Phosphorus Movement under a Decommissioned Septic System in Southern Wisconsin

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Abstract

Excess phosphorus in the environment has been linked to water quality degradation throughout the world and the agricultural community often is cited as a major source of phosphorus pollution. However, there are many other potential sources that allow phosphorus to enter the environment, such as domestic wastewater treatment systems. The effluent released into the soil by septic systems can contain concentrations of phosphorus in the range of 5 to 20 mg P L^{-1} (Robertson, 2003). These values are well above the levels that cause eutrophication and, therefore, these sites need to be thoroughly examined to determine the possibility of phosphorus loss into both surface and ground water.

In 1988, a research septic system was installed at the Arlington Agricultural Research Station in Columbia County, Wisconsin to study the effects of domestic waste on the environment. The system was operated continuously and then decommissioned in the early 2000s. In 2004, we extracted soil cores in a grid pattern around a septic chamber to study the mobility and distribution of phosphorus at the site. Preliminary results of the Bray P-1, total P and P sorption studies show much higher concentrations of phosphorus below the septic system chamber than in the surrounding soil. Immediately beneath the septic chamber, soluble P reached as much as 0.7 mg P L^{-1}, compared to 0.1 mg P L^{-1} adjacent to the septic chamber, and 0.01-0.03 mg P L^{-1} 25-cm and 1-m distant from the septic chamber. Further analysis of these systems is needed to determine the environmental risks associated with these levels of phosphorus in the soil profile.

Introduction

Many Canadian studies, including Robertson (2003); Robertson and Harman (1999); Zanini et al. (1998); and Zurawsky et al. (2004), have examined active and decommissioned septic system sites to evaluate the chemical makeup of soils affected by discharged waste. The sites tended to be in areas of sandy soils with relatively high groundwater tables. These studies often found high P levels very near the infiltration pipes that correlated to increased iron or aluminum and decreased pH values. It was noted that the soils at many of the sites easily retained the phosphorus added, but occasionally plumes did travel through the groundwater. These studies also showed that acidic soil conditions were better for retarding phosphorus (Robertson, 2003) and that once the phosphorus reached the groundwater, it was rarely removed by the surrounding soil (Robertson and Harman, 1999).

The Canadian studies were conducted at sites that were composed of sandy soils with high groundwater tables; however, septic systems are in use in many different soil areas. It was determined that P research should be undertaken in soils that have relatively high sorption capability but have been actively used for a number of years. So for this study, we chose to evaluate the soils beneath a decommissioned septic field, which was previously used as a research site. The soil beneath the Arlington, Wisconsin site is a Plano silt loam (fine, silty, mixed, mesic Typic Argiudoll) and the depth to groundwater is approximately 24 meters. It is assumed that the wastewater infiltrating the soil travels mainly downward and not laterally. This allows for the use of deep, vertical soil cores to attempt to determine the placement of phosphorus. In this experiment, small-scale, fine resolution techniques were employed to try to answer the questions of where the phosphorus was located, if vertical migration was the main path, and whether the soil has greater capacity for phosphorus attenuation.

Materials and Methods

Site Information

Soil samples were removed from a decommissioned septic system research site located at the University of Wisconsin-Madison Arlington Agricultural Research Station, Arlington, Wisconsin. The research system was installed in 1988 with three infiltration cells and a depth to infiltration of approximately 61 to 66 cm. Each infiltration cell was 186 cm long by 80.6 cm wide and the three cells received a total daily load of septic tank effluent at a rate of 39 L m^{-1}. The wastewater used for this research originated from the farmhouse adjacent to the site. This site was operated continuously until an unknown date between the years 2002 and 2004. For further information see Milner et al (1991), Keys et al. (1998), and Erickson (2002).

