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Researchers at Oklahoma State University found that using vegetative buffers maintained at multiple mowing heights improved the ability to limit both nitrogen and phosphorus runoff compared to buffers maintained at a single height of cut.

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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 290 projects at a cost of $25 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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Managing Golf Course Roughs to Reduce Runoff

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SUMMARY

Few rainfall events during a season provide enough precipitation to produce runoff from golf course fairways. In addition, the management protocols practiced by superintendents add to the natural buffering capabilities of turf to help reduce golf course runoff. However, an amount as small as 1% of the phosphorus applied to golf course fairways as fertilizer could have a substantial impact on lakes and other surface water.

Research suggests that a higher cut turf such as roughs bordering fairways provides a barrier to surface water runoff that must be overcome before the flow can continue down slope. Therefore, a multiple-barrier system of rough such as apron-to-first cut-to-primary rough might provide three heights of cut resulting in three barriers. This multiple-barrier strategy could provide the best alternative to reducing nutrient runoff from fairways. The objective of this research was to compare this multiple-barrier strategy with the single-buffer strategy that is already known to be effective. The research found:

- The multiple barrier strategy reduced natural rainfall runoff by 19% and irrigation runoff by 16% compared with the single-buffer strategy.
- The multiple-barrier strategy reduced N loss by 17% in natural rainfall runoff and by 18% in irrigation runoff compared with the single-buffer strategy.
- The multiple-barrier strategy reduced P loss by 11% in natural rainfall runoff and by 14 % in irrigation runoff compared with the single-buffer strategy.

There were approximately 16,000 golf courses in the United States in 1999 (6). On average, each golf course maintained approximately 35 acres of fairways for a total area of roughly 560,000 acres. Golfers prefer excellent playing conditions and in most cases, demand them. Therefore, golf course fairways tend to be highly fertilized compared with most turfgrass areas to promote good turf cover, high turf density, and minimal weed encroachment.

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There is a slight, but nonetheless dangerous, possibility that a small portion of the fertilizers applied to golf course fairways can dissolve in surface water runoff and contaminate lakes, streams, and other water features. There is a need for golf course superintendents to practice turf management procedures that maintains adequate playability but reduces the potential for nutrient runoff. Consequently, it is necessary for turf scientists to pursue and investigate management methods that help superintendents develop environmentally sound practices that reduce the potential for nutrient runoff.

Environmentally sound golf course management is a major factor in most superintendents' maintenance programs and the danger of nutrient runoff is small but present. For instance, fertilizers are not applied to frozen or saturated soil because those conditions promote nutrient losses to surface runoff. 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

Samplers were programmed to determine water flow rate from these water level measurements based on a pre-determined calibration of each flume and to collect runoff samples every five minutes for 60 minutes These samples were tested to determine the amount of N and P in the runoff.

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environment because the first rainfall event following fertilization is the most likely event to produce nutrient runoff (11). On the other hand, golf course fairways 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 from runoff (11).

The higher-cut golf course rough that commonly surrounds fairways acts as a vegetative filter strip or buffer that reduces runoff (3). Research suggests that the higher the buffer, the longer the period between rainfall initiation and runoff and the more likely that runoff will be eliminated or reduced by a particular rainfall event (2). The density of the turf on the fairway or in the rough also has an impact on runoff (4, 5). 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.

Grass buffers are recommended between agricultural cropping fields and water features to help prevent runoff (12). Even under worst-case conditions where fertilizer was applied to turf but not watered in and a major storm event or simulated event occurred within a few hours of application, the amount of fertilizer nitrogen (N) and

The water runoff research site at Oklahoma State University consisted of three irrigation blocks with two 40 by 80 ft. plots per block for a total of six plots on 0.44 acres.

phosphorus (P) lost to runoff was generally less than 10% of applied and, more often, only 2-4% of applied (14). The levels of P that were found during studies of nutrient runoff from turf were often less than those found in natural rainfall (9).

Most rainfall events do not produce runoff. In Oklahoma, for instance, few rainfall events occur that 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 (7). 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 infiltration rate was very low or the soil was already near saturation.

