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Researchers at Oklahoma State University conducted a five-year study to measure the loss of N and P caused by natural rainfall from a common bermudagrass fairway managed with typical fertilization and irrigation practices. Among their findings, in a worst case scenario during a season of near record rainfall, they estimated that a fairway they studied would lose around 1.3% of the N and 7.7% of the P applied as fertilizer.

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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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Natural Rainfall Runoff from a Bermudagrass Golf Course Fairway

Gregory E. Bell and Kyungjoon Koh

SUMMARY

Researchers at Oklahoma State University conducted a five-year study to measure the loss of N and P caused by natural rainfall from a common bermudagrass fairway managed with typical fertilization and irrigation practices. The study found:

- Natural rainfall tends to occur in a somewhat consistent pattern and that pattern is not consistent with simulated rainfall.
- There was a nearly perfect relationship between the amount of natural rainfall runoff that occurred and the amount of nutrient lost. The effect of variation in nutrient concentrations was negligible.
- We estimated that under slightly dry but relatively normal conditions, a bermudagrass golf course fairway on a 5% slope in Stillwater, OK was likely to lose around 0.5% of the N applied and 2.0% of the P applied as fertilizer.
- In a worst case scenario, during a season of near record rainfall, this same fairway would lose around 1.3% of the N and 7.7% of the P applied as fertilizer.

Golfers prefer excellent playing conditions and in some cases, demand them. Therefore, golf course fairways tend to be highly fertilized compared with most turfgrass areas. Proper fertilization promotes good turf cover, high turf density, rapid divot recovery, and minimal weed encroachment. There is a slight, but nonetheless dangerous, possibility that a small portion of the fertilizers applied to golf course fairways could dissolve in surface water runoff and contaminate lakes, streams, and other water features.

Runoff from Golf Course Fairways

Environmentally sound golf course management is a major factor in most superintendents'

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maintenance programs and the danger of nutrient runoff is small, but, nonetheless, present. Most turfgrass sites such as home lawns and parks are not irrigated, so it is a common practice to apply fertilizer just prior to predicted rainfall. This can be dangerous to the environment because the first rainfall event following fertilization is the most likely event to produce nutrient runoff (1). Fairways, on the other hand, are usually irrigated. Consequently, golf course superintendents do not apply fertilizer when rainfall is predicted. Instead, they fertilize during dry periods and use light irrigation to water-in the fertilizer. This practice substantially reduces potential nutrient losses in runoff (2).

The density of the turf on the fairway or in the rough also has an impact on runoff (1,3). Golf course superintendents strive to maintain full turf cover and maximum turf density reducing the likelihood that runoff will occur. The presence of turf is a strong deterrent to runoff even if additional runoff management is not performed. Even under worst-case conditions where fertilizer was applied to turf but not watered-in and a major



The Oklahoma State University Turfgrass Runoff Research Site in 2003.

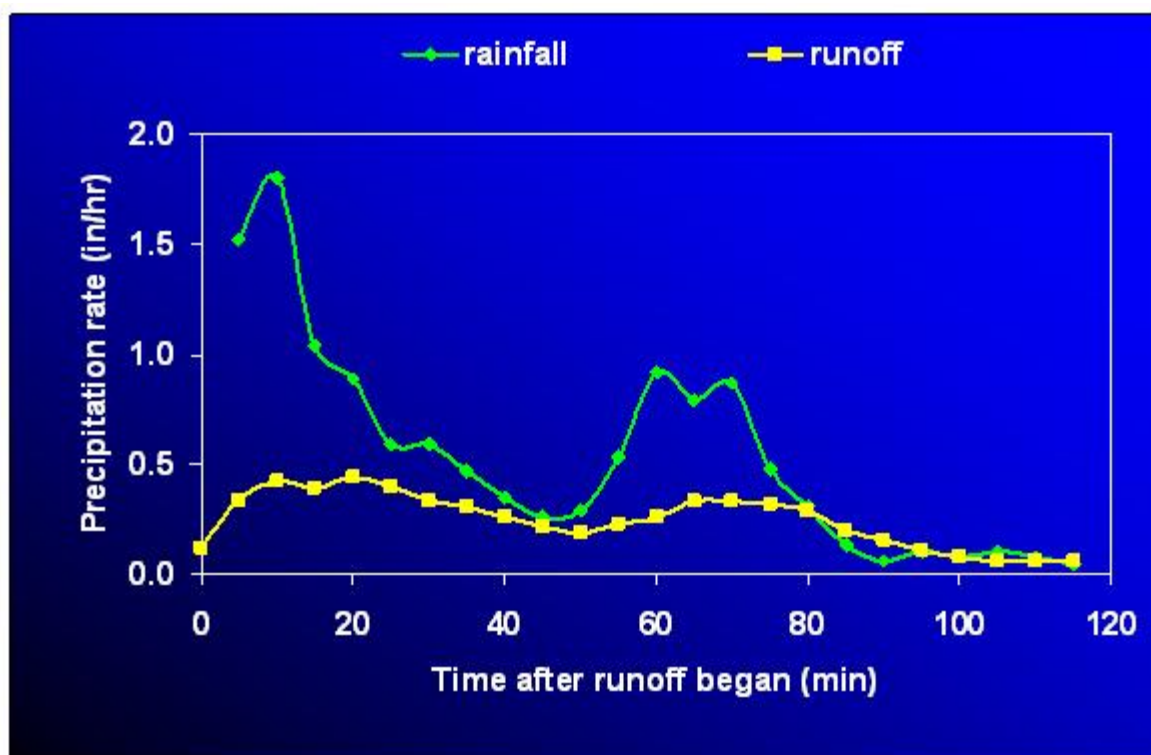


Figure 1. Rainfall and runoff that occurred during an average natural rainfall event during the growing seasons from 2003 through 2007.

