CHAPTER 4: THE EFFECTS OF SOIL PHOSPHORUS AND NITROGEN AND PHOSPHORUS FERTILIZATION ON PHOSPHORUS RUNOFF LOSSES FROM TURFGRASS

ABSTRACT

Turfgrass accounts for a large percentage of land in urban and suburban areas and thus, it is important to understand the effects of turfgrass on surface water quality. Runoff from natural and simulated rain events was collected for two years from fertilized (N, P, or N + P) and unfertilized plots and analyzed for dissolved and total phosphorus. When corrected for P in the unfertilized control plots, P losses were 0.05% of fertilizer applied for both dissolved and total P. Low mass losses of dissolved P were observed (<0.05 kg ha^{-1} yr^{-1}) and can be attributed to the small amount of precipitation that became runoff. Application of N or P did not affect the amount of runoff from natural or simulated events. Fertilization with N or P increased the concentration of P in the runoff to a similar extent. Soil P levels had no effect on runoff P concentrations or mass losses, despite Morgan extractable soil P levels ranging from 3.7 to 35.6 mg kg^{-1} at the 0 – 5 cm depth. The simulated events supported the data observed from the natural events in most cases. Significant differences in infiltration rate among treatments were found on 2 of the 6 simulation dates. Significant differences in P loss were only observed when no precipitation fell between a fertilization event and a simulated runoff event. However, a significant increase in P concentration from the plots receiving N was not observed as in the natural events. The results of this study suggest that fertilization of established turfgrass does not result in a reduction in runoff volume when visual quality responses to N are similar to those observed in this study. Because increased P runoff concentrations were associated with N and P fertilization,

the environmental impacts of turfgrass could be reduced by withholding or limiting N and P fertilizers under these conditions. It was also discovered that soil P level was not a good indicator of P concentration in runoff for this soil type and across the range of P levels seen in this study. Thus, predictions of runoff P loss based on soil P levels may be misleading or inaccurate for turfgrass areas.

INTRODUCTION

Runoff from urban areas is the 3rd leading source of water quality impairment in rivers, lakes, and streams in the US (USEPA, 2002). One component of urban runoff includes the runoff of nutrients from turfgrass areas such as golf courses, parks, and home lawns. It has been recently estimated that 1.8% of the land area in the US is turfgrass (Milesi, 2005). With respect to the amount of turfgrass, it is therefore of great importance to understand the effects of turfgrass management practices on surface water quality. However, relative to the large amount of turfgrass in the US, little work has been done on the factors that influence runoff losses and runoff water quality from turfgrass.

Linde et al. (1995) found that creeping bentgrass reduced runoff losses compared with perennial ryegrass when both were mown at fairway height. The authors associated the reduction in runoff volume from creeping bentgrass with its greater shoot density which allowed for increased water infiltration. Easton and Petrovic (2004) found that fertilization during establishment decreased runoff losses because shoot density was increased leading to a reduction in runoff volume from the fertilized plots. Gross et al. (1991) seeded tall fescue (*Festuca arundinacea* Schreb.) at different rates to achieve a range in shoot density, then simulated rainfall to force runoff on the plots.

They found no difference in runoff volume for shoot densities ranging from 867 – 5692 tillers m^{-2}, a range on the low end of commonly observed turfgrass densities. Kussow (1996) observed a 47 – 59% reduction in runoff P losses from turf fertilized with N and P compared to an unfertilized control. However, because growth responses to P fertilizer are rarely observed in practice, could P losses be reduced further by applying only N?

In response to poor or declining surface water quality in urban areas, Minnesota and Dane Co., Wisconsin have banned P fertilizer applications to turfgrass areas unless a soil test shows that the nutrient is required. However, as soil test recommendations for turfgrass sites typically are based on plant response, they do not consider potential environmental impacts. Furthermore, the loss of sediment from turfgrass has been shown to be minimal even under low maintenance conditions (Gross et al., 1991), suggesting the contact between runoff water and soil is reduced. Sharpley (1981) concluded that crop canopy leaching could account for a significant portion of P in runoff in cotton. For a turfgrass situation, where runoff interaction with soil is reduced at the expense of an increased interaction with turfgrass tissue, it is unclear to how much soil P levels will influence runoff P losses.

This study had 2 objectives: 1) examine the effects of N and P fertilization of established turfgrass on runoff P losses; and 2) examine the effect of soil P level on P losses from established turfgrass. It is hoped that the results will contribute to a better understanding of runoff losses from turfgrass and lead to improved fertilizer recommendations and soil test interpretations for turfgrass areas.

