CHAPTER 3: THE EFFECT OF SOIL PHOSPHORUS LEVELS ON PHOSPHORUS RUNOFF CONCENTRATIONS FROM TURFGRASS

ABSTRACT

Phosphorus (P) loss from urban areas has been identified as a major contributor to declining surface water quality. The objective of this study was to determine the relationship between soil P level and runoff P concentration from turfgrass areas. Three soil P extractants (Morgan, Mehlich-3, and 0.01 *M* $CaCl_2$) and three soil sampling depths were evaluated. A small rainfall simulator (241 mm diameter) was used to force runoff from turfgrass areas at 6 locations selected to represent the soil and climactic diversity of New York. At each site, runoff was generated on turfgrass and adjoining areas where turfgrass cover was removed having a wide range of soil P levels. Across all soil types, the 3 soil P extractants predicted P levels in runoff equally well (r^2 = 0.42 – 0.64). However, small but important improvements in runoff P concentrations were achieved when relative soil P saturation was used in lieu of extractable soil P. Despite a high degree of soil P stratification, shallower sampling depths provided little improvement in estimating runoff P losses for the three extractants. Presence of turfgrass cover resulted in a 32 – 79% decrease in the slope of the relationship between soil P and runoff P concentration, likely due to decreased interaction between runoff and soil at the expense of an increased interaction with turfgrass vegetation. This suggests that tissue P could be an important contributor to P in runoff from turfgrass areas. Supporting this hypothesis was the observation that at low soil P levels, P concentrations were greater from turfgrass than from bare soil. We found little evidence to suggest soil testing is a good predictor of runoff P concentrations from turfgrass (r^2 = 0.02 – 0.23) across the range of soil P levels common to lawns in New York (0 – 50 mg kg^{-1} Morgan extractable soil P.

INTRODUCTION

Eutrophication is the leading cause of surface water body impairment in the US (USEPA, 2002). In freshwater bodies, P is often the nutrient which limits primary production, and is therefore associated with eutrophication (Correll, 1998). Agricultural and urban areas are cited as major contributors of P to surface water bodies (USEPA, 2002). Recently, there has been a great amount of research on the effect of soil P levels and management practices on the loss of P in overland flow in agro-ecosystems (Sims and Sharpley, 2005); but relatively little work has been conducted on P loss from urban areas and in particular, turfgrass which has been recently estimated to account for 1.8% of the land surface area of the US with an acreage 3 times greater than that of irrigated corn (Milesi et al., 2005).

There are a few potentially important ways in which turfgrass ecosystems differ from agricultural systems. First, sediment losses from turfgrass areas tend to by much lower than those of cropland and grazed pastures (Soldat, 2007) suggesting a decreased interaction between runoff and soil at the expense of an increased interaction with vegetation. Soil P levels under turfgrass have the potential to become highly stratified due to the surface application of P-containing fertilizers as incorporation occurs very infrequently. Soil P levels have been shown to be up to 6 times greater in the upper 7.5 cm compared to soil 7.5 – 15 cm deep in a sand-matrix putting green root zone (Branham et al., 1996); however, the degree of P stratification in finer textured soils in turfgrass systems has not been documented.

Recently, in an attempt to reduce P losses from urban areas, governments at the state and local level have shown interest in, or passed legislation to restrict the use of P fertilizer to turfgrass areas. Generally, the legislation prohibits the application of P fertilizer unless a soil or tissue test can be provided showing an agronomic need for P. Researchers in Wisconsin concluded that lawns and driveways contribute large P loads in residential areas (Bannerman et al., 1993). However, other researchers have generally found P fertilizer to be a relatively small source of P in runoff from turfgrass (Kussow, 1996; Easton and Petrovic, 2004). In addition, it has been estimated that 50% of homeowners do not apply fertilizer to their lawns (Bonnaffon, 2006). For these reasons, losses of P from sources other than fertilizer, such as soil, may prove to be important in identifying areas prone to increased runoff P loss. When information on sources of P in runoff from turfgrass is coupled with model-generated information on where disproportionate amounts of runoff are occurring, management practices could be implemented to reduce P losses in these areas.

Therefore, the objective of this study was to determine the relationship between soil P levels and P concentrations in runoff from turfgrass areas. To achieve this objective we studied the effect of various soil sampling depths and soil P extractants on the concentration of P in runoff from turfgrass areas growing on soils with a wide range in soil P levels, including turfgrass areas that received P fertilizer or composted animal manures.

MATERIALS AND METHODS

Description of Research Sites

To capture the variability of soil types and climates throughout New York State, data were collected on research plots in six cities distributed widely throughout New York State (Fig. 3.1). These cities included: Farmingdale, NY at the Bethpage State Park Golf Course on Long Island; Ithaca, NY at the Cornell University Turf and Landscape Research Center (Central NY); Lake Placid, NY on the Lake Placid Resort Club in the Adirondack State Park in Northeastern NY; Rochester, NY on a soccer field at Genesse Valley Park (Lake Ontario Shore); Slate Hill, NY on a football field at the