storm event or simulated event occurred within a few hours of application, the amount of fertilizer nitrogen (N) and phosphorus (P) lost to runoff was generally less than 10% of applied and, more often, only 2-4% of applied (4). The levels of P that were found during studies of nutrient runoff from turf were sometimes no greater than those reported in natural rainfall (5).

Typical Rainfall in Oklahoma

Most rainfall events do not produce runoff. Oklahoma, for instance, is internationally known for severe weather, but few rainfall events that occur in Oklahoma provide adequate precipitation to produce runoff from golf course fairways. Between 1948 and 2004, there were an average 81 rainfall events each year in Stillwater, OK (6). Of those 81 events, only seven produced over 0.5 inches of rainfall in an hour or less and lasted longer than one hour. Those seven events would likely produce runoff from an irrigated bermudagrass golf course fairway. However, 74 of the 81 events were probably not adequate to produce runoff from fairway turf unless the surface infil-

tration rate was very low or the soil was near saturation.

Eutrophication

Although nutrient runoff may only occur a few times each year, that runoff can be very detrimental to surface water. A process called eutrophication caused by algal blooms resulting primarily from high N and/or P concentrations has resulted in areas called "dead zones" in the Gulf of Mexico at the mouth of the Mississippi River, in the Chesapeake Bay, and in other localized areas. Eutrophication is present in many lakes and bays in the U.S., but is not highly publicized.

Eutrophication is a process of oxygen depletion caused by algal growth that is encouraged by N and P. This oxygen-depleted water cannot support plants and fish. Hence, it is called "dead". Although excess N is important, it appears that P may be the element most responsible for encouraging eutrophication. Very low concentrations of P such as 25 to 50 parts per billion (ppb) can cause eutrophication (4, 7). Some states, Minnesota for instance, have passed legis-

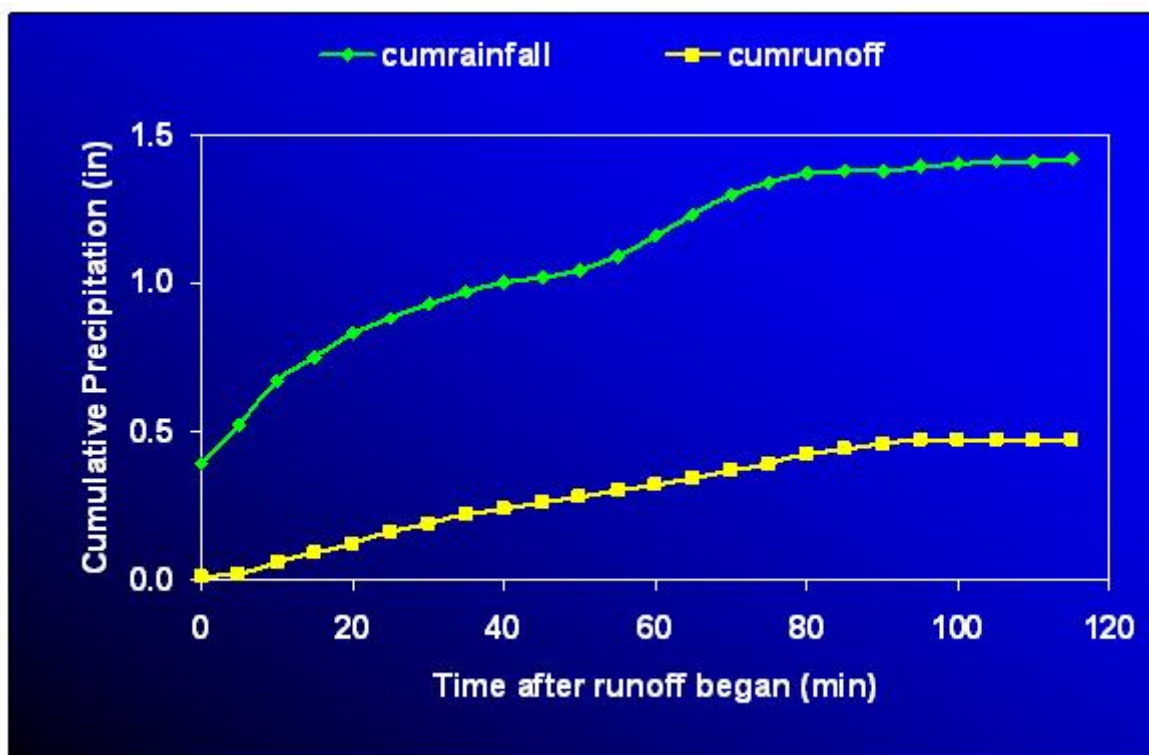


Figure 2. Cumulative rainfall and cumulative runoff that occurred during an average runoff-producing natural rainfall event during the growing seasons from 2003 through 2007.

lation that restricts the application of phosphorus fertilizer to turfgrass (8). Eutrophication requires much higher concentrations of N [1000 ppb = 1 part per million (ppm)]. High levels of nitrate are also detrimental for human consumption. The Environmental Protection Agency limit for nitrate in drinking water is 10 ppm (9).