MATERIALS AND METHODS

The study was initiated in May 2004 at the Cornell University Turfgrass and Landscape Research Center in Ithaca, NY. The experimental plots were 1.8 m long and 0.9 m wide and were situated on a hillside with a slope ranging from 4.4 – 9.6 %. At the downside of each plot a runoff collection unit was installed following the method of Cole et al. (1997). Steel boarders 2.5 mm thick and 10 cm wide were installed in the soil to a depth of 8 cm around the perimeter of each plot (except on the downside) for hydrological isolation. In spring 2004, the steel boarders were replaced with common plastic garden edging.

The plots were situated on an Arkport sandy loam (620 g kg^{-1} sand, 260 g kg^{-1} silt, 120 g kg^{-1} clay) with a pH of 5.5 and organic matter content (as determined by loss on ignition) of 27 g kg^{-1}. The site was not compacted or severely modified before turfgrass establishment as commonly happens to a home lawn during house construction; therefore, these results are more directly applicable to relatively undisturbed sites such as cemeteries, commercial lawns, golf courses, and parks.

The turfgrass growing on the site was a mixture of perennial ryegrass (*Lollium perenne* L.) and Kentucky bluegrass *(Poa pratensis* L.) established in 2000 during a previous study (Easton and Petrovic, 2004). The researchers applied various rates and sources of phosphorus fertilizer which resulted in a wide range of soil P levels across the plots (Fig. 4.1). Plots were mowed at a height of 6.3 cm as needed; clippings were returned.

To study the effects of N and P fertilizer on P runoff losses we employed a 2 x 2 factorial design with the four treatments consisting of various nitrogen (0 and 200 kg ha^{-1} yr^{-1}) and phosphorus (0 and 50 kg ha^{-1} yr^{-1}) fertilizer levels; treatments were replicated 6 times. Eight equal-sized fertilizer applications were made over the course of the two

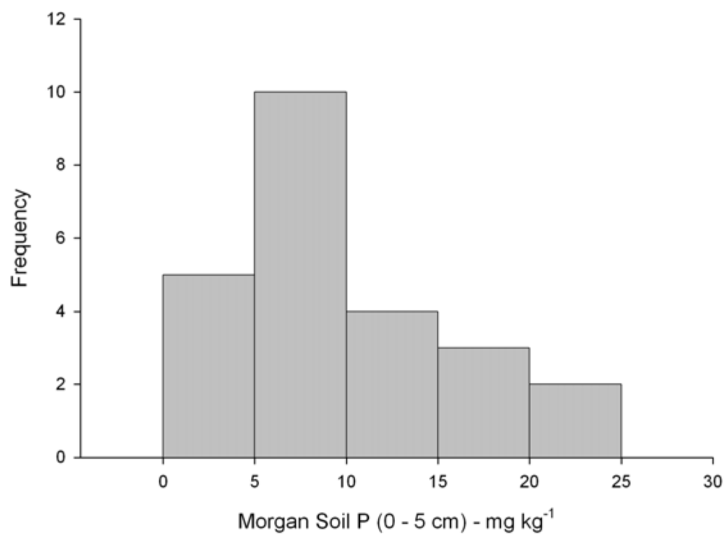

Figure 4.1 Frequency distribution of Morgan extractable soil P levels of research plots. Data from samples taken on 28 Sept. 2005.

year study on the following dates: 16 May 2004, 5 July 2004, 9 Sept. 2004, 9 Nov. 2004, 9 June 2005, 22 July 2005, 23 Sept. 2005, and 11 Nov. 2005. Prior to this study, the plots were last fertilized in Aug. 2001. Nitrogen was applied in the form of sulfur-coated urea [39 – 0 – 0 (Lesco, Strongsville, OH)], and phosphorus as triple super phosphate (0 – 45 – 0). Each application was made individually using a handheld shaker.

Runoff was generated periodically using a miniature rainfall simulator (Ogden et al., 1997) to supplement the data from natural runoff events (Fig 4.2). Conventional rainfall simulators apply water at a constant rate which causes runoff rate from each plot to vary depending on its infiltration rate. The rainfall simulator used in this study has fewer limitations of the conventional simulators and the researcher is able to easily and quickly adjust the rainfall rate to achieve a relatively constant runoff rate from each plot. We adjusted rainfall rates to achieve a runoff rate of 5 cm hr^{-1} and collected the first 7.5 mm of runoff for analysis. This rate and depth were found to be typical of an average runoff event for a small, urban watershed in central New York (Easton, 2006).

