at night, or near daybreak, to take advantage of this condition when working with large plots.

Agricultural crop researchers use large plots because it allows them to capture the effect of large agricultural equipment factors (ie., tire tracks, and groove patterns) on chemical runoff. There are also management practices such banded fertilizer applications and pesticide applications made to the canopy of large crop plants that make it necessary to use large plots (15) to examine chemical runoff from agricultural crops. Turfgrass equipment is generally smaller than agricultural equipment. This along with the factors mentioned previously has lead to the wide spread use small plots in turf chemical runoff investigations (Table 1).

Research on agricultural crops however, has shown runoff and chemical transport from small plots is often substantially higher than from large plots on a unit area basis (10, 16). This has raised questions about the applicability of using small-plot data to characterize chemical runoff losses from larger areas, such as a whole field or, in the case of turf, a golf course fairway.

Processes that affect chemical transport such as sediment transport are more realistically represented in large plots than in small plots. These processes are of minimal importance in turf. This suggests that plot size will have less effect on turf chemical runoff than runoff losses from crops that do not fully shield the soil from impacting raindrops and the erosive forces of moving water. Data in support of this line of reasoning is lacking and is needed to support extending the results small-plot turfgrass runoff investigations to larger scales of measure.

In 2002 and 2003, a runoff facility was constructed at the University of Maryland Paint Branch Turfgrass Center to evaluate the effect of plot size on chemical runoff. McDonald and Son's, a National Golf Course Construction Company, donated their time and equipment to grade an existing hillside into a multi-tier plot runoff facility. The facility consists of three repli-