Soil Sampling

Soil cores, 45-mm in diameter (1 ¾”) and 1-m to 1.5-m depth, were obtained using a truck-mounted hydraulic soil probe in the summer of 2004. Surface debris was removed before sampling and sampling depth was determined relative to the undisturbed soil surface. Cores were removed from directly below the septic system chamber and in a grid pattern from locations that radiated outward into the drainage field and the apparently undisturbed zone outside of the research plot. A total of 15 cores were sampled (Figure 1).

After removal, cores were stored in capped liners (Giddings Machine Company Inc., Windsor, Colorado; www.soilsample.com) at 4º C until processing. Cores removed from directly below the septic system chamber were processed individually by sectioning into 1-cm intervals for the first 40 cm and then 5-cm intervals for the remainder of the profile. Cores removed from outside the septic system chamber were sectioned into 1-cm intervals for the first 20 cm and then

5-cm intervals for the remainder of the profile. The samples were air-dried and hand-ground for analysis.

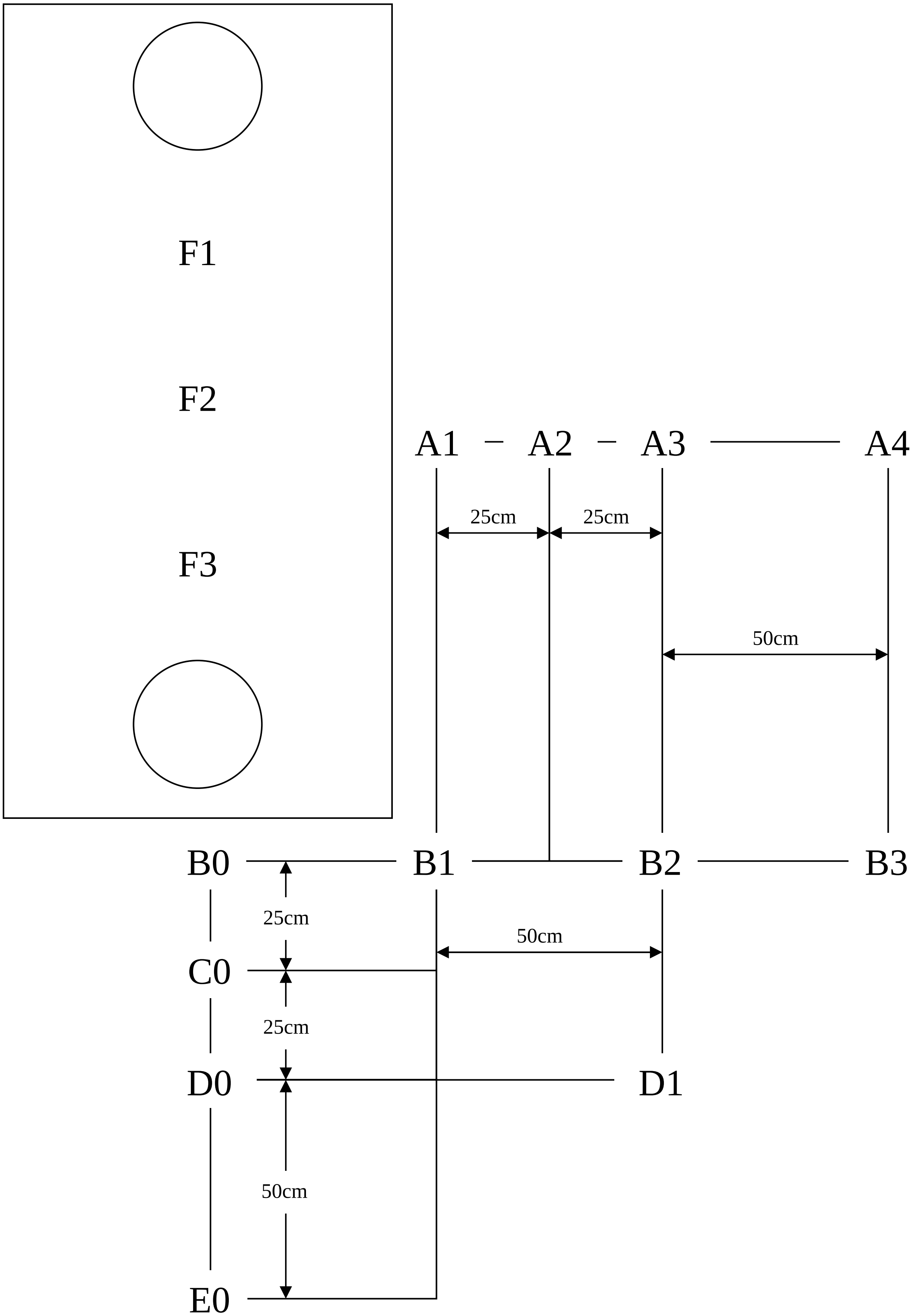
At this initial stage, four cores were processed: one core from directly below the septic system chamber (F1) and three cores directly to the west of the chamber (A1, A2, and A4). Core A1 was removed from just outside the septic chamber, core A2 was taken from a distance of 25 cm from A1, and core A4 was sampled 100 cm from core A1 (as a probable background sample; see Figure 1).