Although golf course superintendents tend to be good environmental stewards and employ management practices to reduce runoff, some of the fertilizer applied to golf course turf may still be lost to surface water. Fairways are fertilized throughout the growing season and surface runoff of nutrients can occur. Although studies have measured the amount of nutrient runoff from turf that occurs during major storm events, the amount of nutrient runoff that is likely to occur during relatively normal rainfall under typical maintenance conditions is not known.

The objective of this study was to measure the loss of N and P caused by natural rainfall from a common bermudagrass fairway managed with typical fertilization and irrigation practices for a five-year period.

Runoff Collection

Collection troughs and automated samplers were positioned at the bottom of six 40 x 80 feet (12 by 24 m) plots (5% slope) for surface runoff collection. Urea (46-0-0) and triple superphosphate (0-0-60) were applied to two of these plots measuring 6,400 square feet (595 m²) at the beginning of each month during the growing season on a site specifically constructed and managed to simulate a 'U3' bermudagrass (*Cynodon dactylon* L.) golf course fairway. The rates applied varied randomly by month. The N rates remained within a range typical for bermudagrass fertilization but the P rates were higher than normal. On average, 3.3 pounds actual N/1000 square feet (160 kg/ha) and 1.2 pounds actual P/1000 square feet (60 kg/ha) was applied per year on a monthly basis from April through August.

A system of time domain reflectometers (18 in all) were used to monitor antecedent soil moisture, and irrigation was used to maintain the site at approximate field capacity throughout the study. Runoff samples were collected and tested

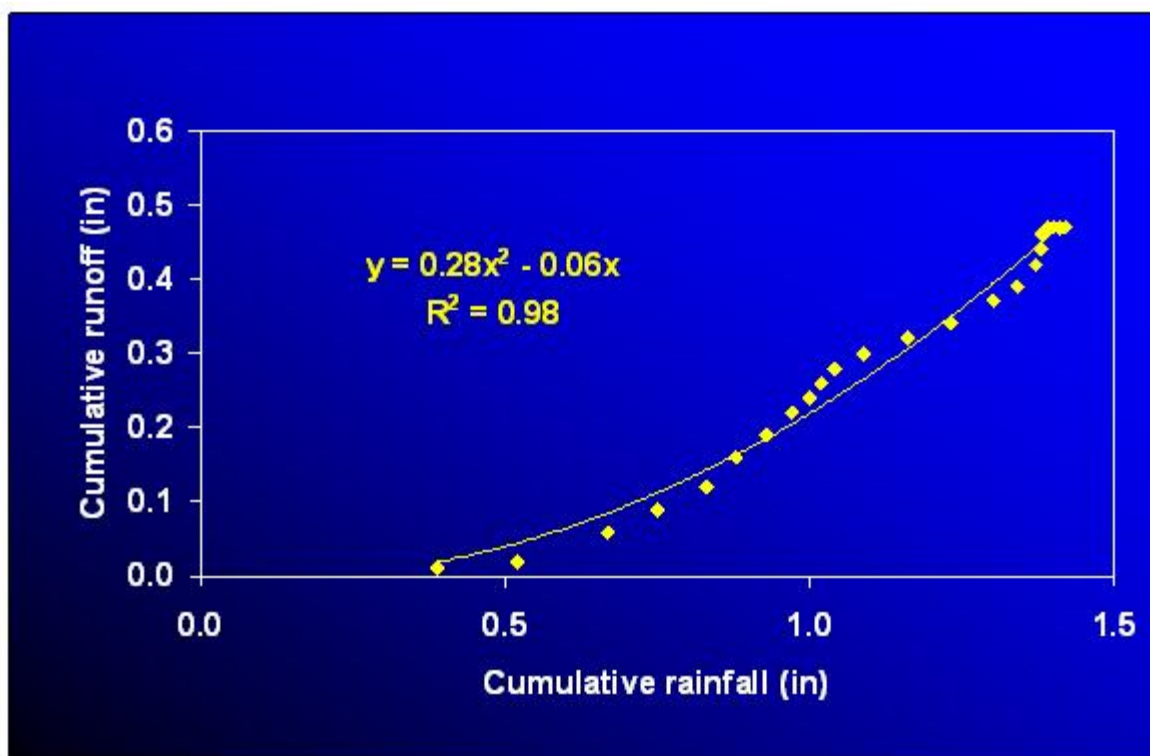


Figure 3. The relationship between cumulative natural rainfall and cumulative runoff.

for $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and dissolved reactive phosphorus (DRP) during natural rainfall events that produced runoff in 2003 through 2007.

Mean Rainfall and Runoff for Five Years from 2003 Through 2007

An average of seven rainfall events occur each year that have sufficient intensity and duration to generate runoff from this particular site, but not all of these events occur during the growing season. A total of 30 runoff events were monitored for runoff losses during the growing seasons from 2003 through 2007, and nutrient samples were collected for 24 of these events. Runoff flow rates and nutrient samples were collected in 5-minute intervals for up to 115 minutes. The events resulted in total losses of 0.7% of the N and 3.1% of the P applied as fertilizer during the 5-year period.