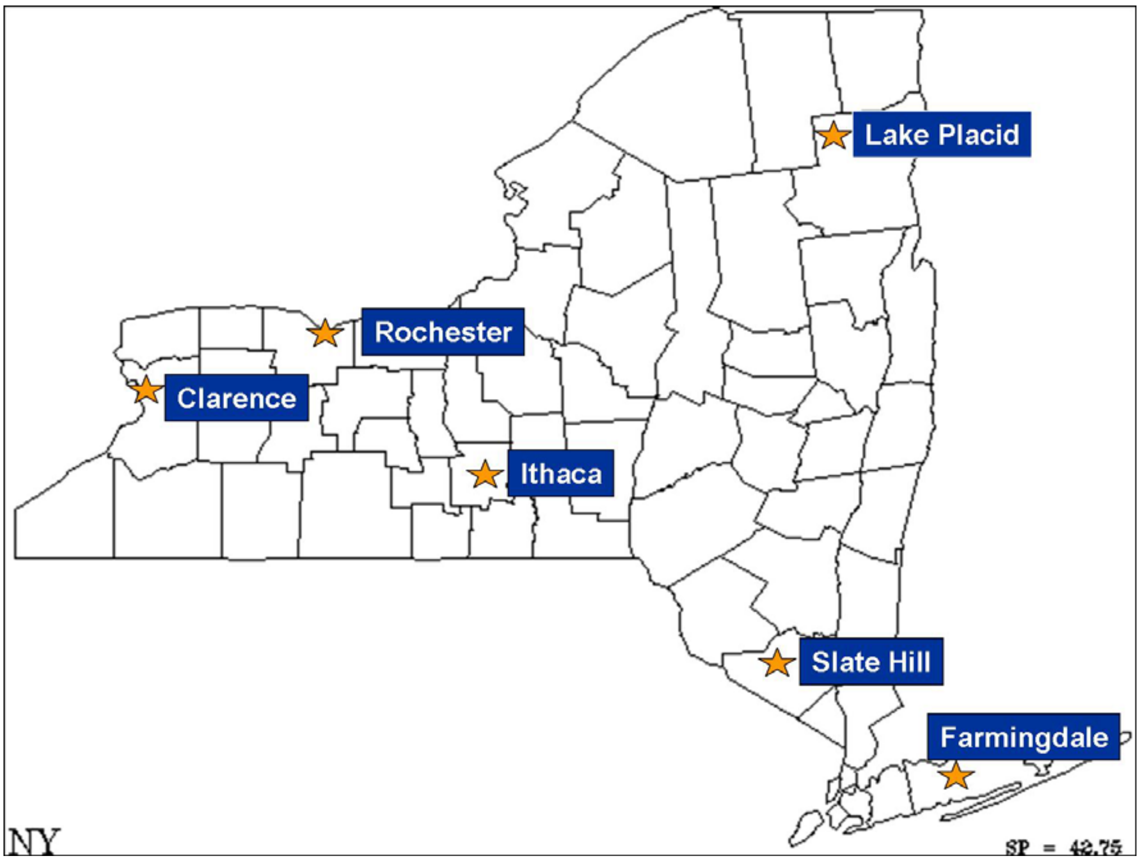

Figure 3.1 Locations of study sites.

Minisink School District (Southeastern NY); and Clarence, NY on a baseball field in Town Park (Western NY).

The sites in Monroe, Slate Hill, and Rochester were part of an ongoing study examining the effect of composted manure on turfgrass quality. The study was initiated in 2003 and treatments consisted of 1) unfertilized control 2) fertilized at an annual rate of 98 kg N ha^{-1}, as sulfur-coated urea 3) composted dairy manure applied to an annual depth of 6 mm and 4) composted dairy manure applied to a depth of 12 mm per year. Soil and compost properties are listed in Tables 3.1 and 3.2, respectively. At the time of data collection, plots had received a year's worth of compost or fertilizer split into 2 annual applications. Runoff was generated over a four day period beginning 9 May 2005; approximately 9 months following the final compost or fertilizer application on each of the 4 treatments (3 replications).

The sites in Lake Placid and Farmingdale were established with *Poa pratensis* L., *Festuca longifolia* Thuill., and *Lolium perenne* L. in 2001 and 2002 respectively. These sites were part of a soil test calibration study for turfgrass growing in New York., that is described in detail by Petrovic et al. (2005). Four of the ten treatments (3 replications each) were used in this study. They were selected to provide a wide range in extractable soil P and consisted of plots receiving either 0, 23, 44, or 88 kg P_2O_5 ha^{-1} yr^{-1} as triple super phosphate (0 – 45 – 0). The annual rate was split into four equally sized applications. The Lake Placid plots received 3 years of fertilizer applications before they were used in the current study. The Farmingdale plots received 2 years of fertilizer treatments prior to rain simulation. Fertilizer was not applied for 9 months prior to our rain simulation at each of the sites. Runoff was generated on 28 June 2005 in Lake Placid and on 31 May 2005 in Farmingdale.

The site in Ithaca, NY was part of a study examining the effect of various fertilizer sources on runoff water quality (Easton and Petrovic, 2004). The varying N: P

Table 3.1 Soil classifications and properties of study sites.

Location (NY)	TaxonomicClass	Soil Series	Texture	Sand	Clay	pH†	O.M. ‡	S_{max}*
				%	%		%	mg kg^{-1}
Farmingdale	Typic Dystrudepts	Enfield	Loam	46.7	10.5	5.3	8.8	435
Ithaca	Lamellic Hapludalfs	Arkport	Sand loam	66.0	9.1	4.9	5.3	98
Lake Placid	Typic Haplorthods	Monadnock	Sand loam	77.7	2.6	5.0	15.6	833
Slate Hill	N/A §	N/A §	Sand loam	70.5	7.8	6.3	14.1	64
Clarence	Glossic Hapludalfs	Wassaic	Loam	48.3	15.0	6.3	9.7	217
Rochester	Aeric Endoaqualfs	Niagara ¶	Very fine sandy loam	61.3	9.6	6.8	5.7	123

† 1:1 in 0.01 *M* $CaCl_2$
‡ O.M; organic matter by loss on ignition (16 h at 400°C)
* S_{max}; Phosphorus sorption maximum as determined by Nair et al. (1984).
§ N/A; not applicable, plots on an athletic field with a constructed root zone.
¶ classified as urban land by soil survey, nearest classified soil is Niagara silt loam

Table 3.2 Properties of composted dairy manure used on plots in Clarence, Slate Hill, and Rochester.

Compost properties	Dairy Compost #1 (Clarence, Rochester)	Dairy Compost #2 (Slate Hill)
Solids, %	39.3	31.0
pH	7.9	7.4
Soluble salts, mmhos cm^{-1}	4.1	4.8
Organic Matter, %	38.0	67.5
Total N, %	1.7	1.8
Total P, %	0.38	0.33
Total C, %	20.1	38.1

ratios of the fertilizers used in that study resulted in a wide range of soil P levels. Rainfall was simulated in the current study on 27 Sept. 2003, 2 years after the final fertilizer application was made to the site.

Rainfall simulation and runoff

Runoff was generated on research plots using a portable miniature rainfall simulator described by Ogden et al., 1997. In addition to collecting runoff from turfgrass, runoff was also collected from bare soil within each plot by carefully removing the turfgrass with a flat garden spade. This allowed for a comparison of the effect of turfgrass cover on P in runoff.