Laboratory Experiments

Labile phosphorus was extracted by the Bray P–1 dilute acid extraction (Bray and Kurtz, 1945) as modified by Avila-Segura et al. (2004) in which a 1-mL aliquot of Bray extractant was added to the individual 100-mg soil samples. The samples were mixed on a Vortex Genie II for ten minutes at maximum speed and centrifuged, twenty-four at a time, at a rate of 8,000 rpm (~8,000 *g*) for three minutes. Solutions were recovered with a transfer pipette and stored in cluster tubes until the analysis by the ascorbic acid method was completed (Avila-Segura et al., 2004; Murphy and Riley, 1962).

Total phosphorus was determined by the sulfuric acid-hydrogen peroxide-hydrofluoric acid method (Bowman, 1988; Kuo, 1996) as modified by Avila-Segura et al. (2004). A combination of reagents is added to approximately 250-mg of soil; the mixture is heated, transferred to 100-mL polymethylpentene volumetric flasks and diluted to volume. Phosphorus in the digest was determined using the ascorbic acid method (Kuo, 1996; Murphy and Riley, 1962) with standard addition in order to matrix match.

Figure 1. Schematic of sampling grid.



Phosphorus sorption isotherms were measured using the techniques of Graetz and Nair (2000) as modified for a microplate reader by Avila-Segura et al. (2004). Solutions were analyzed by the ascorbic acid method (Avila-Segura et al., 2004; Murphy and Riley, 1962) and plotted using the Langmuir equation. As soil sorption is nonlinear, the data were fit to this equation using the nonlinear optimizing routine “Solver” (Microsoft Excel 2000) to minimize the sum of squares of the residuals (Barrow, 1978). The fitted data were graphed and inspected to assure that local minima were avoided. Equilibrium P concentration and the P buffer capacity were analytically calculated from the fitted parameters.

Soil pH was measured on a subset of samples from two cores, one core from directly below the septic system chamber (F1) and the background core (A4). Samples were tested in water with a 1.5g soil to 10 mL water ratio and using a Corning® Chekmite pH–10 (Corning Inc., Corning, NY) pH meter. Samples were shaken and settled before the pH was measured.