Runoff volumes were recorded by tipping buckets outfitted with dataloggers. If the runoff depth from a rainfall event exceeded 0.1 mm, a subsample was saved and stored at 4° C for dissolved and total P analysis. Total P was determined colorimetically using stannous chloride after a persulfate digestion. For determination of dissolved P, each runoff sample was centrifuged for 10 minutes at 2500 rpm and P was measured in the supernatant using the method of Murphy and Riley (1962).

Turf quality is a subjective measure of color, density, and uniformity accepted and widely practiced by turfgrass researchers in field research settings (Skogley and Sawyer, 1992). Turfgrass quality was assessed monthly during the study in an attempt to account for any differences in runoff volumes among the plots. A rating scale of 1 – 9 was used with 1 being completely brown or dead turf and 9 being the highest quality

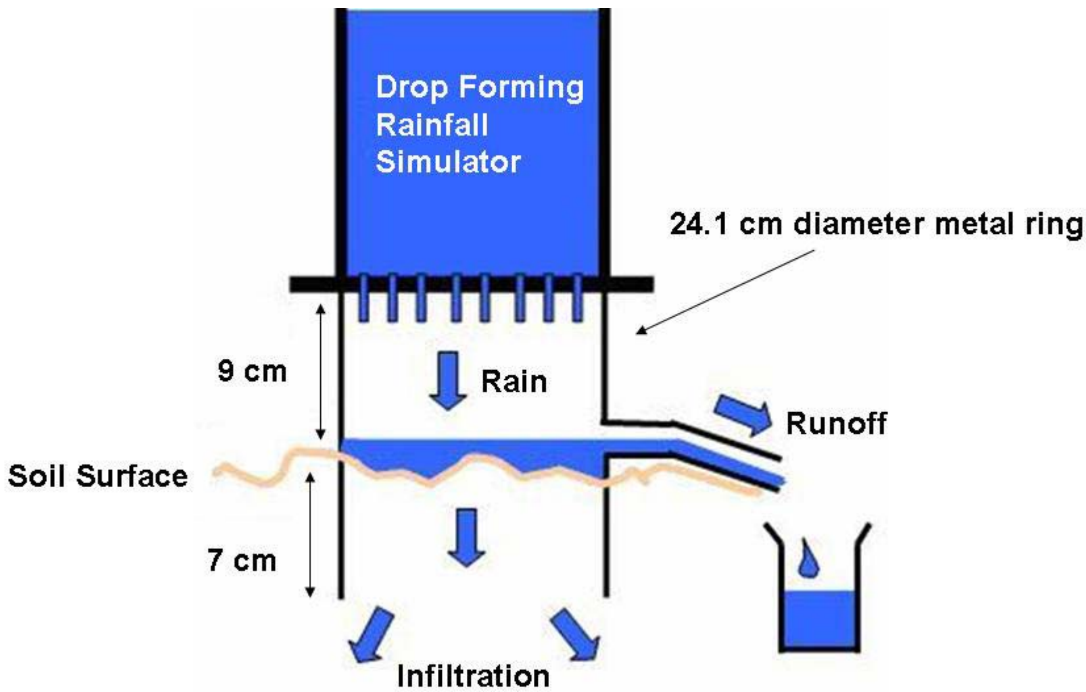

Figure 4.2 Diagram of rainfall simulator used in this study.

turf possible. An intensive, destructive density count was taken near the end of the study to measure the treatment effects on shoot density over the course of the study. Three plugs were taken with a golf hole cutter (10.2 cm diameter) and all shoots were counted.

Soil samples were taken to a depth of 0 – 5 cm and analyzed for available P on 1 May 2004, 9 Dec. 2004, 25 May 2005, and 28 Sept. 2005. Available soil P was measured using the method of Morgan (1941).

Statistical Analysis

Small-plot runoff research is usually associated with a very high degree of variation. For this reason, it is important to take steps to minimize variation to more accurately detect the effects of treatments employed. To minimize variance and increase our ability to detect effects we utilized a spatially balanced incomplete block design with 6 replications (Fig. 4.3). Each incomplete block consisted of 2 adjacent plots, which was found to be the most effective layout for minimizing error mean square and average coefficient of variation (van Es et al., 1989). Dummy variables were assigned to each plot and spatially balanced top to bottom and left to right across the hillside to give similar comparison distances within and among treatments which were assigned to the dummy variables randomly.