The runoff from natural rainfall seems to follow a particular pattern in Oklahoma (Figure 1). Runoff flow rates increase rapidly for a short

time after initiation reaching a peak at about 20 minutes after runoff begins. A decline to zero usually follows within 90 minutes. However, major rainstorms sometimes cause a second peak in runoff at about 65 minutes followed by declines to zero or near zero at 115 minutes.

During the study, once runoff began, approximately 27% of the rainfall that occurred became runoff (Figure 2). However, the relationship between runoff and rainfall was not linear suggesting that the faster rainfall accumulated, the greater the amount of rainfall that became runoff (Figure 3). After averaging 30 events by 5-minute time intervals following the initiation of runoff, cumulative rainfall with cumulative runoff exhibited a strong quadratic relationship ($r^2 = 0.98$). Using the same preliminary averaging, the relationship between cumulative nutrient losses and cumulative runoff volume was nearly perfect (Figure 4). However, the N loss rate had a poor relationship ($r^2=0.06$) with N concentrations in runoff, and although the P loss rate with P concentration relationship was much stronger

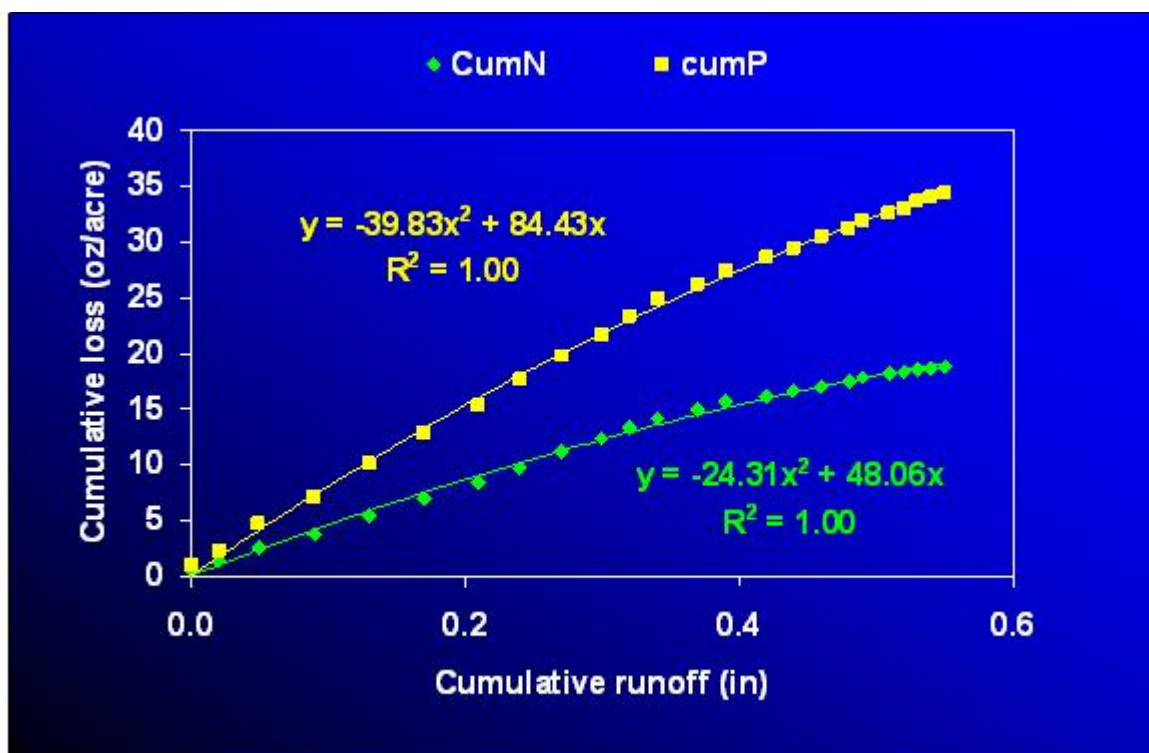


Figure 4. The relationship between cumulative runoff volume and cumulative nutrient losses.

($r^2=0.65$), the comparisons suggested that runoff volume was the primary factor that influenced nutrient losses. There was a reasonably strong linear relationship between runoff flow rate and N loss rate ($r^2=0.89$) and between runoff flow rate and P loss rate ($r^2=0.90$).

Typical Runoff Losses in Oklahoma

Most turfgrass runoff research is performed for worst-case scenarios (10). Research typically is performed by applying major amounts of irrigation water closely following applications of N and P. Although these studies provide valuable information from controlled experiments, they overestimate the amount of runoff and nutrient losses that would typically occur under natural conditions. The amount of irrigation applied during these studies matches natural rainfall events that rarely occur. In addition, natural rainfall does not provide a sustained rate of runoff that is assumed by irrigated plot studies (Figure 1).

A few studies have measured the amount of pesticide or nutrients lost from golf courses during natural rainfall events on a watershed-scale (11, 12, 13). Other studies have also measured

natural rainfall from golf course turf on a plot-scale to determine the effects of management practices such as hollow tine aerification, vegetative buffers, or verticutting for runoff reduction (14, 15, 16). However, published information about the typical amount of nutrient losses that occur on a controlled, plot-scale experiment is, perhaps, non-existent.