The simulator sits 9 cm above the soil surface atop a 24 cm-diameter stainless steel ring inserted 7 cm in to the soil (Fig. 3.2). Mean water droplet size was 4.0 mm. The first 7.5 mm of runoff from each simulation was collected in a polypropylene storage bottle and saved for analysis. Rainfall rate was adjusted based on the individual plot or site to achieve a constant runoff rate of approximately 5 cm hr^{-1} for each simulation event. This meant that plots with greater infiltration rates would receive greater amounts of total water – possibly diluting the P concentration in the runoff. However, after controlling for soil test P, we failed to find a significant relationship between runoff P concentration and total water applied for any site. This suggests that the amount of water applied did not affect P concentration in runoff.

Runoff water was analyzed for dissolved reactive phosphorus (DRP) using a sensitive colorimetric method (Murphy and Riley, 1962) after passing the runoff through a 0.45 μm membrane. Sediment in each runoff sample was measured by evaporating a 50 mL sub-sample for 48 hours at 105 °C, weighing the remaining material, and correcting for soluble salts in the simulation water.

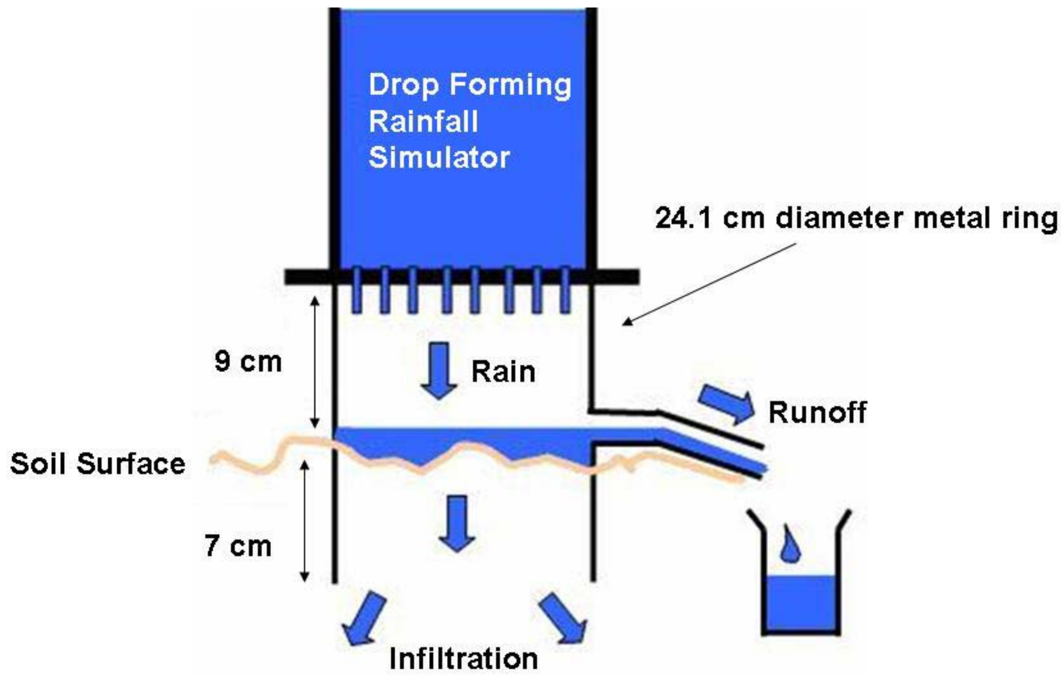

Figure 3.2 Diagram of simulator with relevant measurements.

Soil Sampling and Analysis

Composite soil samples were taken to depths of 0 – 2 cm, 0 – 5 cm, and 0 – 15 cm from each plot. Soil samples were air-dried, ground and passed through a 2 mm sieve. Extractable soil P was measured for each depth using the Mehlich-3 extractant (Mehlich, 1984), the Morgan extractant (Morgan, 1941), and a 0.01 *M* $CaCl_2$ extractant (Olsen and Sommers, 1982). Particle size distribution for the soil at each site was determined using the pipette method (Gee and Or, 2002). Separate soil samples were taken to determine soil moisture at the time of sampling. Organic matter was determined by loss on ignition for 16 hours at 400 C.

Phosphorus sorption isotherms were calculated following the procedure of Nair et al. (1984). The P sorption maximum (S_{max}) for each soil was calculated as the reciprocal of the slope of the regression between C/S and S; where C is the concentration of P in solution and S is the concentration of sorbed P. Soil P saturation was calculated for the Morgan and Mehlich-3 soil tests at the 0 - 2 cm sampling depth by dividing the soil test P (mg kg^{-1}) by the sum of S_{max} (mg kg^{-1}) and the soil test P (Kleinman and Sharpley, 2002).

Statistical Analysis

The relationship between extractable soil P level or soil P saturation and P in runoff was described either by a linear model or a split-line model (Mcdowell and Sharpley, 2001) using the REG and NLIN procedures respectively in the SAS software package (SAS Institute INC, Cary, NC). The split-line model describes two different linear relationships before and after a statistically determined change point. R-squared values reported for split-line model were calculated as the proportion of sum of squares of the non-linear model divided by the total sum of squares. An F-test was used to determine whether the split-line model is appropriate in place of a linear model. The

General Linear Model and Regression procedures in the SAS software package were used for all other statistical tests.

RESULTS AND DISCUSSION

The soils selected for this study represented had a wide range of physical and chemical properties. Sand content of the 6 sites ranged from 47 – 78% (Table 3.1). P sorption maximum varied by a factor of 13, and organic matter content ranged from 5.3 – 15.6%. The pH of all sites was < 7.0.

Effect of soil sampling depth on runoff P concentrations

Morgan soil P level at the 0 – 5 cm depth across all sites ranged from 0.03 – 372 mg kg^{-1} (Table 3.3), accounting for 99% of the variation of soil P levels of home lawns and athletic fields according to an analysis of soil samples sent to the Cornell Nutrient Analysis Laboratory between 2001 and 2005 (Soldat, 2007). As expected, soil P was highly stratified throughout the soil profile. Soil test P levels from 0 – 5 cm were 33 – 45% lower than those from 0 – 2 cm. Samples taken from 0 – 15 cm were 63 – 79% lower than soil test P levels at the 0 – 2 cm depth (Table 3.3). These results clearly demonstrate the importance of specifying a soil sampling depth when fertilizer recommendations are to be based on the results from a soil test. Testing a soil at a shallower or deeper depth than that of which the calibrations were originally based could lead to erroneous fertilizer recommendations.