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 primarily by high nitrogen (N) and/or phosphorus (P) concentrations has resulted in an area called the "dead zone" in the Gulf of Mexico at the mouth of the Mississippi River and similar problems in Chesapeake Bay. Eutrophication is a process of oxygen depletion caused by algal growth that is fueled by N and P. This oxygen-depleted water cannot support plants and fish. Although excess N is important, P may be the element most responsible for rapidly accelerating eutrophication (9). Very low concentrations of P such as 25 to 50 parts per billion (ppb) can cause eutrophication (8, 14). Eutrophication requires much higher concentrations of N, generally greater than 1 ppm. High levels of nitrate are also detrimental for human consumption. The Environmental Protection Agency limit for nitrate in drinking water is 10 parts per million (ppm, 13).

Although golf course superintendents tend to be good environmental stewards and employ several management practices to reduce runoff, some of the fertilizer applied to golf course turf may still be lost to surface water. The search for

Time	Flow rate		N lost to runoff		P lost to runoff		N conc.		P conc.	
	Multiple	Single	Multiple	Single	Multiple	Single	Multiple	Single	Multiple	Single
--min--	--gal/ac/min--		--------------------- lb/ac/min --------------------				------------------- ppm-------------------			
Irrigation runoff										
5	62	73	0.0005	0.0005	0.0015	0.0010	1.0	0.7	2.9	*1.7
10	151	182	0.0018	0.0015	0.0050	0.0043	1.4	*1.0	4.0	*2.8
15	234	*286	0.0046	0.0042	0.0120	0.0122	2.3	1.7	6.2	5.1
20	285	*345	0.0075	0.0081	0.0185	0.0204	3.2	2.8	7.8	7.1
25	313	*381	0.0093	0.0112	0.0215	0.0254	3.5	3.5	8.2	8.0
30	334	*398	0.0102	*0.0126	0.0221	*0.0260	3.6	3.8	7.9	7.8
35	347	*412	0.0102	*0.0128	0.0207	*0.0243	3.5	3.7	7.1	7.1
40	348	*422	0.0097	*0.0126	0.0180	*0.0220	3.4	3.6	6.2	6.3
45	363	*423	0.0096	*0.0122	0.0164	*0.0197	3.2	3.5	5.4	5.6
50	365	*412	0.0090	*0.0113	0.0144	*0.0172	3.0	3.3	4.7	5.0
55	354	*406	0.0082	*0.0105	0.0125	*0.0150	2.8	3.1	4.2	4.4
60	341	*406	0.0074	*0.0102	0.0104	*0.0135	2.6	*3.0	3.6	4.0
Natural rainfall runoff										
5	284	277	0.0037	0.0034	0.0090	0.0061	1.6	1.5	3.8	*2.6
10	512	508	0.0073	0.0066	0.0205	0.0145	1.7	1.6	4.8	*3.4
15	349	409	0.0057	0.0057	0.0188	0.0183	2.0	1.7	6.5	5.3
20	191	*266	0.0034	0.0041	0.0124	0.0160	2.1	1.8	7.8	7.2
25	153	*195	0.0027	0.0033	0.0104	0.0127	2.1	2.0	8.1	7.8
30	170	*198	0.0029	0.0035	0.0107	0.0127	2.0	2.1	7.6	7.7
35	157	*218	0.0026	*0.0039	0.0091	*0.0130	2.0	2.1	6.9	7.1
40	126	*194	0.0019	*0.0033	0.0064	*0.0102	1.8	2.1	6.2	6.3
45	82	*143	0.0012	*0.0023	0.0037	*0.0066	1.7	2.0	5.3	5.5
50	45	*93	0.0006	*0.0015	0.0017	*0.0038	1.6	1.9	4.6	4.9
55	18	*55	0.0002	*0.0008	0.0006	*0.0020	1.5	1.8	4.0	4.4
60	11	*33	0.0001	*0.0005	0.0003	*0.0011	1.4	1.8	3.4	3.9

*Indicates a significant difference between the multiple-barrier and single-barrier rough ($P<0.05$)

Table 1. Mean runoff flow rate, amount of N and P, and N and P concentrations (conc.) during 5-minute intervals in runoff produced by six irrigation events and four natural rainfall events.

management practices that further reduce nutrient runoff from golf course fairways and other turf areas continues to be necessary. The search for management practices that reduce nutrient runoff is conspicuously important to the turfgrass industry and to golf courses in particular. If fertilizer use is restricted, recreation areas would probably be the first areas restricted.

Based on previous research, we reasoned that it is difficult for water to flow through the dense system of shoots formed by closely-mowed turf (4, 5). Consequently, because turf density tends to increase with decreasing mowing height, it may be reasoned that a low mowing height should be more effective than a higher one for providing resistance to flow. That may be the case for turfgrass stands of a single mowing height but did not prove correct for turfgrass stands that include vegetative buffers (2). When runoff flows from a low cut turf to a higher cut turf, its passage is further restricted (3).

