CHAPTER 5: SOIL PHOSPHORUS LEVELS AND STRATIFICATION AS AFFECTED BY FERTILIZER AND COMPOST APPLICATIONS

ABSTRACT

Phosphorus can accumulate in the upper soil profile of turfgrass areas where P-containing fertilizers are commonly applied and soils are infrequently mixed. However, little information exists that describes how soil P levels and vertical distribution throughout the soil profile are influenced by common home lawn fertilization practices and the addition of soil amendments such as composted manures. Two field studies were designed to provide more information on how common fertilization practices may influence the concentration and distribution of P in turfgrass soils. The first study examined how common turfgrass fertilization practices influence the soil P levels and vertical distribution (stratification) of soil P. The second study was conducted to determine how the application of composted manures can affect soil P level and stratification throughout the profile. Application of P-containing fertilizer at rates ranging from 10 – 72 kg P_2O_5 ha^{-1} yr^{-1} over a period of 4 or 5 years increased soil P in the upper 0 – 5 cm of soil by a factor of 3.5 – 7.5 depending on the extractant used. Soil P levels at depths of 5 – 10 or 10 – 15 cm were not increased by fertilizer applications. Adding composted manures to plots at rates of 6 to 12 mm yr^{-1} resulted in a dramatic (up to 300 fold) increase in soil P in the upper 5 cm of soil. This is due to the large amount of P that is applied (186 – 470 kg ha^{-1}) when compost is added to turfgrass at these rates. Soil P levels also increased substantially at the deeper layers as a result of compost application. The results of this study suggest that common fertilization practices have a much smaller influence on soil P levels compared to composted

manures. The benefits of using composted manures must be weighed against the potentially negative environmental impacts that could result from a large increase in soil P level.

INTRODUCTION

Phosphorus (P) can accumulate in the upper soil profile when continuous surface P fertilizer applications are made due to the relatively high P sorption capacity of most soils compared to P application rates. In conventionally tilled soils, P is usually evenly distributed throughout the plow layer. However, vertical soil P stratification is likely to occur in no-till systems (Andraski et al., 2003) or in turfgrass areas where soil mixing is very infrequent. Howard et al. (1999) found soil test P levels in the upper 8 cm of soil to be 1.6 – 4.5 times greater than P levels in the layer from 8 – 15 cm in no-till cotton soils. Similar differences in soil test P level with respect to depth have been reported in sand-based putting green root zones (Branham et al., 2000; Guertal 2006).

The spatial distribution of P in the soil is important for both agronomic production and environmental protection. Phosphorus is used in plants (and all organisms) for energy transfer via the adenosine triphosphate molecule and P is also used as a structural component of DNA and RNA. Properly maintained lawns have been shown to reduce runoff and nutrient loading (Easton and Petrovic, 2004) and sequester C from the atmosphere (Qian and Follett, 2002). Adequate P is required by turfgrass to perform these functions. In addition to the potential environmental problems caused by inadequate P supply to turfgrass, declining surface water quality in the US has been linked to excessive P losses from agricultural and urban areas (Carpenter et al., 1998). Soil P level has been shown to be an important variable for predicting P loss from agriculture (Sharpley, 1995). Runoff interacts with and removes P from only the upper few cm of the soil (Sharpley, 1985). A traditional soil test is taken from the surface to 10-15 cm and therefore might not adequately account for the P in upper few cm.

Lawn maintenance practices of homeowners are known to vary widely (Osmond and Hardy, 2004). However, no information exists that describes the effect of various fertilization practices on soil P stratification in turfgrass areas on fine-textured soils. Therefore, one goal of this study is to examine how P stratification differs under a wide range of traditional homeowner fertilization practices.

Application of composted manures to turfgrass areas is a relatively new practice developed to reduce P inputs to soils associated with concentrated animal feeding operations, while attempting to improve the physical and chemical properties of urban soils (Cogger, 2005; Vietor et al., 2002). Many university extension bulletins explain the benefits of adding composted manures to urban soils; and Dane County, WI has specifically exempted compost from its ban on P-containing turfgrass fertilizer. However, little attention is paid to the fact that composted manures contain significant amounts of P. In addition, typically suggested application rates of compost are high enough to suspect that soil P is inadvertently being elevated to potentially environmentally hazardous levels. Therefore, a second goal of this work is to examine the effect of various sources and rates of composted manure on the vertical stratification of soil P.