A Natural Rainfall Runoff Worst-Case Scenario

We were fortunate during this project to have the opportunity to study natural rainfall runoff under fairly typical, but slightly dry, conditions in Stillwater, OK and to study a natural rainfall worst-case scenario. Stillwater normally receives 37.34 inches (95 cm) of rainfall annually. The wettest year recorded was 61.9 inches (157 cm) in 1959. At our Oklahoma Mesonet Station, 0.25 miles (0.40 km) from our runoff site, 26.5 inches (67 cm) of precipitation was recorded in 2003. The precipitation recorded at that station in 2004 was 37.3 inches (95 cm), in 2005 was 30.3 inches (77 cm), and in 2006 was 26.0 inches (66 cm).

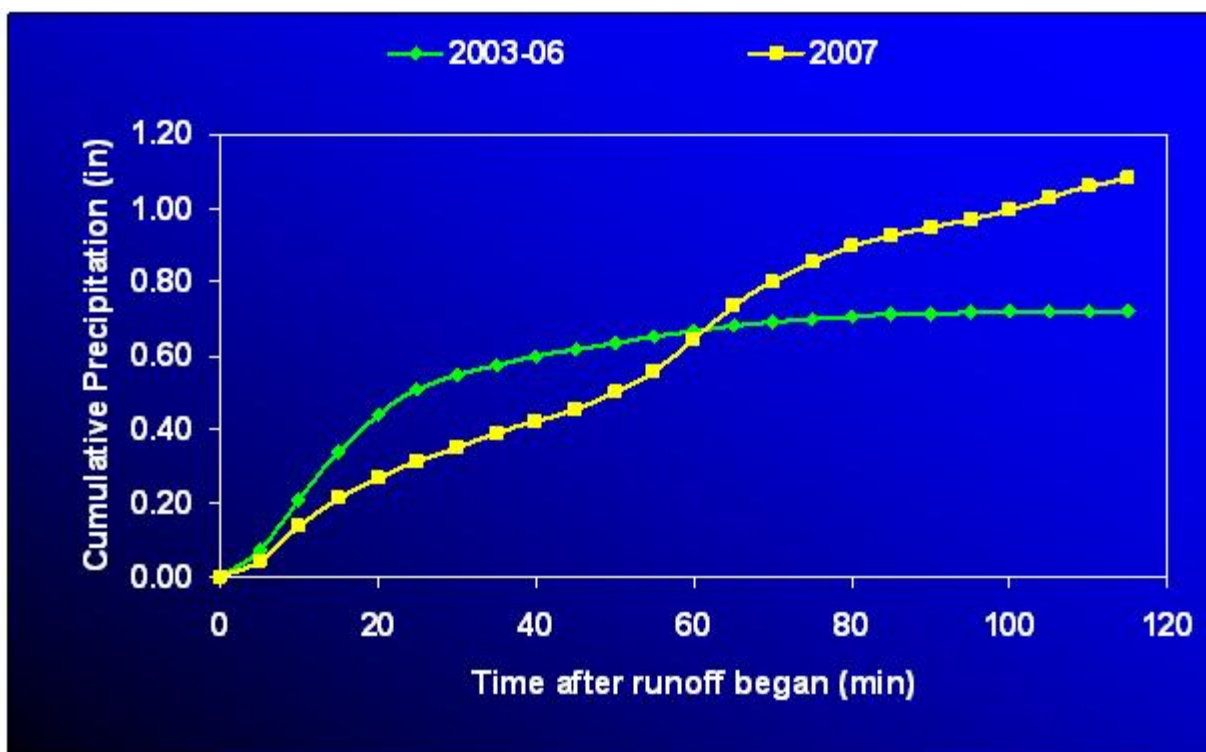


Figure 5. Cumulative precipitation during an average natural rainfall runoff event in 2003 through 2006 and in 2007.

The data indicate that the years from 2003 through 2006 were relatively normal, but slightly dry. In 2007, the station recorded 56.7 inches (144 cm) of precipitation, 5.2 inches less than the greatest total rainfall ever recorded in Stillwater in a single year. In 2007, the relatively huge amount of precipitation caused a worst-case scenario for natural rainfall runoff in Stillwater. Consequently, we had an opportunity to estimate the greatest amount of runoff that was likely to occur from a golf course fairway in Stillwater, OK and how much N and P were likely to be lost. For that reason, our remaining discussion will be presented in two parts: typical runoff likely to occur from a golf course fairway in Stillwater, OK (results from 2003 through 2006) and the most annual runoff likely to occur from a golf course fairway in Stillwater, OK (the results of 2007).

Rainfall and Runoff in 2003-06 and in 2007

The average rainfall event in 2007 differed from an average event during 2003-06 (Figure 5). A typical rainfall event in 2003-06 accumulated precipitation rapidly until 20-25 minutes after

runoff began. After 25 minutes, the rate of rainfall decreased rapidly to near zero, and accumulation slowed to almost nothing.

A typical rainfall event in 2007 had two periods of rapid accumulation. Precipitation accumulated rapidly until about 20 minutes after runoff began then slowed to a lower rate. A second period of rapid accumulation occurred from approximately 50 minutes to 75 minutes before the rainfall rate declined again. Unlike rainfall in 2003-06, rainfall in 2007 continued to accumulate slowly to the end of the collection period. After 115 minutes, the average rainfall event in 2003-06 had deposited 0.72 inches (1.8 cm) of precipitation on the site and the average event in 2007 had deposited 1.08 inches (2.7 cm) on the site. The average precipitation rate for a 115-minute period in 2003-06 was 0.36 inches/hour (0.9 cm/h). The peak rate was 1.69 inches/hour (4.3 cm/h) and occurred at 5 minutes after runoff began.