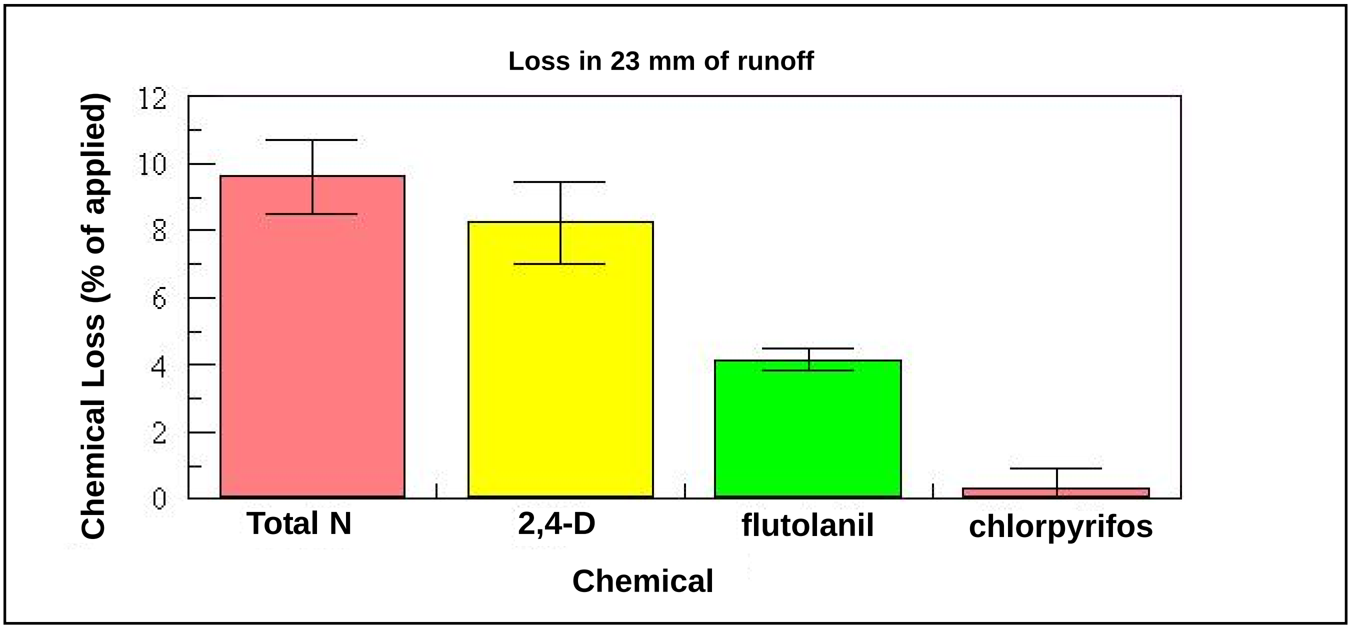

Figure 1. Two-year average chemical runoff losses for total N, 2,4-D and flutolanil, and average lost of chlorpyrifos for the 2006 runoff event only (% of applied)

cates of two plots sizes, with each plot having a 3.5% slope. The small plots are 13 m x 9.1 m (12 ft x 30 ft = 360 ft^2), making them similar in size to those used in previous turf runoff investigations (Table 1). The large-size plots are 12.2 m by 38.1 m (40 ft by 120 ft = 5000 ft^2), which places them in the nearly-field scale or meso-plot category (15). The plots were seeded with 'L-93' creeping bentgrass in spring of 2003. The turf was maintained using fairway management practices typical of the mid-Atlantic region of the United States for the duration of the study.

Experimental Methods

Chemical runoff was evaluated by applying urea and triple superphosphate granules and a tank mix of Prostar (flutolanil) and Dursban (chlorpyrifos) and Three-Way Bentgrass Selective (2,4-D, MCPP, dicamba) to the plots. Neither the granular material nor the tank mix was watered-in after application. Approximately 24 hours after the application, a 36 mm hr^{-1} (1.4 inch hr^{-1}) simulated rainstorm was applied to the plots for the time needed to initiate runoff, plus 90 additional minutes. Runoff from the lower end of the plots was directed to a flume where flow was continuously monitored by a bubble-flow meter. Manual measurements of flow were also collected from the small-size plots by measuring the amount of water exiting the flume over specific periods of time.

Water samples were collected every five minutes for the first 90 minutes of runoff in 2005. In 2006, the sampling period was extended to include the entire period of time runoff was observed from the plots. At the end of the event, the samples were placed into a freezer for later chemical analysis. A portion of each sample was not frozen upon collection but instead was used to determine the amount of suspended solids in present in runoff at the time of collection. The concentration of 2,4-D, flutolanil, and chlorpyrifos in the samples were determined by direct injection high performance liquid chromatography (HPLC) analysis. Analysis of chlorpyrifos in runoff was limited to the runoff samples collected in 2006.

Results

Our interest was in seeing how chemical runoff losses varied with plot size for equivalent amounts of runoff. To evaluate chemical runoff losses on this basis, we compared the amount of chemical that was loss once 23 mm (std error = +/-

Figure 2. Two-year average total phosphorus losses in 23 mm of runoff (% if applied P)

0.3 mm) of runoff had occurred from each plot. This amount was selected because it represented the smallest total runoff depth observed from any plot for which runoff chemical concentration data is available.

Statistical analysis of the sprayed materials revealed that plot size had no effect on pesticide runoff losses. When expressed as a percent of the amount applied, pesticide runoff losses followed a pattern than was consistent with the water solubility of the active ingredient (Figure 1). Runoff losses were greatest for water soluble (4500 ppm) 2,4-D and least for water insoluble (0.1 ppm) chlorpyrifos. Flutolanil, which has a relatively low water solubility (10 ppm), had chemical runoff losses between 2,4-D and chlorpyrifos.