MATERIALS AND METHODS

Description of Research Sites

To accomplish our objectives, two studies were conducted; each replicated at two different locations in New York State. The first study, hereafter referred to as the “fertilizer study”, was designed to investigate differences in P stratification under typical homeowner fertilization regimes was conducted in Lake Placid, NY at the Lake Placid Resort Club and Farmingdale, NY at Bethpage State Park. Soil properties of each site are described in Table 5.1. Treatments at each site were identical and selected to encompass a wide range of soil P fertility representative of potential homeowner fertilizing practices. A randomized complete block design was used. Treatments were replicated 3 times and consisted of: 1) unfertilized control, 2) 10 kg P_2O_5 ha^{-1} yr^{-1} (as triple superphosphate), 3) 19 kg P_2O_5 ha^{-1} yr^{-1} (as triple superphosphate), 4) 38 kg P_2O_5 ha^{-1} yr^{-1} (as triple superphosphate), and 5) 192 kg N ha^{-1} yr^{-1} + 72 kg P_2O_5 ha^{-1} yr^{-1} + 120 kg K_2O ha^{-1} yr^{-1} (as 8 – 3 – 5 Nature Safe organic fertilizer). The treatments receiving triple superphosphate were half, equal to, and double the recommendations based on soil test calibration data from the Cornell University Nutrient Analysis Laboratory in Ithaca, NY. Treatments were applied at a quarter of the annual rate in May, June, Sept. and Oct. each year. At the time of soil sampling to determine vertical P stratification, treatments had been applied for 5 years (2002 – 2006) at the Lake Placid site and for 4 years (2003 – 2006) at the Farmingdale site.

The second study, hereafter referred to as the "compost study", was designed to investigate the effect of applications of composted manure on vertical soil P stratification, was conducted at Genesee Park in Rochester, NY and on a youth baseball field in Clarence, NY. Soil properties for these two sites are also listed in Table 5.1. A randomized complete block design was used. Treatments were replicated 3 times and consisted of: 1) unfertilized control, 2) composted dairy manure applied to a depth 6 mm yr^{-1} (31 Mg dry matter ha^{-1}, 234 kg P ha^{-1}), 3) composted poultry manure applied to a depth of 6 mm yr^{-1} (28 Mg dry matter ha^{-1}, 186 kg P ha^{-1}), 4) composted dairy manure applied to a depth 12 mm yr^{-1} (62 Mg dry matter ha^{-1}, 470 kg P ha^{-1}), 5) composted poultry manure applied to a depth of 12 mm yr^{-1} (56 Mg dry matter ha^{-1}, 372 kg P ha^{-1}). Compost treatments were applied twice each year at half the annual rate. Properties of the composted dairy and poultry manure are listed in Table 5.2. At the time of soil sampling to determine vertical P stratification, treatments had been applied for 3 years (2003 – 2005). Turfgrass at all 4 locations was maintained in a similar fashion: plots were not irrigated and mowed as needed at a height of 5 cm, and clippings were returned.

Soil Sampling and Analysis

Composite soil samples (six per plot, 25 mm diameter) were taken in the fall of 2006 to depths of 0 – 5 cm, 5 – 10 cm, and 10 – 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). Soil particle size distribution was determined on 0 – 15 cm depth samples using the pipette method (Gee and Or, 2002). Soil organic matter content was determined on 0 – 15 cm samples by loss on ignition for 16 hours at 400 C.

RESULTS

Fertilizer Study

Average extractable soil P levels of unfertilized plots at Farmingdale were 2 – 7 times greater that of those at Lake Placid depending on which extractant was used (Table 5.3). The original soil P level at the Farmingdale site was classified as “Medium” according to Cornell University soil test interpretation (based on Morgan levels). Original soil P level at the Lake Placid site was classified as “Very Low”. However,

Table 5.1 Soil classifications and properties of study sites.