The high degree of stratification suggests that sampling depth may determine the effectiveness of a soil P test to predict runoff P losses from a site. Several researchers have found little advantage to using a shallower soil sample in lieu of a traditional

Table 3.3 Ranges and mean soil P values for three sampling depths and for the three soil P extractants used in this study.

		Soil P Extractant					
	Sample	Morgan		Mehlich-3		0.01 *M* $CaCl_2$	
Location (NY)	Depth	Mean (SD†)	Range	Mean (SD)	Range	Mean (SD)	Range
	cm	----------------	----------------	---------------- mg kg^{-1}	----------------	----------------	
All Sites							
	0 – 2	73 (129)	0.3 – 658	205 (214)	10 – 930	5.4 (5.3)	0.07 – 20.4
	0 – 5	40 (73)	0.3 – 372	137 (143)	7 – 609	3.5 (3.6)	0.09 – 15.2
	0 – 15	15 (28)	0.2 – 165	74 (61)	7 – 275	1.5 (1.6)	0.02 – 7.4
Clarence							
	0 – 2	209 (238)	7.6 – 658	321 (345)	17 – 930	8.3 (7.9)	1.0 – 20.4
	0 – 5	105 (134)	3.4 – 372	178 (206)	10 – 600	4.5 (5.2)	0.6 – 15.2
	0 – 15	37 (50)	2.4 – 165	75 (83)	8 – 275	1.2 (1.2)	0.3 – 4.3
Rochester							
	0 – 2	132 (143)	8.0 – 384	264 (245)	32 – 699	6.6 (5.6)	1.0 – 14.9
	0 – 5	72 (80)	3.8 – 236	177 (160)	28 – 456	3.8 (2.8)	1.0 – 8.3
	0 – 15	35 (39)	2.4 – 102	108 (86)	27 - 258	2.1 (1.1)	0.3 – 3.8
Slate Hill							
	0 – 2	163 (106)	45 – 331	487 (179)	272 – 808	10.8 (4.1)	5.3 – 17.7
	0 – 5	108 (61)	41 – 239	371 (115)	227 – 609	7.7 (2.5)	4.5 – 12.3
	0 – 15	ND§	ND	ND	ND	ND	ND
Lake Placid							
	0 – 2	3.4 (4.5)	0.3 – 15	49 (49)	10 – 162	0.3 (0.3)	0.07 – 1.2
	0 – 5	1.2 (1.3)	0.3 – 4.6	22 (18)	7 – 68	0.3 (0.3)	0.09 – 1.1
	0 – 15	0.8 (0.5)	0.2 – 2.0	16 (7)	7 – 27	0.1 (0.04)	0.05 – 0.2
Farmingdale							
	0 – 2	13 (10)	4 – 40	91 (59)	40 – 257	0.4 (0.3)	0.18 – 1.5
	0 – 5	5 (4)	1 – 14	54 (29)	19 – 125	0.2 (0.08)	0.08 – 0.36
	0 – 15	2 (1)	1 - 4	34 (14)	12 - 58	0.06 (0.03)	0.02 – 0.12
Ithaca							
	0 – 2	18.3 (7.7)	8 – 40	140 (66)	60 – 318	5.5 (2.9)	1.7 – 14.4
	0 – 5	9.9 (5.6)	3 – 27	98 (45)	43 – 245	4.0 (3.0)	0.7 – 13.7
	0 – 15	9.2 (4.0)	4 – 19	96 (39)	48 - 208	2.3 (1.7)	0.8 – 7.4

† SD; Standard deviation of the mean

§ ND; No data for 0 – 15 sampling depth at Slate Hill, NY; soil was only 10 cm deep.

agronomic sample in agricultural systems (Schroeder et al., 2004; Daly and Casey, 2005, Pote et al., 1996, Pote et al., 1999, Andraski and Bundy 2003). This may be due to a high degree of correlation of soil P levels among depths as a result of tillage and/or consistent cultural practices. However, this condition may not apply to home lawns in the US where approximately 50% of homeowners do not apply fertilizer to their lawns (Bonnaffon, 2006), and the other 50% do so to differing extents. A survey of turfgrass fertilization practices in 5 North Carolina communities found 70% of turfgrass areas were fertilized (Osmond and Hardy, 2004), but the number of annual fertilizer applications ranged from none to 5 (0 – 155 kg N ha^{-1} yr^{-1}, annual P fertilization rate unknown). This will presumably lead to varying degrees of soil P stratification in lawns, making soil sampling depth a potentially very important factor for predicting runoff P losses.

The six sites used in this study contained a mixture of fertilized and unfertilized plots (at least since researchers gained control of the plots). Large differences existed in the relationship between soil P levels of different depths for the fertilized and unfertilized plots. A very strong correlation was found to exist for extractable soil P at 0 – 2 cm and 0 – 15 cm depths for the unfertilized turfgrass plots in the study. However, the relationship for fertilized plots is much weaker and exhibits a slope of over twice that of the unfertilized plots (Fig. 3.3). Therefore, differing fertilization practices should lead to differences in the degrees of soil P stratification. Sampling soil deeper than the depth at which runoff interacts with the soil, or effective depth of interaction (EDI) may lead to poor predictions of P loss from turfgrass soils. The EDI has been shown to vary with slope, rain intensity, soil aggregation, and ground cover (Sharpley, 1985). Assuming a typical lawn has a relatively low slope and high degree of ground cover, an EDI > 0.5 cm would be unusual (based on data from Sharpley, 1985). However, sampling soil to a depth less than 2 cm may prove to be impractical.