Results and Discussion

Bray and Total Phosphorus

Four cores were analyzed for Bray P–1 phosphorus, an acid extraction that measures plant-available phosphorus often associated with the labile pool and the results are shown in Figure 2a. Bray P–1 phosphorus is the highest underneath the septic chamber, with the maximum amount of phosphorus, 225 mg P kg^{-1}, located at approximately 90-cm beneath the soil surface (about 30-cm from the bottom of the septic chamber). When compared to the remaining cores, that have much less labile phosphorus within each soil profile, core F1 has an average of approximately 150 mg P kg^{-1} soil more phosphorus beneath the septic chamber. Core A1, the core adjacent to but just outside the chamber, has the second highest level of phosphorus, but the maximum amount of phosphorus is found at the surface of the profile, above the septic chamber. The two cores taken from further away have similar amounts of phosphorus in the profiles and each is less than cores F1 and A1. In all of the cores, there is a noticeable increase in phosphorus at the depths of 60-cm to 120-cm. This corresponds with the increasing level of phosphorus in core F1 and could potentially be a result of phosphorus loading from the septic system. Yet, research from Meyer (2004) shows similar increases in Bray P–1 phosphorus levels starting at approximately the same depth in the same soil type and so this increase in phosphorus in cores A1-A4 may be attributed to other causes. It should be noted that in core F1 the 60-cm sample is a sample of the biologically active layer (i.e., clogging mat) and should not be compared directly with the soil samples.

Total phosphorus was measured in the four cores at various depth intervals with the results shown in Figure 3. The levels of total phosphorus were similar in each of the four cores, with core F1 having the highest amount of total P in the profile. Core A1 had the second highest amount of P in the profile, core A4 had the third highest amount, and core A2 had the least. Since the levels of total phosphorus are similar in the three cores removed from outside the septic system chamber, it is likely that the excess phosphorus being added to the system from the wastewater has highly affected the total amount of P in the soil below the chamber (F1). It should be noted that when the amount of Bray P–1 phosphorus is compared to the total P in each core, F1 has a much higher percentage of labile P than any of the other cores.

pH

The pH values in the two cores sampled are shown in Table 1. The pH ranges from 5.84 to 7.59 in core F1 and 6.74 to 8.53 in core A4. The lowest pH in core F1 was located directly below the clogging mat and could be caused by the oxidation reaction of the effluent NH_4^+ converting to NO_3^- as well as the reducing environment caused by the conversion of Fe^{2+} to Fe^{3+} (Robertson, 2003; Robertson and Harman, 1999; Zanini et al., 1998; Zurawsky et al., 2004). The lowest pH found in core A4 is from much deeper in the profile, indicating little to no effect from the septic system effluent at this location. Due to the high pH values in the deepest core samples, it is possible that the Bray P-1 extraction was not as effective and these P values may be suspect.