Location	Taxonomic Class	Soil Series	Texture	Sand	Clay	pH†	O.M. ‡
				%	%		%
Farmingdale, NY	Typic Dystrudepts	Enfield	Loam	46.7	10.5	5.3	8.8
Lake Placid, NY	Typic Haplorthods	Monadnock	Sand loam	77.7	2.6	5.0	15.6
Clarence, NY	Glossic Hapludalfs	Wassaic	Loam	48.3	15.0	6.3	9.7
Rochester, NY	Aeric Endoaqualfs	Niagara ¶	Very fine sandy loam	61.3	9.6	6.8	5.7

† 1:1 in 0.01 *M* $CaCl_2$

‡ O.M; organic matter by loss on ignition (16 h at 400°C)

¶ classified as urban land by soil survey, nearest classified soil is Niagara silt loam

Table 5.2 Properties of composted dairy and poultry manure used on plots in Clarence and Rochester.

Compost properties	Dairy Compost	Poultry Compost
Solids, %	39.3	64.6
pH	7.9	8.8
Soluble salts, mmhos cm^{-1}	4.1	9.8
Organic Matter, %	38.0	29.5
Total N, %	1.7	1.2
Total P, %	0.38	0.33
Total C, %	20.1	14.9

both sites were considered “Below Optimum” according to Penn State University soil P interpretations for home lawn maintenance (based on Mehlich 3 levels).

For unfertilized plots, vertical soil P stratification was minor, and no statistical differences in soil P level existed among the 3 sampling depths for the Morgan and Mehlich 3 extractants (Table 5.3). Soil P level was statistically greater in the 0 – 5 cm layer of unfertilized plots than in the 10 – 15 cm layer in Farmingdale for the 0.01 *M* $CaCl_2$ extractant, and statistically greater in the 0 – 5 cm layer than both deeper layers in Lake Placid.

In contrast to unfertilized plots, statistically significant soil P stratification existed for all fertilized plots for both sites with all extractants. Generally, greater P fertilization rates led to increased soil extractable P in the 0 – 5 cm layer regardless of extractant. However, plots fertilized at the lowest rate (10 kg P_2O_5 ha^{-1} yr^{-1}) did not have greater soil P levels compared to the unfertilized control plots in the upper 5 cm of soil. Plots fertilized at the highest rate (38 kg P_2O_5 ha^{-1} yr^{-1}) had P levels 3.5 times greater in the upper 0 – 5 cm than at 5 – 10 cm for the Mehlich 3 extractant, 7.5 times greater for the Morgan extractant, and 3.6 times greater for the 0.01 *M* $CaCl_2$ extractant. At depths of 5 – 10 cm and 10 – 15 cm, very few treatment differences existed suggesting that the movement of the P fertilizer was largely restricted to the upper 5 cm over the course of the study.

The inclusion of the organic treatment (72 kg P_2O_5 ha^{-1} yr^{-1}) was meant to assess how fertilization with an organic source to meet N needs of turfgrass (as is almost exclusively practiced) would affect soil P level and soil P stratification over time. In this study, we observed that although the P application rate of the organic source was double that of the greatest inorganic P fertilization rate, soil P levels were not significantly different between those two treatments. This result is not surprising as the inorganic source would be available for sorption by soil particles immediately following

Table 5.3 Mehlich 3, Morgan, and 0.01 *M* $CaCl_2$ soil P levels for 3 sampling depths at two sites where various rates of P fertilizer were applied for 4 and 5 years at Farmingdale and Lake Placid, respectively.