Based on the density principle, water flowing from a short mowing height to a taller mowing height should pass easily through the rel-

Wax was used to seal the interface of the turfgrass plots with the collection trough to ensure that total runoff was being measured.

atively low density of the higher height of cut. Research indicates, however, that this does not occur. Buffers of 1.5 inches did not restrict flow as effectively as buffers of 3.0 inches (2).

When surface runoff from a golf course fairway encounters golf course rough, it tends to slow and puddle until sufficient energy builds to allow the water to flow through or over the higher height of cut. The higher cut turf forms a barrier to gravitational flow that must be overcome before the surface runoff continues down the slope providing more time for the runoff to infiltrate into the thatch and soil. Therefore, a graduated system of rough such as apron-to first cut-to-primary rough would provide three heights of cut resulting in three barriers. Since wider buffers do not seem to deter runoff with greater effectiveness than shorter ones (3) and since exceptionally high mowing heights could negatively affect playability, this multiple barrier strategy could provide the best alternative to reducing nutrient runoff from fairways. The objective of this research was to effectively compare this multiple-barrier strategy with the single-buffer strategy that is already known to be effective.

The Research Site

The water runoff research site at Oklahoma State University consisted of three irrigation blocks with two 40 by 80 ft. plots per block for a total of six plots on 0.44 acres. The site is mature common bermudagrass (*Cynodon dactylon*) on compacted silt loam soil with a surface infiltration rate of less than 0.5 inches per hour. The turf irrigation system delivers a 2 inches per hour precipatation rate. A series of 18 time domain reflectometer probes served to monitor soil moisture so that the site could be maintained at field capacity consistently. The turf was mowed at 0.5 inch across the upper sections of each plot three times per week to simulate golf course fairways.

The fairway sections were 40 ft. wide by 62 ft. long and were bordered by rough, 40 ft. wide by 18 ft. long at the bottom of the slope. The single barrier rough was mowed at 2 inches for the full 18-ft. length from fairway to collection trough and the multiple barrier rough was mowed at increasingly higher heights every 6 ft. down the slope. The mowing heights for the multiple barrier rough increased from 1.0 inch at the highest surface elevation to 1.5 inches at the intermediate location then to 2.0 inches at the lowest elevation. The buffers were mowed once each week.

Fertilizer, Precipitation, and Sample Collection

To test nutrient runoff, urea and triple super phosphate fertilizer were applied at 1 lb. nitrogen (N) per 1000 sq. ft.and 0.5 lb. phosphorus (P) per 1000 sq. ft. four hours before irrigating and again following irrigation events to await natural rainfall. The fertilizers were applied as granules and were not "watered in" so that the study represented worst-case conditions. Fertilizers were applied to the simulated golf course fairway area six times in 2001 and six times in 2002. Fertilizer was not applied to the rough.

Covered troughs collected runoff water from each plot and channeled it through calibrated Parshall flumes by gravity flow. Ultrasonic modules (Isco 710) mounted over each Parshall flume used ultrasonic reflection to measure water level. Isco 6700 portable samplers (Isco, Lincoln, NE) were secured to concrete platforms located between each experimental block. The samplers were programmed to determine water flow rate from these water level measurements based on a pre-determined calibration of each flume and to collect runoff samples every five minutes for 60 minutes These samples were tested to determine the amount of N and P in the runoff. The time from the beginning of precipitation to the beginning of runoff was also measured for each plot during each event.

Runoff caused by irrigation was collected three times in 2001 and three times in 2002. Natural rainfall runoff was collected once in 2001 and three times in 2002. Each time precipitation occurred, multiple samples of the irrigation or rainfall were collected and the concentrations of N and P in the samples were determined. Background concentrations were subtracted from the nutrient concentrations in the runoff to determine the actual amount of N and P removed from the turf.

The irrigation system provided precipitation at 2.0 inches per hour resulting in applications of 905 gallons per acre per minute. The coefficient of uniformity (1) for the system averaged 81% (1 trial per plot = 6 trials) compared with 95% for natural rainfall calculated as the average of four natural rainfall events. Runoff during irrigation events began slowly reaching an average maximum flow rate of 393 gallons per acre per minute at 45 minutes after runoff began (Table 1).


The irrigation system provided precipitation at two inches per hour resulting in applications of 905 gallons per acre per minute.