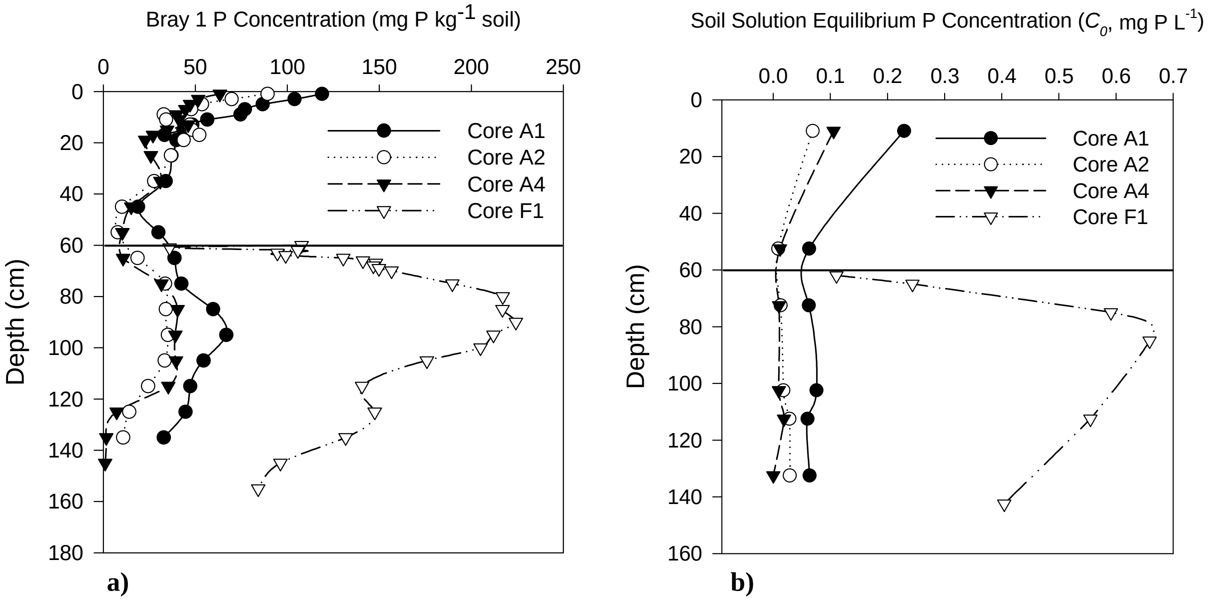


Figure 2. a) Bray P-1 phosphorus concentrations to depth at four locations potentially affected by a septic system. b) Soil solution equilibrium P concentration, calculated from the soil sorption isotherms, to depth. Core F1 was removed from directly beneath the septic chamber and cores A1-A4 were taken from outside the zone of wastewater infiltration. The horizontal line at 60 cm indicates the bottom of the septic system chamber.

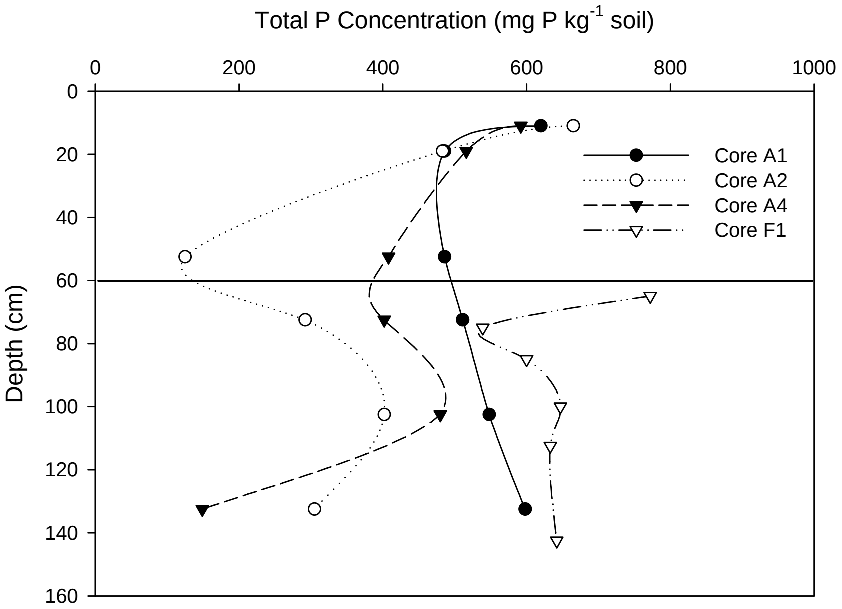


Figure 3. Total phosphorus concentrations to depth at four locations potentially affected by a septic system. Core F1 was removed from directly beneath the septic chamber and cores A1-A4 were taken from outside the zone of wastewater infiltration. The horizontal line indicates the bottom of the septic system chamber.

Soil Sorption Isotherms

Phosphorus sorption research was conducted on a selected group of soil samples. Results of the phosphorus sorption/desorption protocol (Avila-Segura et al., 2004; Nair et al., 1984) were fit to a form of the Langmuir equation written as:

$$S - S_0 = k_l S_{\max} \frac{C}{1 + k_l C},$$

where S is the sorbed P, S_0 is the initial sorbed P, k_l is the Langmuir constant, C is the soil solution concentration, and S_{max} is the P sorption maximum (Avila-Segura et al., 2004; Lyne, 2002). The data were fit to this equation using the nonlinear optimizing routine “Solver” (Microsoft Excel 2000) to minimize the sum of squares of the residuals (Barrow, 1978). The fitted data were graphed and inspected to assure that local minima were avoided. Equilibrium P concentration (C_0) and the phosphorus buffer capacity (dS/dC at C_0) were analytically calculated from the fitted parameters of k, S_{max}, and S_0 with the results shown in Table 1, Figure 2b, and Figures 4 through 7.