		Farmingdale, NY			Lake Placid, NY		
Depth of Sample	Treatment	Mehlich 3	Morgan	0.01 *M* $CaCl_2$	Mehlich 3	Morgan	0.01 *M* $CaCl_2$
cm	kg P_2O_5 ha^{-1} yr^{-1}	----------------------	----------------------	----------mg kg^{-1}	----------------------	----------------------	----------------------
0 – 5	0	30.5 BCD¶	2.51 BC	0.219 BC	11.3 EF	0.46 BC	0.231 A
	10†	34.6 BC	3.46 B	0.202 BC	21.0 CDEF	0.93 B	0.156 CDE
	19	99.5 A	12.83 A	0.669 A	25.6 CD	0.85 BC	0.161 BCD
	38	84.9 A	11.99 A	0.600 A	54.9 A	2.51 A	0.225 AB
	72 ‡	81.3 A	13.77 A	0.346 B	45.6 AB	2.57 A	0.185 ABC
5 – 10	0	21.6 CD	0.87 CD	0.104 CD	9.7 F	0.15 BC	0.087 F
	10	13.7 D	0.61 CD	0.063 CD	10.4 F	0.17 BC	0.042 FG
	19	44.2 B	2.18 BCD	0.110 CD	14.5 DEF	0.20 BC	0.063 FG
	38	24.3 BCD	1.59 BCD	0.081 CD	13.5 DEF	0.47 BC	0.063 FG
	72	32.0 BCD	1.55 BCD	0.098 CD	19.8 CDEF	0.32 BC	0.098 DEF
10 – 15	0	24.0 BCD	0.78 CD	0.006 D	19.7 CDEF	0.01 C	0.034 FG
	10	14.0 CD	0.33 D	0.006 D	21.8 CDEF	0.08 BC	0.040 FG
	19	24.5 BCD	1.07 CD	0.058 CD	26.5 CD	0.05 C	0.017 G
	38	19.6 CD	0.63 CD	0.075 CD	23.9 CDE	0.21 BC	0.046 FG
	72	31.7 BCD	1.15 CD	0.308 B	32.5 BC	0.40 BC	0.092 EF

† 10, 19, and 38 kg P_2O_5 ha^{-1} yr^{-1} treatments were applied as triple superphosphate

‡ 72 kg P_2O_5 ha^{-1} yr^{-1} treatment applied as 8 – 3 – 5 organic fertilizer

¶ Column means followed by the same letters are not statistically different, alpha = 0.05

dissolution, while the organic source would require mineralization before its P would be made available for soil sorption. Therefore, a larger amount of an organic source of P fertilizer is required to elevate soil P to a similar degree as a soluble inorganic source of P.

Compost Study

The sites in Clarence and Rochester had similar initial soil P values. Both sites had "High" soil P levels according to Cornell University soil test interpretation for home lawns (based on Morgan soil P levels). However, according to Penn State University soil test interpretation for home lawns, the Clarence site would be considered "Below Optimum" and the Rochester site would be considered "Optimum" (based on Mehlich 3 soil P levels).

Small, but statistically non-significant differences in soil P level among the three sampling depths existed for the un-amended control plots. The plots receiving applications of compost showed greatly elevated soil P levels in the upper 5 cm of soil (Table 5.4). Soil P levels in the upper 5 cm of soil were elevated in the following order: composted poultry manure at the high rate (12 mm yr^{-1}) > composted poultry manure at the low rate (6 mm yr^{-1}) > composted dairy manure at the high rate > composted dairy manure at the low rate. Although the total P content of both composts were similar (Table 5.2), and actual P application rates were greater for dairy compost than poultry compost; differences in P solubility or mineralization rate between composts may account for the different rates at which soil P levels increased in response to the compost applications.

The composted poultry manure at the high rate increased extractable soil P in the upper 5 cm to levels greater than 2 orders of magnitude over the control plots. The compost treatment which increased soil P to the least extent (dairy, low rate) exhibited

Table 5.4 Mehlich 3, Morgan, and 0.01 *M* $CaCl_2$ soil P levels for 3 sampling depths at two sites where composted dairy and poultry manure were surface applied at 2 rates for 3 years.