Treatment effects were determined by analysis of variance using the general linear model in the SAS software package (SAS Institute Inc, Cary, NC). Type III sums of squares were used to determine significance of model parameters. Linear regression analysis was performed by the SigmaPlot graphing software (SPSS Inc, Chicago, IL).

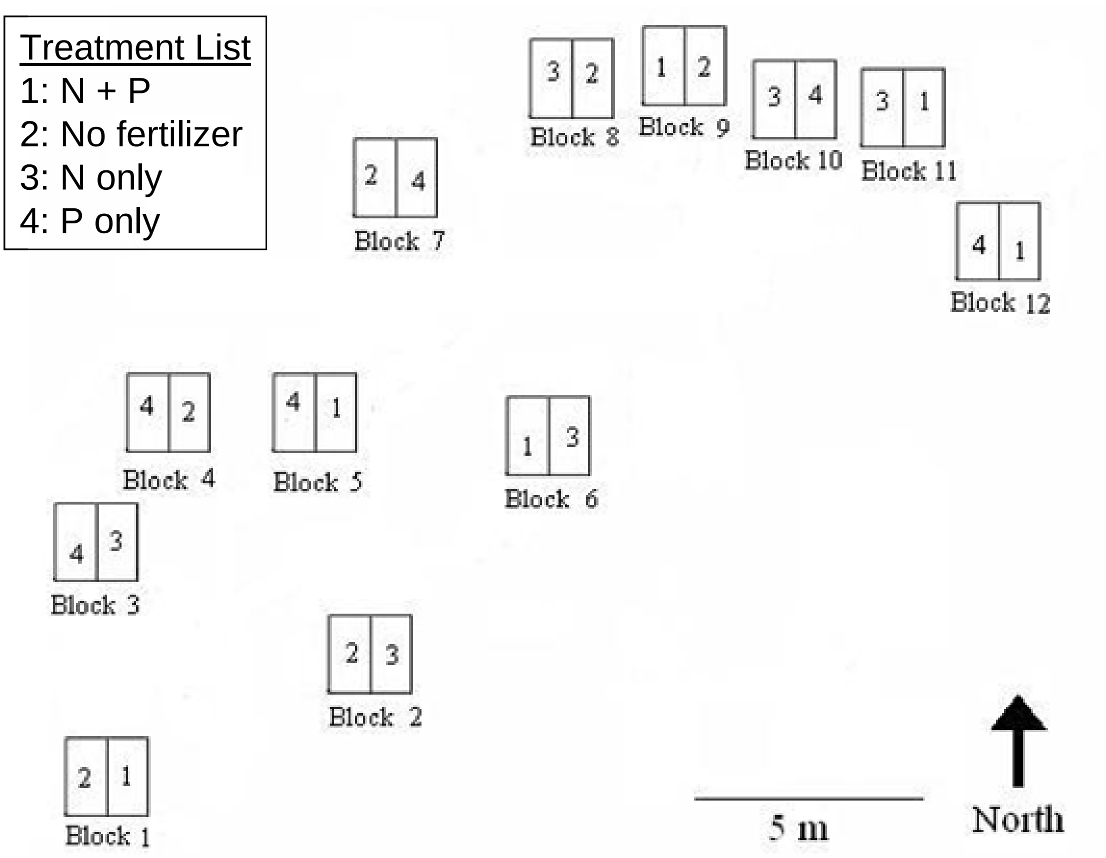

Figure 4.3 Layout of blocks on hillslope.

RESULTS AND DISCUSSION

Natural Runoff Events

The study site had a very low runoff potential. During the study, 18 runoff events from natural precipitation were observed. Precipitation averaged 1052 mm yr^{-1} over the study period, slightly greater than normal for Ithaca, NY (948 mm yr^{-1}). The amount of precipitation associated with the 18 runoff events was 533 mm. The average amount of runoff from the plots over the same time period was 3.2 mm, meaning only 0.6% precipitation from runoff-causing storm events became runoff, or only 0.2% of total precipitation became runoff. The results of the study should be interpreted with these facts in mind. Sites with low runoff potential are not uncommon in the northeastern USA and these results are applicable to these areas.

In only 3 of the events was runoff observed on more than 80% of the plots, thus preventing individual statistical analysis of most runoff events. Therefore, runoff depths and mass P losses were summed, and P concentrations were averaged for statistical analysis.

Total runoff losses were not affected significantly by either nitrogen or phosphorus fertilization (Table 4.1). A possible explanation for this was that turf quality differences among the treatments were observed on only 4 of the 11 dates. On these four dates the differences plots receiving N had significantly greater turf quality ratings than the others. The greatest difference was observed on 28 June 2005 when plots with N had a turf quality rating of 1.2 units higher than plots that did not receive N. For the unfertilized control plots, turf quality dipped below 6.0 on only 2 of the 11 dates.