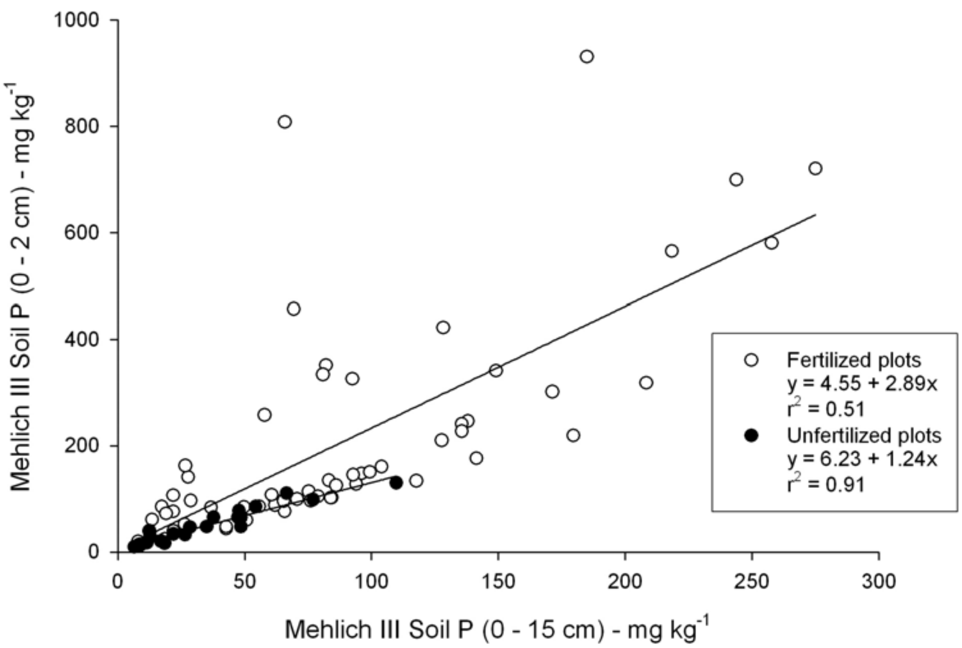

Figure 3.3 Relationship between Mehlich-3 soil P levels at 0 – 2 cm and 0 – 15 cm sampling depths.

For this study, despite the differences in P stratification among the research plots discussed above, no obvious advantage was gained from sampling soil from a shallower depth for the Morgan and 0.01 *M* $CaCl_2$ soil P extractants (Table 3.4). Using shallower samples accounted for more variability in the relationship between of Mehlich-3 extractable P and runoff P than deeper samples, but the increase in r^2 values never exceeded 11%. These data support the findings of previous researchers that using shallower sampling depths provide little obvious benefit over using their deeper agronomic counterparts for predicting concentrations of P in runoff.

Effect of Soil P Level on Runoff P concentrations

Agronomic soil extractants were developed to estimate plant availability of nutrients. However, research has shown that they are also useful for predicting P release from soil to runoff (Sharpley, 1995). To be used effectively, these soil tests should be calibrated with environmental response data, just as they must be calibrated with crop response or yield data for agronomic interpretation.

In an attempt to improve predictions of P release from soil to water, other environmental soil P tests have been proposed. These are designed to more accurately represent the release of P from soil to water that occurs during a runoff or drainage event. Such tests include but are not limited to, deionized water, 0.01 M $CaCl_2$, iron oxide-impregnated filter paper, and anion exchange resins. In this study, the two conventional soil test extractants predicted P concentrations in runoff as well as the non-conventional 0.01 *M* $CaCl_2$ test for the 0 - 2 cm sampling depth (Fig. 3.4) and for deeper sampling depths as well (Table 3.4). R-squared values ranged from 0.42 – 0.64 for turfgrass plots and from 0.46 – 0.60 for bare soil plots. Percent soil P saturation was calculated for the Morgan and Mehlich-3 tests by using data from P sorption isotherms.