		Clarence			Rochester		
Depth of Sample	Treatment	Mehlich 3	Morgan	0.01 *M* $CaCl_2$	Mehlich 3	Morgan	0.01 *M* $CaCl_2$
cm		----------------	----------------	----------------	mg kg^{-1}	----------------	----------------
0 – 5	Control	22.8 F†	10.7 E	0.31 G	39.5 F	8.6 E	0.37 G
	6 mm dairy	381.0 D	290.4 D	7.69 EF	320.3 DE	157.9 CDE	6.45 DEF
	6 mm poultry	1121.7 B	1660.9 B	26.61 B	1079.3 B	1046.4 B	21.64 B
	12 mm dairy	797.8 C	623.5 C	16.40 C	775.9 C	347.7 C	15.72 C
	12 mm poultry	3879.4 A	3329.3 A	53.61 A	3349.9 A	2438.4 A	63.64 A
5 – 10	Control	55.7 F	5.4 E	0.10 G	59.0 F	22.1 E	0.21 G
	6 mm dairy	60.2 F	6.8 E	0.81 G	119.1 EF	36.0 DE	1.00 G
	6 mm poultry	293.9 DE	299.9 D	11.37 D	324.2 DE	170.0 CDE	4.55 EFG
	12 mm dairy	206.6 DEF	137.7 DE	5.21 F	261.3 DEF	123.5 DE	4.32 EFG
	12 mm poulry	703.8 C	492.1 C	26.2 B	454.1 D	237.4 CD	8.21 DE
10 – 15	Control	23.8 F	6.8 E	0.06 G	35.2 F	5.4 E	0.11 G
	6 mm dairy	26.9 F	7.9 E	0.19 G	54.0 F	5.5 E	0.11 G
	6 mm poultry	137.6 EF	74.9 E	1.55 G	123.3 EF	33.5 E	1.88 FG
	12 mm dairy	206.6 DEF	20.3 E	0.25 G	77.6 EF	16.8 E	4.32 EFG
	12 mm poultry	313.4 DE	264.4 D	8.48 DE	207.5 DEF	102.5 DE	9.86 D

† Column means followed by the same letters are not statistically different, alpha = 0.05

soil P levels 8 – 27 times greater than the control plots depending on which extractant was considered.

Significant P stratification was evident in plots receiving compost. Mehlich 3 soil P in the upper 0 – 5 cm was 2.7 – 7.4 times greater than in the 5 – 10 cm layer. Morgan soil P levels were 2.8 – 42.7 times greater in the upper 5 cm and 0.01 M $CaCl_2$ was 2 – 14.7 times greater in the upper 5 cm than in the 5 – 10 cm layer.

DISCUSSION

Although the two studies were not designed to allow for direct statistical comparison, important differences between the two are evident. Several years of fertilization at various rates with inorganic and organic sources of P increased soil P levels only in the upper 0 – 5 cm of soil. In addition, fertilization at a rate of 10 kg ha^{-1} over a period of 4 to 5 years did not change soil P compared to the unfertilized control over the course of the study. In a review of the literature Soldat (2007) estimates that watershed scale inputs of P fertilizer to home lawns (on a watershed-scale) likely ranges from 3 – 10 kg ha^{-1}. This suggests that under normal situations, typical fertilization practices are unlikely to greatly influence soil P levels in the upper 0 – 5 cm over a period of 4 to 5 years. Fertilization at relatively high rates of P resulted in substantial increases of soil P level in the upper 0 – 5 cm of soil; however, few differences in soil P level were detected in the soil below the 0 – 5 cm depth. Turfgrass roots are known to extend significantly deeper than 0 – 5 cm (Beard, 1973). In addition, plant roots have been shown to proliferate in patches of high soil P (Hodge, 2004). Given the degree of P stratification witnessed under the conditions of this study, one logical question is: to what extent does the soil P stratification influence root architecture and distribution?

Other questions remain as to how the potentially altered root distribution could influence turfgrass water use and drought tolerance.

In contrast to the fertilizer study, the use of composted dairy or poultry manure at 2 different rates resulted in a large increase in soil P level across all depths; although highest soil P levels were observed in the 0 – 5 cm depth. At this depth, compost elevated soil P to levels that would likely take decades or centuries to achieve through the “normal” fertilization practices as demonstrated by the fertilizer study. This is a result of the large P application that is made when composted manures are applied to amend soil physical properties. Based on the known relationship between soil P level and runoff from turfgrass (Soldat, 2007), it can be concluded that composted manures should not be used in environmentally sensitive areas where runoff or leaching losses are likely to occur.

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