On 26 Sept. 2005, an intensive shoot density count was taken and no significant differences were found among the treatments (mean shoot density = 123 tillers dm^{-1}). It can be concluded that, over the 2-year study period, fertilization with N did not create large differences in turf quality or shoot density, and therefore fertilization effects on runoff depth were not observed.

Although differences in runoff depth were not influenced by fertilization practices ($p = 0.27$ and 0.99), they were influenced ($p=0.08$) by block (Table 4.1). Plots near to each other tended to have similar runoff depths although no clear trends based on slope, soil texture, or spatial location in runoff could be identified as has been shown by Easton et al. (2005).

Dissolved P concentrations were significantly affected by plot location, P fertilization, and N fertilization (Table 4.1). Interestingly, fertilization with nitrogen increased the average dissolved P concentration in the runoff compared to the non-fertilized plots (Table 4.2). Clipping yield or tissue P content was not measured during this study. However, it is possible that N fertilization increased clipping yield without decreasing clipping P content compared to the unfertilized control resulting in a greater amount of P in tissue to interact with runoff water. Indeed, Petrovic et al. (2005) found that applying N fertilizer increases clipping yield as well as increasing tissue P content.

Similarly, but less surprisingly, significantly greater P runoff concentrations were measured for plots fertilized with P than those that were not (Table 4.2). The source of P from these plots could be from direct fertilizer losses, an increase in P content of the tissue, or and increase in clipping yield; though the latter two explanations are unlikely based on the soil P levels of the test site being adequate for maximum growth of the test site (Petrovic et al., 2005). No significant difference existed between the P concentrations in runoff from turfgrass fertilized with N or P. Total P concentrations were not significant for any of the model parameters (Table 4.1).

Dissolved and total P runoff mass losses were small (DP < 0.1 kg ha^{-1}; TP < 0.14 kg ha^{-1}) and no significant differences were detected among treatments (Table 4.2). Mass loss is the product of runoff volume and P concentration in the runoff. In this study treatment differences in runoff were not detected ($p = 0.27$ and 0.99), but treatments significantly influenced P concentration. Differences in mass losses were not detected because the large amount of error associated with runoff volume (Table 4.2) masked the differences in concentration among treatments. Dissolved P losses from plots receiving P accounted for 0.2% of the P applied. When corrected for the control plots, dissolved P losses were 0.04% of P applied. Total P losses from plots receiving P accounted for 0.05% of applied P when P in control plots was accounted for. These losses are in accordance with other studies on runoff P losses from turfgrass from natural events. Kussow (1996) observed no increase in P loss due to P fertilizer application, and an expected annual P loss of 0.2 – 1.3 kg ha^{-1}; however P fertilizer was always applied with N fertilizer thus confounding the results. Easton and Petrovic (2004) found runoff losses of P fertilizer ranged from less than the control to 0.6% of P applied for various P sources when compared to unfertilized control plots during the first two years after seeding. In their study, N was always applied with P which allowed for the fertilized plots to establish quicker and thus reduced runoff losses compared to the unfertilized control plots. Gross et al. (1990) found dissolved PO_4-P losses ranged from 0.007 – 0.12 kg ha^{-1} yr^{-1} from plots that did not receive any P fertilizer. The differences in mass P loss were explained by the amount of rainfall in a given year. Similarly we found that dissolved and total P load was more closely related to runoff volume than P concentration (Fig. 4.4).

We did not observe a reduction in P loss due to the application of N as found by the two previously mentioned studies. Researchers have reported greater P losses in studies where rainfall simulators are used to force runoff immediately following a fertilizer application. Schuman (2002) found 10 -11% of applied P was lost from turfgrass when runoff was forced 4 hours after P application; and Linde and Watschke

(1997) found runoff P losses of 11% of P applied when runoff was forced 8 hours after the application.

Although the range in Morgan extractable soil P levels represented over 60% of the variation in soil P levels of lawns and athletic fields in New York State (Soldat, 2007), extractable soil P level had no influence on the average concentration of P in the runoff (Table 4.1) or the total mass loss of P (Fig. 4.5). Similarly, Barten and Janke (1997) found a poor relationship ($r^2 = 0.14$) between soil P and dissolved P in runoff from turfgrass over a very wide range of soil P levels (5 – 65 mg kg^{-1} Bray-1 P). Much recent work in agriculture has shown that dissolved P concentrations in runoff tend to be strongly correlated with soil P levels especially within a soil type (Maguire et al., 2005). However, significant sediment loss is rarely observed from established stands of turfgrass (Gross et al., 1990; Gross et al., 1991; Linde et al., 1995; Easton and Petrovic, 2004), suggesting a reduced interaction between the runoff and soil.