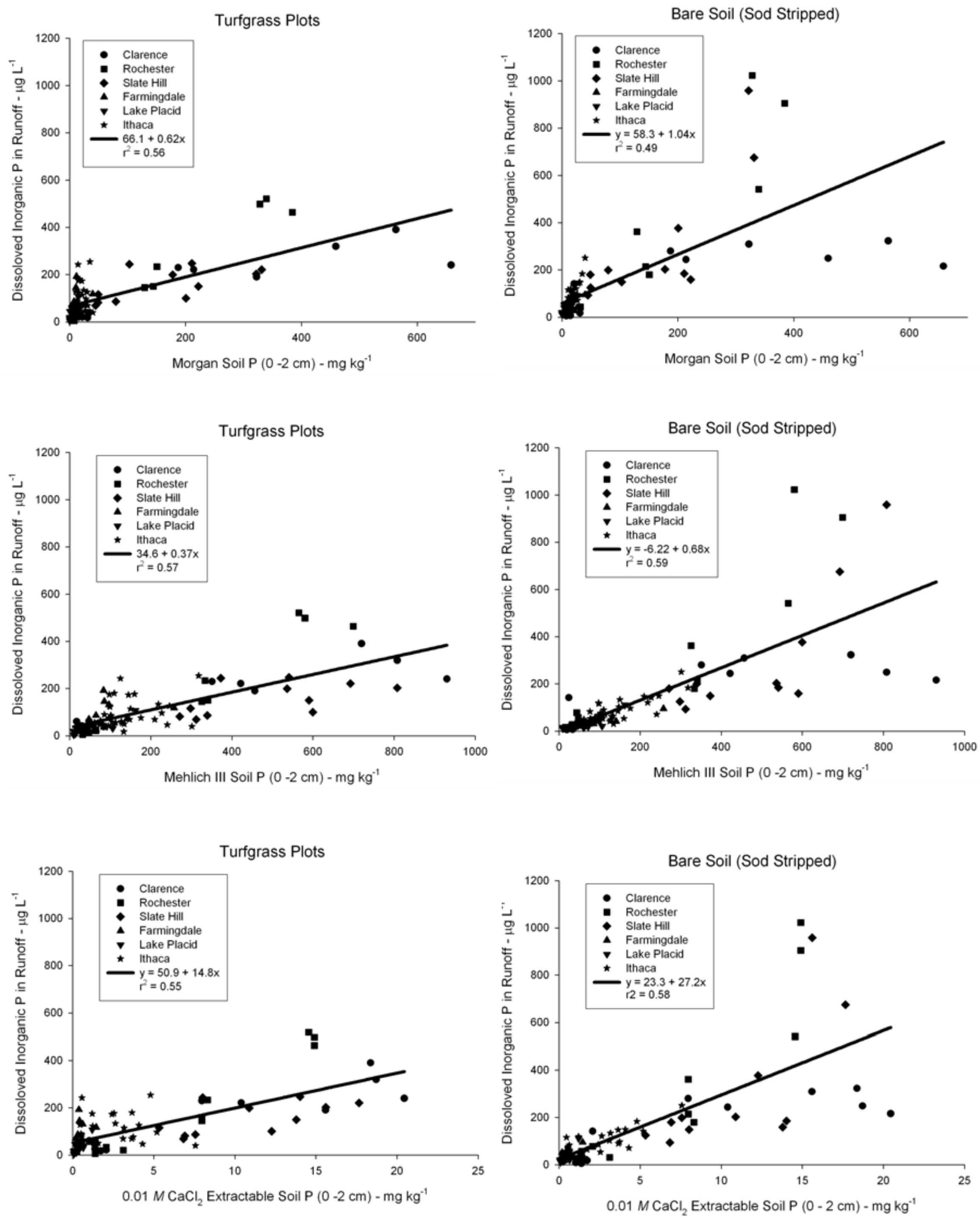

Figure 3.4 Relationships between various soil test P levels at 0 – 2 cm and dissolved inorganic phosphorus in runoff from plots with and without turfgrass.

Phosphorus release from soil to water has been found to be soil specific (Sharpley, 1995) and can also vary significantly within a soil series (Schroeder et al., 2004). To account for these differences, soil P saturation has been used to predict P concentration in runoff in place of a soil test with great success (Sharpley 1995). In this study, soil P sorption improved runoff P predictions -- although not necessarily evident by the r^2 values. For example, when Morgan soil test values were used to predict P concentration in runoff for bare soil and turfgrass plots, several data points were clustered below 50 mg kg^{-1} (Fig. 3.4). However, when Morgan soil P saturation was used to predict P in runoff, the cluster disappeared (Fig. 3.5). This area of the relationship is important because the soil P level of the majority (over 95%) of home lawns and athletic fields in New York fall within this range (Soldat, 2007).

When soil P sorption isotherm data were used to calculate percent P saturation with Mehlich-3 and Morgan soil P levels, a split-line model was sometimes appropriate over a linear model for identifying a distinct change point above which losses of P increased at a greater rate per unit increase in soil P than below it (Fig. 3.5, Table 3.5). Table 3.5 shows the relationship between soil P saturation for both Morgan and Mehlich-3 extractants and runoff P. A split-line model was evident for 5 of 6 bare soil relationships, the exception being the Morgan extractant at the 0 – 15 cm sampling depth. However, for turfgrass plots a split-line model was only evident for the Mehlich-3 extractant at the 0 – 2 cm testing depth. For this relationship, the slope of the line after the change point was also much lower than those associated with the bare soil plots (Fig. 3.5). All other relationships were linear for plots with turfgrass cover, suggesting that the dense vegetation significantly alters the release of P from soil to runoff compared to bare soil.

Because over 95% of home lawns and athletic fields in New York were found to have Morgan-extractable soil P levels below 50 mg kg^{-1} (Soldat, 2007), we analyzed the

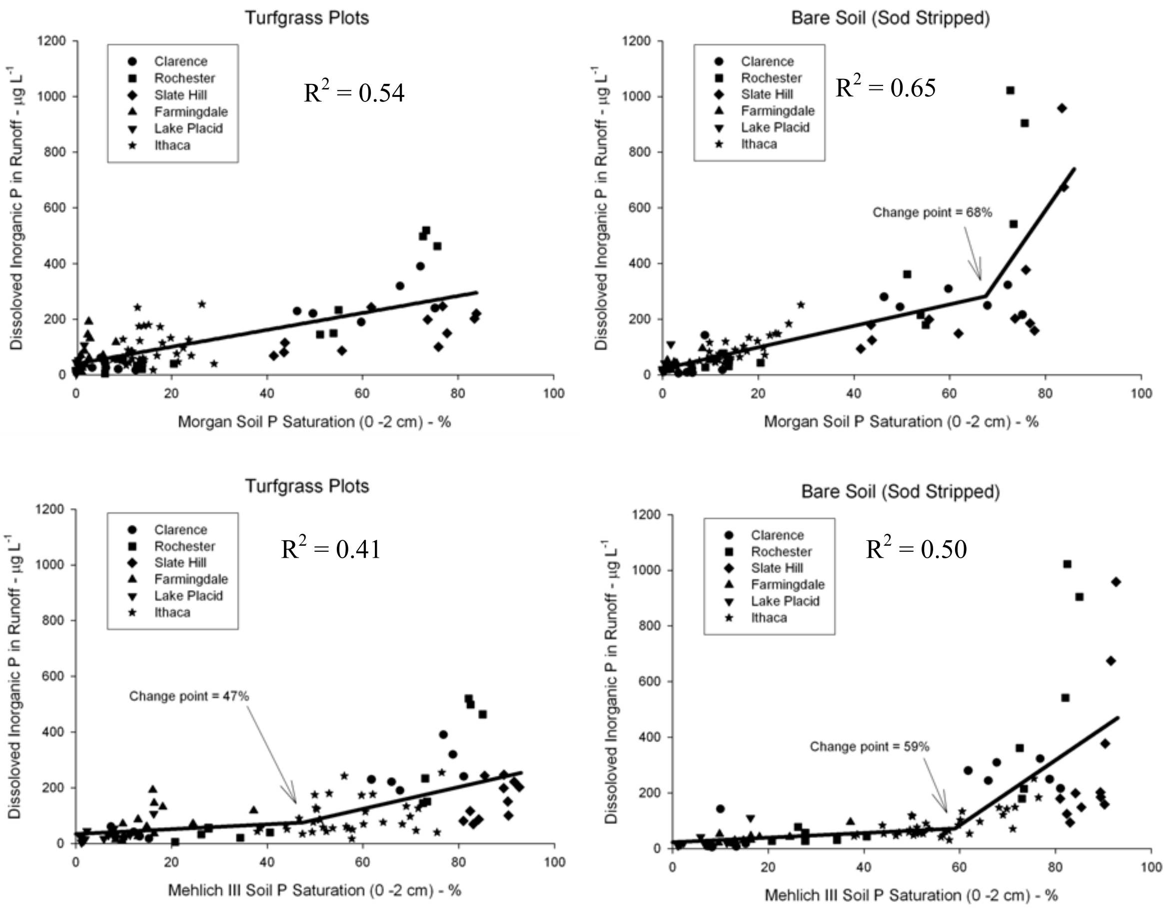

Figure 3.5 Relationship between Morgan and Mehlich-3 soil P saturation at the 0 – 2 cm sampling depth and dissolved inorganic phosphorus in runoff from plots with and without turfgrass.