Although the average precipitation rate during 115 minutes was higher in 2007 at 0.54 inches/hour (1.4 cm/h), the peak rate was lower at 1.28 inches/hour (3.3 cm/h) and occurred at 60 minutes. Consequently, the storms in 2007 were

not necessarily more intense than those in 2003-06, but they were longer in duration. The sustained rainfall that occurred in events in 2007 resembled rainfall simulation studies a little more closely than the events in 2003-06, but neither were really consistent with simulated rainfall. Rainfall rates were recorded by the minute and substantial minute-to-minute variation occurred in each event.

Runoff accumulation tends to follow the same pattern as the rainfall that produced it, but with fewer sharp increases and decreases (Figures 1, 2, 5 and 6). In 2003-06 when runoff occurred, 53% of the rainfall became runoff. When runoff occurred in 2007, 63% of the rainfall became runoff. After 115 minutes, the average event in 2003-06 had accumulated runoff to a depth of 0.38 inches (1.0 cm) from 0.72 inches (1.8 cm) of rainfall. In 2007, after 115 minutes the average event accumulated runoff to a depth of 0.68 inches (1.7 cm) from 1.08 inches (2.7 cm) of rainfall.

Although we sampled runoff for 115 minutes each time it occurred, the runoff from a single event rarely lasted that long, except for a period during the summer of 2007. The average peri-

od of runoff in 2003-06 was 59 minutes and the average period of runoff in 2007 was almost twice that at 109 minutes. As Figure 3 demonstrates, the longer the period of runoff the greater the proportion of rainfall that became runoff. In addition, Figure 4 indicates that the amount of runoff that occurred directly determined the amount of nutrients lost. Consequently, substantially more nutrients were lost to runoff in 2007 than were lost in 2003-06 (Figures 7 and 8).

Nutrient Losses in 2003-06 and in 2007

Our biggest problem with the study of nutrient runoff, or the evaluation of nutrient runoff concerning its effect on eutrophication, is that we have no benchmarks with which to measure the risk. We can determine the concentration of nutrients in runoff as it moves off-site. We can also determine how much total nutrient was lost in a runoff event. However, that does not tell us what effect the nutrient had on the potential for eutrophication of surface water.

Our study determined that under the conditions we maintained at our site, we lost 2.0% of

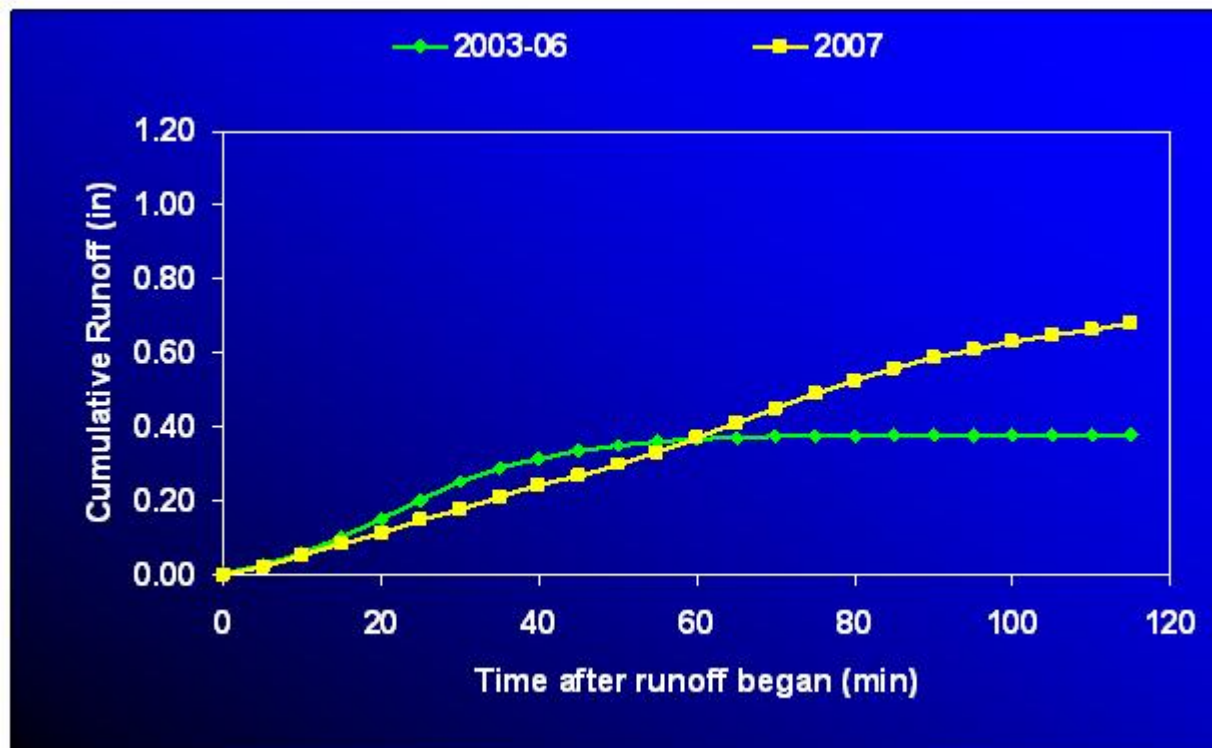


Figure 6. Runoff accumulation during the average rainfall event in 2003 through 2006 and the average rainfall event in 2007.