Simulated Runoff Events

Over the course of the study, six runoff events were simulated to supplement the data from the natural runoff events. We were able to generate runoff from each plot on all simulation dates allowing for the data from each date to be analyzed individually. During rainfall simulation, data were collected to allow us to calculate the infiltration rate of each plot which serves the same purpose as runoff depth from the natural runoff events.

Statistically significant differences in infiltration rate among the treatments were detected on two of the six simulation dates (Table 4.3). In both cases, the N+P treatment had a significantly greater infiltration rate than the other three treatments which were not significantly different from each other. Also, on each of these dates the plot location was statistically significant (Table 4.3). These findings agree with the results of the

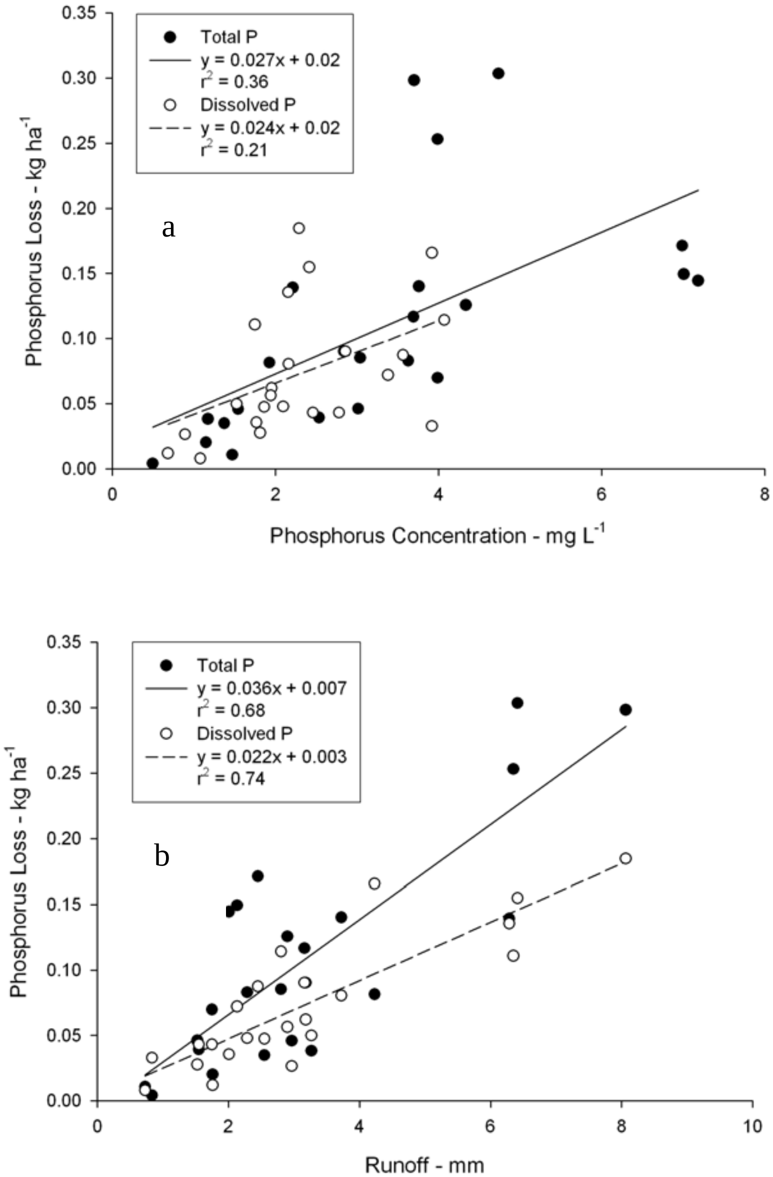

Figure 4.4 Relationship between (a) dissolved or total P concentration and dissolved or total P mass loss and (b) relationship between runoff depth and dissolved or total P mass loss.

Table 4.1 ANOVA table for total runoff depth, and average dissolved (DP) and total P (TP) concentrations in runoff.