Results

Runoff Rate

During irrigation, the multiple-barrier rough reduced the peak runoff rate by 14% compared with the single-barrier rough and reduced the total runoff at 60 minutes by 16%. In contrast, peak runoff occurred more rapidly during the natural rainfall events producing an average of 510 gallons per acre per minute at 10 minutes after runoff began (Table 1). The multiple-barrier rough did not significantly affect the peak natural rainfall runoff rate, but it did significantly reduce the cumulative runoff volume by 19% during 60 minutes of runoff.

Time to Runoff

The multiple-barrier rough significantly delayed the time from the beginning of precipitation to the beginning of runoff compared with the single-barrier rough during both irrigation and natural rainfall. The multiple-barrier rough delayed runoff initiation by approximately four minutes during irrigation and by two minutes during natural rainfall. The average time to initiation of runoff during irrigation events was 20 minutes for the multiple-barrier rough and 16 minutes for the single-barrier rough. Time to runoff for natural rainfall events was 39 minutes for the multiple-barrier rough and 37 minutes for the single-barrier rough. Both results were significantly different ($P < 0.05$). The delay from the beginning of precipitation to runoff of four (irrigation) or two (rainfall) minutes resulted in a minor reduction in nutrient losses compared with the reductions resulting from lower runoff volumes.

Fertilizer Losses

Fertilizer losses in runoff were small compared with fertilizer applied. On average, 1.5% of the N applied was lost to irrigation runoff and 0.5% to natural rainfall runoff during 60 minutes of runoff. Irrigation runoff caused a 5.5% loss of applied P and natural rainfall runoff caused a 3.3% loss of applied P during 60 minutes of runoff. These results are comparable with the results of other researchers and further support the contention that turf has a positive influence on the reduction of nutrient losses from runoff (4, 10).

Worst-case Conditions

The fertilizer application methods that were applied to the irrigation experiments in this study were established to provide worst-case conditions. Shuman (11) demonstrated that light irrigation following fertilization reduced nutrient losses. Walker and Branham (14) stated that as the period between the first runoff event and fertilizer application is extended, a greater proportion of nitrogen will be immobilized by plants or soil or leached past the active mixing zone reducing nitrogen runoff.

Because of these and other recommendations, golf course superintendents generally do not apply fertilizer within 48 hours prior to predicted rainfall and nearly always "water in" the fertilizer immediately following application to minimize possible runoff losses. The nutrient losses in this study are representative of a worst-case scenario and are likely to be more severe than what typically occurs.

Nutrient Losses

The reduced runoff volume resulting from the use of the multiple-barrier rough compared with the single-barrier rough caused a significant reduction in the amount of N and P lost to both irrigation and natural rainfall runoff (Table 1). The multiple-barrier rough reduced the amount of N lost with 60 minutes of irrigation runoff by 18% and the amount of N lost with 60 minutes of natural rainfall runoff by 17%. The multiple-barrier rough reduced the amount of P lost to irrigation runoff by 14% and the amount of P lost to natural rainfall runoff by 11% during 60 minutes of runoff.

The concentration of NO_3-N never exceeded the recommended EPA limit for drinking water of 10 ppm (12), but both dissolved N (NO_3-N + NH_4-N) and dissolved P consistently exceeded 1 ppm and 25 ppb, respectively, the commonly recommended allowances for reducing the likelihood of eutrophication (14). Further research is needed to continue the development of management strategies that help reduce nutrient losses to surface water runoff from highly maintained turfgrass areas.

This study found the same runoff activity, high nutrient runoff concentrations in the early stages of runoff followed by declining concentrations with time, suggested by Walker and Branham (14). The N concentrations in both irrigation and natural rainfall accelerated rapidly from 5 to 25 minutes and were highest between approximately 25 to 35 minutes (Table 1). The P concentrations also accelerated rapidly and were highest in both forms of precipitation at approximately 20 to 35 minutes (Table 1).

The rapidly accelerating nutrient losses during the beginning of runoff overcame the delay in time to runoff between treatments and effectively neutralized the beneficial effects of the multiple-barrier rough during the initial stages of

Ultrasonic modules (ISCO 710) mounted over each Parshall flume used ultrasonic reflection to measure water levels.