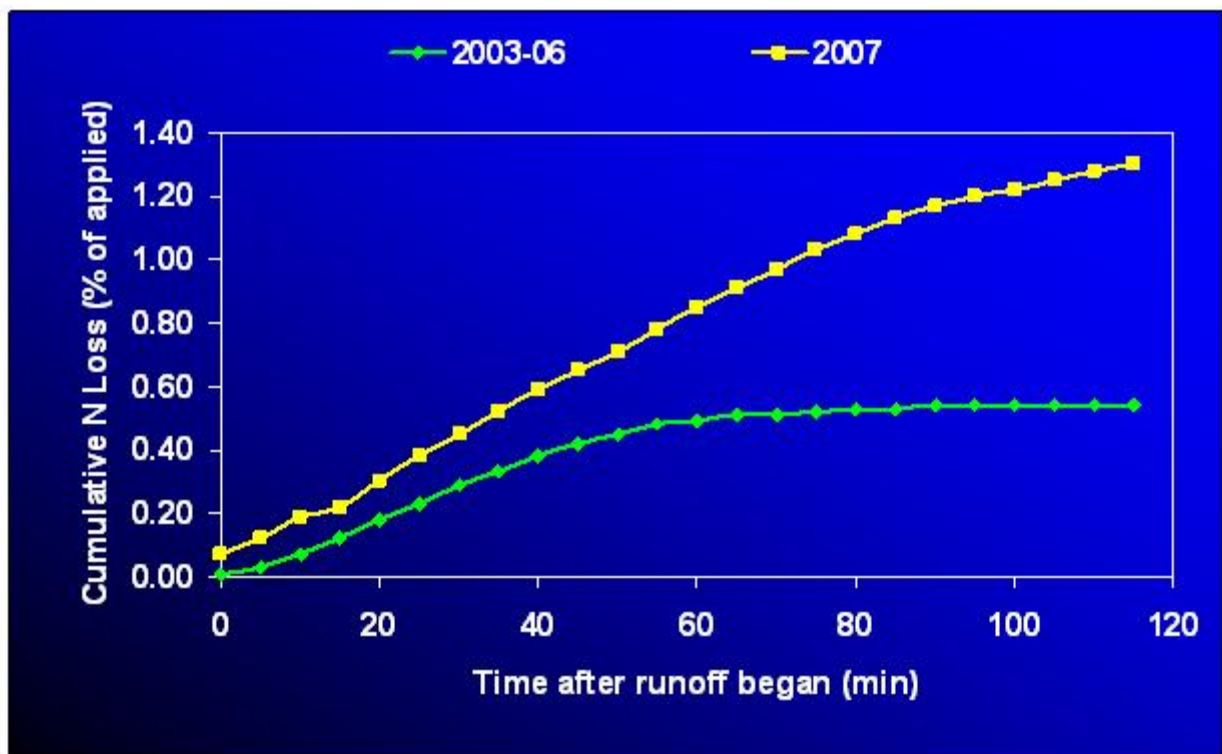


Figure 7. The amount of nitrogen (N) lost in natural rainfall runoff from the study site in 2003-06 and in 2007. Runoff losses are measured as a percentage of N applied.

the P applied during an average runoff event in 2003-06 and 7.7% of the P applied during the worst-case scenario in 2007 (Figure 8). Since most sources agree that 50 ppb (parts per billion) is sufficient to encourage eutrophication of surface water, 2.0% or 7.7% of the P applied seems like a lot of P (18). Since more N (1.0 parts per million) is required to encourage eutrophication, and since our study indicated that we lost only 0.5% of the N applied during a normal runoff event and 1.3% during the worst-case scenario, we should be more concerned about P losses than N losses (Figure 7).

It is not uncommon to find 10 ppb DRP (dissolved reactive phosphorus) in natural rainfall. Most people realize that rain contains dissolved N, but it also contains P (5, 15, 19). We have tested our irrigation water several times during simulated rainfall events, and although it varies considerably, during one two-year study it averaged 50 ppb DRP (14). The natural rainfall collected during that study also averaged 50 ppb DRP. The natural rainfall collected during another study was 90 ppb DRP, and in this study was 180 ppb DRP. It

must be pointed out, however, that during this and our other studies, the rainfall collectors were left in the open and not cleaned between rainfall events. Therefore, dust and other P-containing materials were allowed to build up in the collector.

We collect that way because we want accurate measurements of the amount of environmental nutrients that have been naturally applied to the turf between rainfall events in addition to our synthetic fertilizer. Regardless, these concentrations equal or exceed the P concentrations that encourage eutrophication with no fertilizer added. The concentration of this environmental influence is subtracted from our runoff concentrations before analysis to try to achieve an accurate measure of fertilizer runoff.