Source of Variation	D.F.	Runoff	DP	TP	DP	TP
		mm	mg L^{-1}	mg L^{-1}	kg ha^{-1}	kg ha^{-1}
		---------------------------------p-value---------------------------------				
Block (plot Location)	11	0.08	<0.01	0.29	0.04	0.31
Soil P level	1	0.58	0.58	0.85	0.26	0.71
Nitrogen level	1	0.99	0.03	0.26	0.17	0.48
Phosphorus level	1	0.27	0.02	0.66	0.08	0.75
Nitrogen x phosphorus	1	0.30	0.46	0.27	0.53	0.75

Table 4.2 Effect of N and P fertilization on mean dissolved P (DP) and total P (TP) concentrations and mass losses in runoff water.

Treatment	Runoff (s.e.)	DP (s.e.)	TP (s.e.)	DP (s.e.)	TP (s.e.)
kg ha^{-1} yr^{-1}	mm	mg L^{-1}	mg L^{-1}	kg ha^{-1}	kg ha^{-1}
N					
0	3.14 (0.48) a	2.09 (0.17) b	2.83 (0.85) a	0.063 (0.011) a	0.099 (0.033) a
200	3.22 (0.43) a	2.75 (0.15) a	4.37 (0.76) a	0.089 (0.010) a	0.136 (0.29) a
P_2O_5					
0	2.84 (0.40) a	2.10 (0.14) b	3.86 (0.71) a	0.061 (0.010) a	0.110 (0.028) a
50	3.52 (0.46) a	2.74 (0.16) a	3.34 (0.79) a	0.093 (0.011) a	0.125 (0.031) a

Table 4.3 Analysis of variance table for infiltration rate for simulated events.

	D.F.	28 July 2004	23 Sept. 2004	27 June 2005	23 July 2005	24 Sept. 2005	27 Sept. 2005
Source of Variation		-----------------------------------p-value-----------------------------------					
Block (plot location)	11	0.460	0.194	0.023	0.035	0.758	0.496
N Level	1	0.464	0.405	0.121	0.038	0.351	0.145
P Level	1	0.788	0.172	0.212	0.210	0.057	0.324
N x P Level	1	0.889	0.849	0.007	0.126	0.082	0.923

natural runoff events where plot location was found to be the most significant factor in determining runoff depth.

An equal amount of runoff (7.5 mm) was collected from each plot in order to compare treatment differences in P concentration. With one exception, no significant differences in P concentration were observed among fertilization treatments. The exception, an event that occurred on 24 Sept. 2005, is clearly due to the P fertilizer application made on the previous day. On 23 July 2005, a rainfall event was also simulated 1 day after fertilizer was applied except in this case, no significant differences in dissolved P concentration were found among the treatments. This finding is likely due to the 15 mm of rainfall that fell during the night between the fertilizer application and the simulated rain event (Table 4.4). These results are supported by Shuman (2002) who found light irrigation following fertilizer application can greatly reduce P concentration in runoff from subsequent rainfall events. In general, these findings demonstrate that significant P losses from fertilizer can be expected only in cases where a runoff-causing storm event immediately follows an application of P fertilizer.

Soil P level did not predict runoff P concentrations on any of the 6 simulations dates (Table 4.4), these data support the findings of the data collected from natural events.

SUMMARY AND CONCLUSIONS

Mass losses of P in runoff were low as were losses of P associated with fertilizer application. Phosphorus mass losses were 0.05% of fertilizer applied for both dissolved and total P when corrected for P in the unfertilized control plots. The low mass losses of dissolved P (<0.05 kg ha^{-1} yr^{-1}) can be attributed to the small amount of rainfall that