Our pesticide runoff data are consistent with the principal that runoff losses of sprayed materials are the result of washoff of the chemicals from the leaf surface. The susceptibility of an organic chemical to washoff from the leaf surface is largely dependent on the water solubility of the chemical. Organic chemicals having low water solubilities are usually more resistant to leaf surface washoff than are organic chemicals that are readily soluble in water. Once washed off the leaf, water soluble organic chemicals remain in runoff as it moves through thatch and verdure. It is interesting to note that even though the plots were mowed and the clipping returned the day before applying the chemicals, very few clippings were seen in the runoff. This suggests that the transport of clippings is not a major avenue by which pesticides are lost in runoff from turf.

Results for the granular materials were somewhat different than that for pesticides. Plot size had no effect on the urea nitrogen runoff losses. Phosphorus runoff losses however, were greater from the large plots than from the small plots (Figure 2). At first, we thought because P is tightly bound to soil, differences in sediment losses from the two plot sizes would explain our results. Total suspended solids losses, however, were similar for the two plots sizes, indicating the different phosphorus loss rates seen in the two size plots can not be attributed to different amounts of sediment being lost from the large versus small plots. We believe the divergent results obtained for total P losses can be explained by the closed nature of a bentgrass canopy and the low water solubility of triple superphosphate.

The short mowing height used to maintain creeping bentgrass creates a dense carpet-like surface. This carpet-like surface inhibits the fall through of large size granules. Unlike urea granules, triple superphosphate granules do not dissolve in the first few minutes of a rainstorm. As the duration of a simulation rainstorm is extended, overland flow within plots becomes less "sheet-like". In large plots, overland flow becomes concentrated in a few fast moving streams about 30 minutes after the initiation of runoff (Figure 3). Partially dissolved triple superphosphate granules are likely swept up by these streams and are transported to the collection trough located at the base of a plot. Non "sheet like" overland flow also occurs in small plots too, but stream development is far less extensive in these plots mainly because of the shorter down-slope travel distance encountered in these plots.

Perspective on Chemical Runoff Losses

Total chemical runoff losses of 2,4-D and P in this study were similar to those reported by others (9, 12) and demonstrate that turf chemical runoff can be quite large if a protracted high-