Table 3.4 Properties of the linear relationship between soil P levels and P in runoff for 3 soil P extractants, 3 soil sampling depths, and two ground covers.

		Morgan			Mehlich-3			0.01 *M* $CaCl_2$		
Ground Cover	Depth	Y-Int	Slope	r^2	Y-Int	Slope	r^2	Y-Int	Slope	r^2
	cm	$\mu g\ L^{-1}$			$\mu g\ L^{-1}$			$\mu g\ L^{-1}$		
Turfgrass	0-2	66.1	0.62	0.56	34.6	0.37	0.57	50.9	14.8	0.55
	0-5	68.0	1.07	0.53	38.9	0.53	0.51	45.8	20.4	0.42
	0-15	58.0	3.15	0.64	8.0	1.30	0.52	38.7	89.6	0.56
Bare Soil	0-2	58.3	1.04	0.49	-6.22	0.69	0.59	23.3	27.1	0.58
	0-5	56.2	1.92	0.54	-7.00	1.03	0.60	10.2	38.6	0.46
	0-15	42.5	4.60	0.59	-37.6	2.00	0.53	2.73	147	0.64

Table 3.5 Relationships between P in runoff and two measures of soil P saturation from bare soil and turfgrass plots.

		Morgan P Saturation				Mehlich-3 P Saturation			
Ground Cover	Depth	Change point	Y-Int	Slope 1	Slope 2	Change point	Y-Int	Slope 1	Slope 2
	cm	%	$\mu g\ L^{-1}$			%	$\mu g\ L^{-1}$		
Turfgrass	0-2	NA†	39.9	3.05	NA	47	34.3	0.87	3.90
	0-5	NA	53.4	3.34	NA	NA	20.3	2.27	NA
	0-15	NA	33.0	8.87	NA	NA	30.0	2.46	NA
Bare Soil	0-2	68	21.3	3.86	24.7	59	22.7	0.83	11.7
	0-5	68	28.1	5.66	49.4	51	21.1	1.43	9.48
	0-15	NA	-1.0	13.8	NA	61	30.6	1.77	75.3

† NA; Change point model not statistically different than nested linear model.
Slope 1, slope of line prior to change point
Slope 2, slope of line after change point reached

effect of soil P on runoff concentration for only those plots with Morgan soil test P of less than 50 mg kg^{-1} at the 0 – 5 cm depth. Across this range, extractable soil P and soil P saturation were very poor predictors of runoff P concentration from turfgrass plots (Table 3.6), as r-squared values ranged from 0.02 – 0.23. However, for bare soil, the r-squared values were similar across the representative range (Table 3.6) to the entire range for the bare soil plots (Table 3.4). We did not found evidence to suggest that soil testing (as extractable P or soil P saturation) could be used practically to predict P concentrations from turfgrass areas from lawns in New York.

Effect of Ground Cover on Runoff P Concentrations

For these six research sites, only linear relationships existed between extractable soil P level and P in runoff (shown in Fig. 3.4 for 0 - 2 cm sampling depth). Slopes of the relationship between extractable soil P and runoff P were 32 – 79% lower for plots with turfgrass (Table 3.4). The observation that ground cover has an effect on the slope of the relationship between soil P and runoff P has been noted previously by others (Sharpley et al., 2001). At very high soil P levels, the turfgrass cover presumably reduced the interaction of the runoff with the soil, thus reducing the contribution of soil P to runoff. In addition, the Y-intercepts were always greater for plots with turfgrass than those without (Table 3.4). This suggests that at very low soil P levels, greater concentrations of P can be expected from turfgrass areas, presumably due to release of P from sources not accounted for by a soil test such as dead or living turfgrass tissue. This is not to say that greater P losses can be expected from these areas, as lower runoff volumes would most likely occur from an area with turfgrass than an area with bare soil. Indeed, in this study turfgrass plots had infiltration rates 2.7 times greater ($p < 0.0001$) than bare soil plots. This information is important as it suggests vegetation is a relevant source of P in runoff from turfgrass, especially across the range of soil test

Table 3.6 Properties of the linear relationship between soil P levels and P in runoff for 3 soil P extractants, 3 soil sampling depths, and two ground covers. Data were selected to represent 96% of soil P variability in NY.

		Morgan			Mehlich-3			0.01 *M* $CaCl_2$			Morgan P Saturation			Mehlich-3 P Saturation		
Ground Cover	Depth	Y-Int	Slope	r^2	Y-Int	Slope	r^2	Y-Int	Slope	r^2	Y-Int	Slope	r^2	Y-Int	Slope	r^2
	cm	µg L^{-1}			µg L^{-1}			µg L^{-1}			µg L^{-1}			µg L^{-1}		
Turfgrass	0-2	46.4	1.57	0.10	52.2	1.75	0.10	33.2	1.04	0.21	52.2	1.75	0.10	33.2	1.04	0.21
	0-5	55.9	1.77	0.08	59.3	1.77	0.07	39.1	1.06	0.19	59.3	1.77	0.07	39.1	1.06	0.19
	0-15	39.8	5.39	0.19	45.0	5.45	0.19	40.4	1.10	0.18	45.0	5.45	0.19	40.4	1.10	0.18
Bare Soil	0-2	13.8	3.08	0.51	23.4	3.56	0.53	10.9	1.42	0.52	23.4	3.56	0.53	10.9	1.42	0.52
	0-5	33.2	3.35	0.38	37.9	3.62	0.39	16.5	1.52	0.51	37.9	3.62	0.39	16.5	1.52	0.51
	0-15	16.4	7.58	0.55	24.0	7.61	0.52	19.5	1.47	0.45	24.0	7.61	0.52	19.5	1.47	0.45

values typical to home lawns in New York. It also helps to explain the lack of a good relationship between soil P and runoff P concentrations across this range (Table 3.6).