Conclusions

Natural rainfall in Stillwater, OK tends to occur in a somewhat consistent pattern, and that pattern is not consistent with simulated rainfall. In Stillwater, rainfall was always intense at the

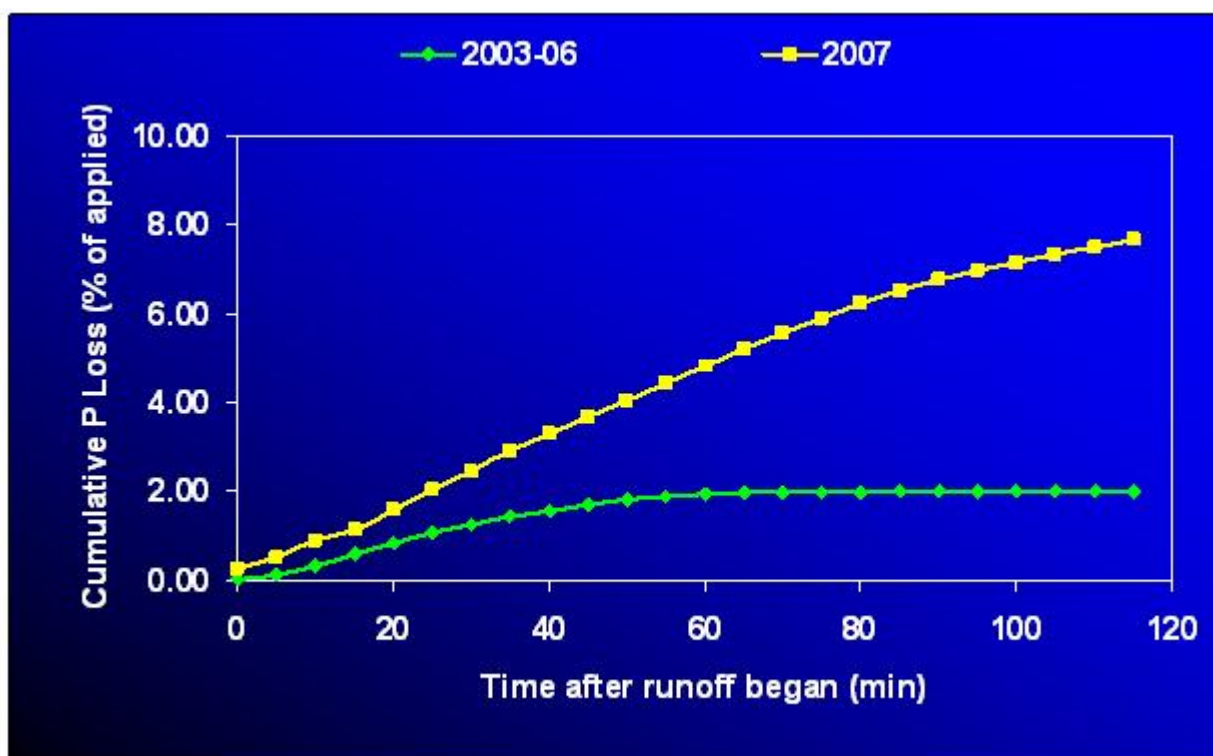


Figure 8. The amount of phosphorus (P) lost in natural rainfall runoff from the study site in 2003-06 and in 2007. Runoff losses are measured as a percentage of P applied.

beginning of a rainfall period, and the rainfall rate declined rapidly after 20-30 minutes after runoff occurred. Extended storms often had a second period of intense rainfall at 50-75 minutes after runoff occurred. Natural rainfall runoff follows the pattern established by rainfall, but tends to have smoother transitions rather than sharp increases and decreases. Theoretically, if we could contain the first 20-30 minutes of runoff from each runoff event, there would be very little off-site movement under normal weather conditions. Presumably, then we could pump the water and nutrients back onto the target site when weather conditions were conducive.

Although nutrient concentrations in runoff are important to the amount of nutrient lost during a runoff event, the concentrations are consistent enough in natural rainfall runoff that they rarely affect the amount of nutrient lost during a natural rainfall runoff event. Although nutrient concentrations varied by event and during an event, the effects of these variations on nutrient losses were negligible. Instead, there was a nearly perfect relationship between the amount of runoff that

occurred and the amount of nutrient lost. The longer the runoff period, the greater the proportion of rainfall lost to runoff and the greater the loss of nutrients.

Scientists estimate the danger of eutrophication based on concentrations of N and, more importantly, P in surface water. However, these concentration benchmarks are not suitable to determine the potential risk in nutrient runoff. In some cases, natural rainfall may contain enough P to be considered a pollutant. We estimated that under slightly dry but relatively normal conditions, a bermudagrass golf course fairway on a 5% slope in Stillwater, OK was likely to lose around 0.5% of the N applied and 2.0% of the P applied as fertilizer. This does not seem to be an excessive amount of N loss, but it might be a dangerous amount of P.

In a worst case scenario, during a season of near record rainfall, this same fairway would lose around 1.3% of the N and 7.7% of the P applied as fertilizer. It would seem that our best alternative is to apply only the amount of P that is absolutely required to maintain adequate playing

conditions. We have reasonably good benchmarks to roughly determine the amount of soil P required to grow most grasses under fairway conditions. A superintendent could reduce P applications or eliminate them until P became a limiting factor for adequate turf. This could be determined by applying P fertilizer to test areas in some fairways. If the turf was substantially better in the test areas than the rest of the fairway, then more P is needed.

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