Covered troughs collected runoff water from each plot and channeled it through calibrated Parshall flumes by gravity flow.

runoff. After 20 to 25 minutes of runoff, nutrient losses were nearly equal among treatments in spite of the average four- or two-minute delay in time to runoff caused by the multiple-barrier rough and the greater volume of irrigation runoff from the single-barrier rough (Table 1). Consequently, the multiple-barrier rough did not affect nutrient runoff significantly for the first 30 to 35 minutes of runoff but maintained an advantage following 35 minutes until at least 60 minutes of runoff during both irrigation and natural rainfall.

Assuming an average 37 minutes from the beginning of precipitation to runoff and sufficient precipitation to cause runoff, a rainfall event would have to last at least 72 minutes (37 min time to runoff + 35 min to significant runoff results) for the multiple barrier rough to make a significant difference in the amount of nutrient runoff that occurred.

Runoff Reduction

Based on 55 years of precipitation data collected at Stillwater, OK, an average of 81 rainfall events occurred each year (7). Most of those events did not produce adequate precipitation to force runoff, but seven events per year produced at least 0.5 inch of rainfall (the amount required to produce runoff at the research site) at an average precipitation rate greater than 0.5 inch (the surface infiltration rate) for at least one hour, and lasted longer than 72 minutes (the average time of precipitation required to produce significant differences in nutrient losses between buffer treatments). Consequently, the use of multiple-barrier roughs could make a meaningful difference in the amount of nutrients lost in runoff during those seven runoff-producing rainfall events that are likely to occur each year in Stillwater, OK. The average annual rainfall in Stillwater is 37 inches per year, a relatively dry climate compared with many regions of the world. The multiple-barrier rough could make a greater difference in regions where rainfall is more plentiful.

As expected, the multiple-barrier rough caused significant delays in time to runoff and lower runoff volume regardless of whether the runoff occurred as a result of irrigation or natural rainfall. These results agree with our hypothesis that mowing at multiple heights results in multiple barriers that reduce runoff. A turfgrass stand is very dense, generally including 300 shoots or more per square meter. Because of this shoot density, multiple researchers have demonstrated and recommended grass buffers along crop production fields to reduce runoff. The dense shoot system in a grass buffer creates considerable resistance to water passage.

A simple observation of turf following a severe rainstorm indicates that runoff not only occurs through the shoots but also occurs over the leaves. Areas of severe runoff are identified by the prostrate appearance of the turf. When runoff water from bare soil encounters a grass barrier, the runoff slows due to shoot resistance until sufficient volume accumulates to provide the force necessary to bend the shoots and the lower leaves allowing the runoff to flow over or around the plants. We hypothesize that when water encounters a second mowing height, a similar resistance occurs and sufficient volume must be accumulated to overcome this second barrier.


The multiple-barrier rough caused significant delays in time to runoff and lower runoff volume regardless of whether the runoff occurred as a result of irrigation or natural rainfall.

During this study, a puddle of water formed each time the runoff encountered a buffer. The puddling was most noticeable at the interface of the fairway and initial buffer but also occurred at the interface of each height increase in the multiple-height buffers. Although turf density can be expected to increase with lower mowing height and have a inhibitory effect on runoff (4, 5), the work of Baird et al. (2) indicated that when a buffer strategy is employed, the shoot height of the buffer vegetation had a greater effect on runoff than turf density. Baird et al. (2) reported that a 3.0-inch buffer height was more effective for reducing water runoff than a 1.5-inch buffer in spite of the tendency for increasing turf density with decreasing mowing height. Multiple mowing heights result in multiple barriers that slow runoff and reduce runoff volume.

Practicality

According to Baird et al. (2), increasing the height of a vegetative buffer from 1.5 inches to 3.0 inches reduces runoff. Consequently, increasing the height of the multiple-barrier rough may cause higher reductions in runoff compared with those reported by this study. However, increasing the mowing height of bermudagrass golf course rough to 3.0 inches or more is not always practical.

A survey of Oklahoma golf courses in 2004 indicated that the maximum mowing height of bermudagrass rough ranged from 0.75 to 4.0 inches with only six courses mowing bermudagrass rough at 3.0 inches or more (unpublished data). The 41 remaining courses that responded to the survey maintained a mean maximum mowing height of 1.9 inches and a median mowing height of 2.0 inches in bermudagrass rough. Although high cut bermudagrass rough could effectively reduce water runoff, golf courses must also maintain adequate playability. Dense bermudagrass rough mowed at more than 2.0 inches makes finding golf balls difficult and slows play considerably. The multiple-barrier rough described in this study could reduce nutrient runoff while still maintaining playability.

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