The 0.01 M $CaCl_2$ extractant has been recommended for estimating dissolved reactive P in subsurface drainage (McDowell and Sharpley, 2001). Although P leaching was not measured in this study, the relationship between 0.01 M $CaCl_2$ extractable P and Morgan and Mehlich 3 extractable P was assessed (Fig. 3.6). A change point, a soil P saturation level above which the increase in 0.01 M $CaCl_2$ extractable P is greater per unit increase in P saturation than below it was evident at 11% Morgan P saturation and 53% for Mehlich III P saturation. Research comparing these data to actual P levels in drainage from turfgrass or agricultural land is needed.

CONCLUSIONS

In this study we found that traditional soil tests predicted P concentration in runoff from turfgrass similarly to the non-conventional 0.01 *M* $CaCl_2$ extractant that was designed to more accurately simulate the interaction of runoff and soil. Despite the differing degrees of soil P stratification in the profile of turfgrass soils, shallower testing depths provided little benefit over the standard 0 – 15 cm sample commonly recommended for interpreting soil nutrient availability. Using soil P saturation yielded small, but important improvements in the soil P/runoff P relationship; the small improvements were especially evident at the low range of the dataset, coinciding with the majority of soil P levels for lawns in New York. When the dataset was reduced to include only soil P levels representative of the majority of New York lawns (< 50 mg kg^{-1}), extractable soil P and soil P saturation were poorly correlated with P

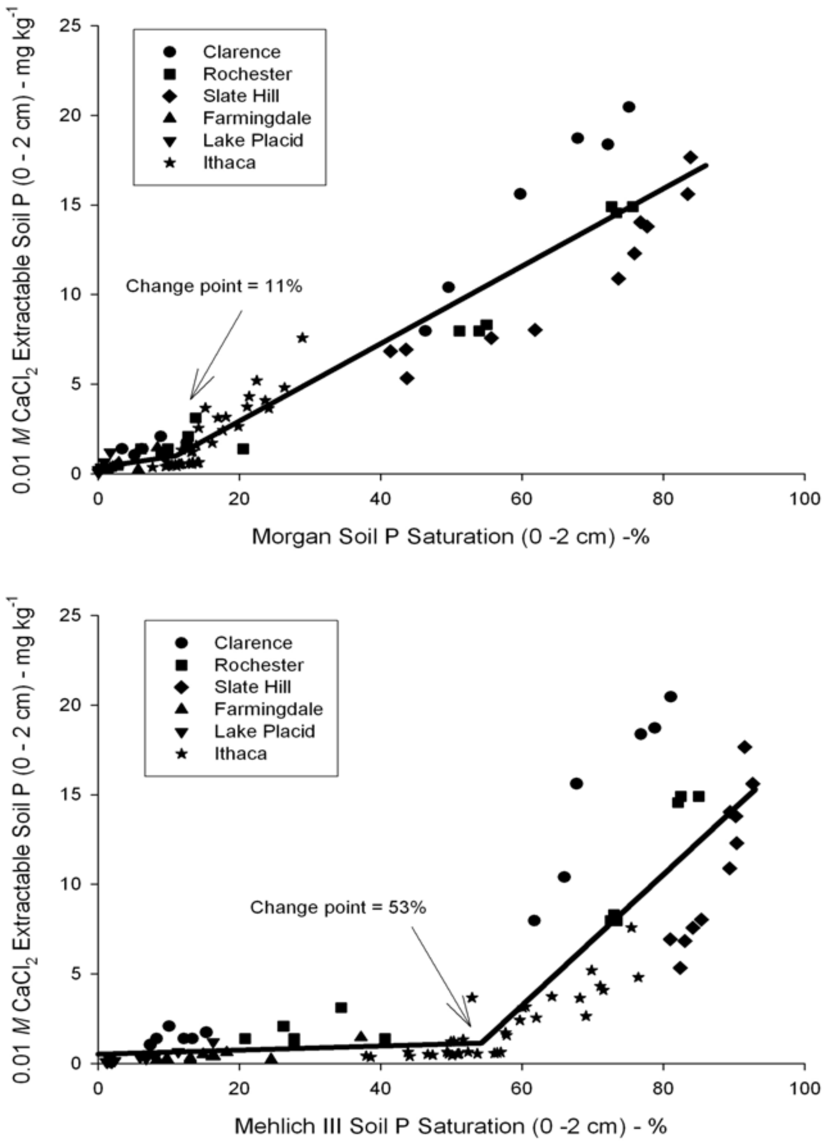

Figure 3.6 Relationship between Morgan and Mehlich 3 soil P saturation and 0.01 M $CaCl_2$ extractable soil P at the 0 – 2 cm sampling depth.

concentration in the runoff. Therefore, we did not find evidence to suggest that soil testing is an efficient tool for predicating losses of P in runoff from turfgrass areas.

Turfgrass cover resulted in a 32 – 79% reduction in the slope of the relationship between soil P and runoff P. This means that at high soil P levels, lower concentrations of P in runoff are expected from turfgrass than bare soil. However, the Y-intercept for sites with turfgrass cover was greater, which suggests that vegetation is contributing to P in the runoff. Future work should focus on identifying the relative contributions of various sources of P in runoff from turfgrass and urban areas in general.

In this study losses of P through leaching were not considered. It is imaginable that leaching could be an important pathway in some urban landscapes as the lack of soil disturbance could allow for the development of a network of stable macropores. A good relationship was found between soil P saturation and 0.01 *M* $CaCl_2$ extractable P across the wide range of soil types used in this study. This indicates the potential for specifying an environmental threshold above which leaching losses become unacceptable. However, this relationship should be tested against actual leaching losses of P from turfgrass and agricultural areas. It is unknown if turfgrass cover alters the relationship between soil P and P concentration in leachate as it was found to do for runoff P concentrations.

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