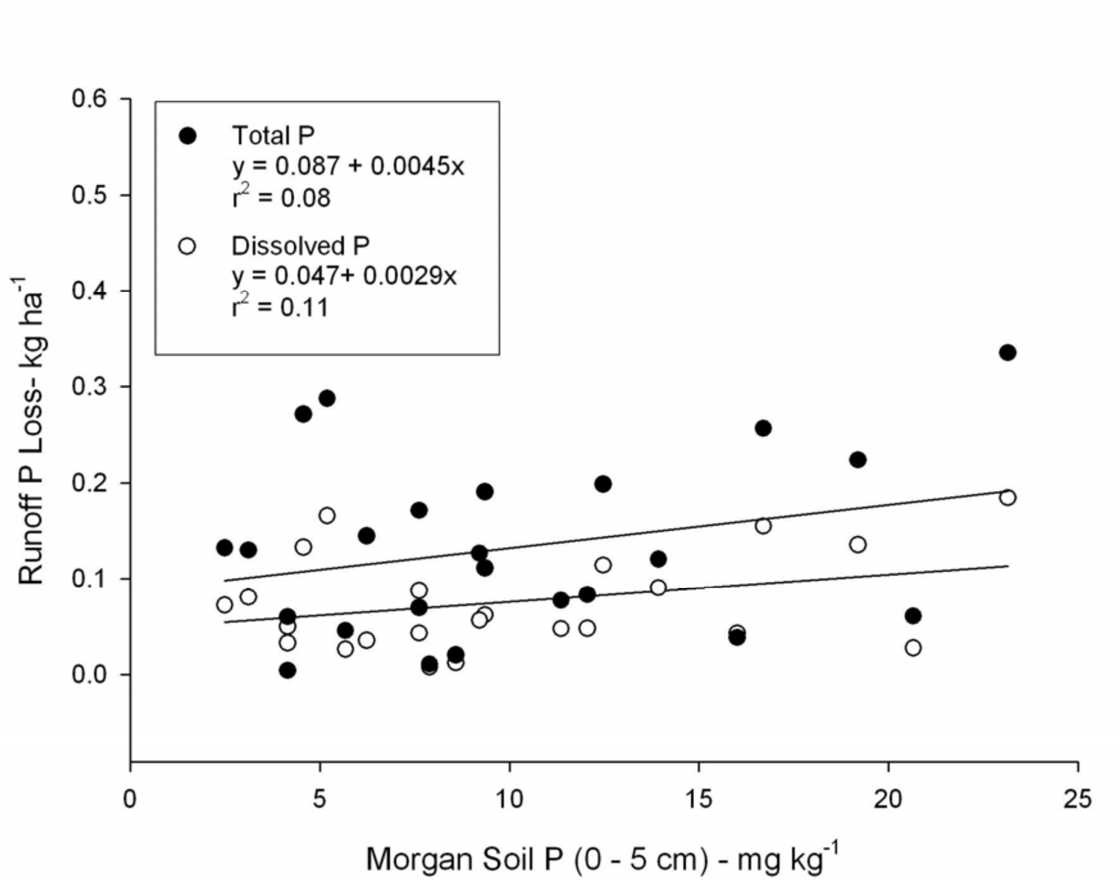

Figure 4.5 Relationship between soil P level and average runoff total P and dissolved P mass losses for natural runoff events.

Table 4.4 Analysis of variance table for dissolved P concentration in runoff from simulated events.

		Days after Fertilizer Application					
		18	14	18	1	1	4
		mm of precipitation that fell between fertilizer application and simulated runoff					
		119	89	74	15	0	230
		Simulation date					
	D.F.	28 July 2004	23 Sept. 2004	27 June 2005	23 July 2005	24 Sept. 2005	27 Sept. 2005
Source of Variation		-------------------------------------p-value-------------------------------------					
Block (plot location)	11	0.538	0.089	0.476	0.943	0.484	0.707
Soil P	1	0.119	0.632	0.383	0.634	0.534	0.161
N Level	1	0.581	0.974	0.217	0.128	0.923	0.528
P Level	1	0.528	0.280	0.751	0.321	0.004	0.209
N x P Level	1	0.894	0.171	0.579	0.539	0.362	0.722

became runoff (0.2%). Application of N or P did not affect the amount of runoff from natural events. However, fertilization with N and P increased the concentration of dissolved P in the runoff to a similar extent. This suggests that P in turfgrass tissue may be an important source of P in runoff from turfgrass areas. The simulated events supported the data observed from the natural events in most cases. Significant differences in runoff P loss occured only when no precipitation fell between a fertilizer application and a simulated runoff event. One difference between the natural and simulated events was that increases in P concentration were not observed with N fertilization for simulated events as were seen in the natural events. The reason for this is unknown but is likely related to the differences in runoff from simulated and natural events. If tissue P is indeed an important source of P in runoff then management practices that can reduce these losses should be developed or employed. The results of this study suggest that fertilization of established turfgrass does not result in a reduction in runoff volume for this soil type and when similar growth responses to N similar to those observed in this study are expected. Because increased P concentrations were associated with N or P fertilization, the environmental impacts of turfgrass could be reduced by withholding or limiting N and P fertilizers under these conditions.

Soil P levels had no effect on runoff P concentrations or mass losses for both natural and simulated runoff events, despite soil P levels ranging from 3.7 to 35.6 mg kg^{-1} at the 0 – 5 cm depth. This suggests that predictions of runoff P loss from turfgrass based on soil P level could be misleading or inaccurate.

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