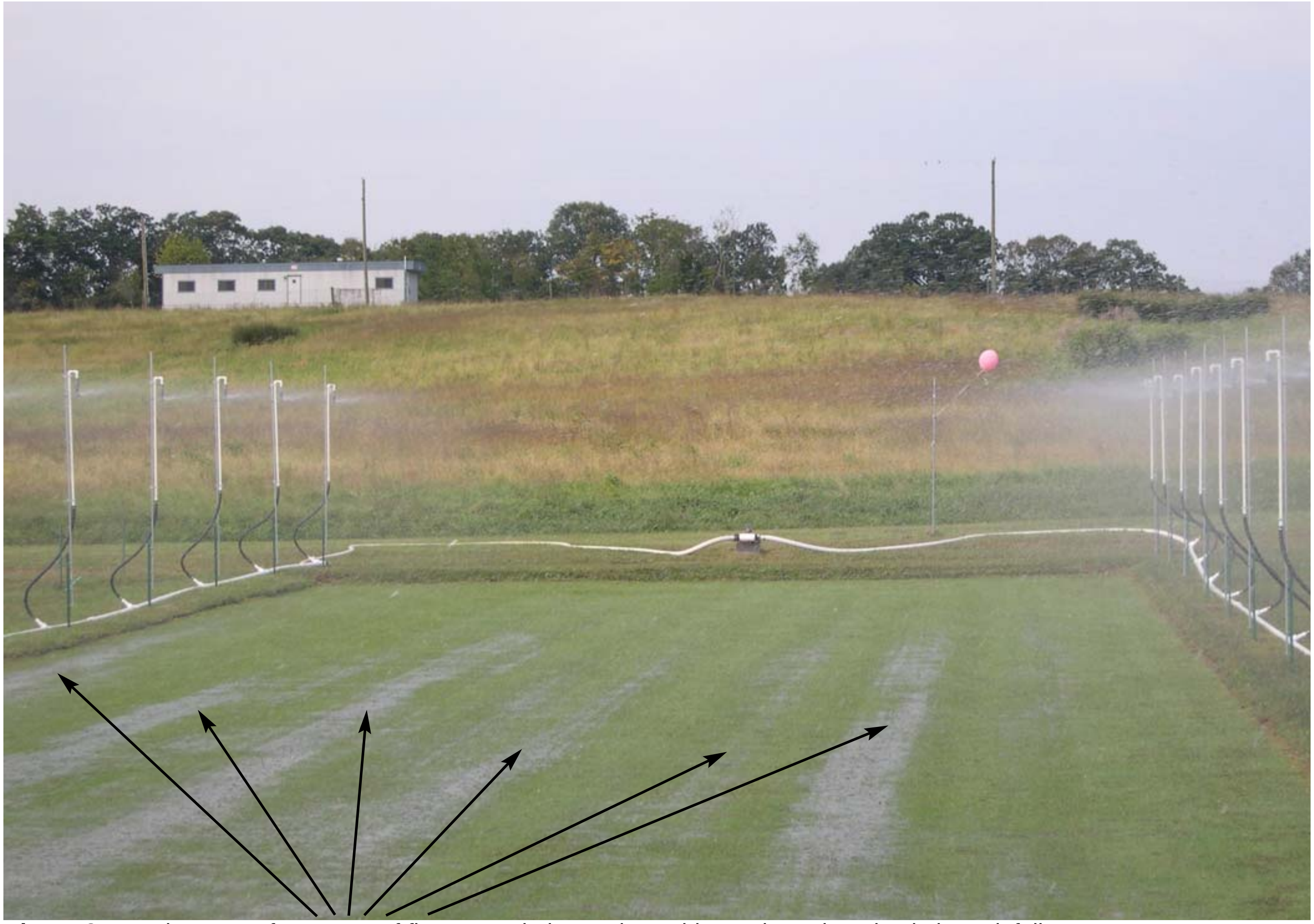

Figure 3. Development of "streams of flow" seen in large plots mid way through a simulation rainfall event

intensity rainfall event occurs within 24 hours of applying chemicals to turf. The return frequency for a 36 mm hr-1 storm that generates 23 mm of runoff at our runoff facility occurs every one to two years. Thus, the rain storm associated with the chemical runoff losses we observed does not occur very frequently, but is by no means a rare rainfall event.

The results of this study, along with those reported by others, emphasize the importance of avoiding making chemical applications when weather conditions favor the occurrence of a high-intensity rainfall event. Scheduling chemical applications around near-term weather conditions that favor runoff-generating storm events is one of the most powerful management tools superintendents have at their disposal to minimize chemical transport to surface waters. One improperly timed fertilizer or pesticide application has the potential to undo many of the benefits that may be derived from other best management practices that have been implemented on a golf course.

One best management practice not followed in this study was watering-in the granular fertilizer materials after applying them to the turf. Schuman (11) has shown previously that granular P runoff losses can be reduced by nearly 75% by simply insuring granular forms of P are watered-in shortly after application. In the case of low-mowed bentgrass, watering low-water-solubility granules into the canopy will reduce the potential for these granules to float in overland streams of runoff. It also needs to be pointed out that fertilizer and pesticide applications in this study were made when the surface soil was close to field capacity. This is a situation that should be avoided when applying chemicals to turf.

The results of this study show that when it comes to the evaluation of foliar-applied pesticides, plot size does not influence turf chemical runoff losses. This is in direct contrast to earlier agricultural crop plot size chemical runoff investigations and likely reflects the overriding effect short dense vegetative cover has on preventing chemical transport. Our results are among the first to show that chemical runoff results obtained from small-plot turf areas are equally valid at larger scales of measure, for both foliar-applied pesticides and water-soluble granular products. This does not, however, appear to be the case for granular materials that are not readily soluble in water and have not been watered-in prior to a high-intensity rainfall event.

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