The equilibrium P concentrations (C_0) were greatest in core F1, ranging from 0.11 mg P L^{-1} to 0.66 mg P L^{-1}. These values are much higher than the remaining three cores (with the exception of the two 11-cm soil measurements from cores A1 and A4; Figure 2b). The C_0 values from cores A1 to A4 range from 0.00 mg P L^{-1} to 0.08 mg P L^{-1}, indicating the extensive influence of the septic wastewater on the soil directly beneath the septic chamber. Comparison of core F1 in Figures 2a and 2b shows clearly that the high C_0 values mirror the high Bray P–1 values, a potentially hazardous environmental situation. Analysis of the sorption curves shows that for all cores, the ability of the soil to remove phosphorus lessens with depth. The cores all show similar sorption information at the deepest depths (between 130 and 145 cm). The low sorption potential at these depths is most likely caused by the change in soil properties, as this zone seems to be surface of the unconsolidated parent material, with much higher sand content.

The sorption ability of the 62-cm interval is greater than that of the remaining soil profile. This location has the lowest C_0 and highest buffer capacity of the F1 core, yet the Bray P value is 106 mg P kg^{-1} soil. Though this seems contrary to the research, there are two plausible explanations. First, it is possible that the organic polyanions derived from decomposing organic matter found in wastewater had coated the soil particles, causing the phosphorus to slip further down the profile while the site was active. Upon the decommissioning of the site, these organic polyanions may have partially decomposed thus revealing unused sorption sites. The second explanation is that during the active use of the site, the soil in this location was subject to anaerobic conditions causing the iron to be reduced from Fe^{3+} to Fe^{2+}, thus decreasing the potential of the soil to sorb phosphorus. In the years after decommissioning, the soil Fe may have been reoxidized, thereby allowing greater sorption to occur when sampled.

Table 1. Compilation of all data including soil sorption parameters, both fitted and calculated, pH, Bray P-1 and total phosphorus for the four cores analyzed.

Core	**Depth**	C_0	dS/dC @ C_0	k	S_{max}	S_0	R^2	**pH**	**Bray P**	**Total P**
		mg L^{-1}							mg kg^{-1}	mg kg^{-1}
F1	62	0.11	788	3.11	458	-117	0.93	n/a	106	n/a
	65	0.24	305	2.10	331	-112	0.98	5.84	131	772
	75	0.59	119	0.85	316	-106	0.99	7.18	190	539
	85	0.66	97.1	0.68	300	-92.4	1.00	7.38	217	600
	110-115	0.56	81.6	0.58	247	-59.8	1.00	7.59	141	633
	140-145	0.40	83.3	0.68	199	-43.0	1.00	7.57	96.3[†]	642
A1	11[‡]	0.23	172	1.06	250	-49.0	0.99	n/a	56.5	620
	50-55[‡]	0.06	740	3.32	326	-56.4	0.89	n/a	29.9	486
	70-75	0.06	1362	8.45	375	-129	0.96	n/a	42.4	511
	100-105	0.08	519	3.09	256	-48.5	0.94	n/a	54.6	n/a
	110-115	0.06	518	3.13	234	-36.8	0.97	n/a	47.3	n/a
	130-135	0.06	406	3.18	185	-31.1	0.98	n/a	32.8[†]	n/a
A2	11[‡]	0.07	364	1.98	238	-28.6	0.94	n/a	34.1	665
	50-55[‡]	0.01	1807	8.62	243	-17.3	0.84	n/a	7.75	125
	70-75	0.01	1000	4.08	272	-13.7	0.86	n/a	33.6	292
	100-105	0.02	793	4.25	216	-15.2	0.96	n/a	33.4	402
	110-115	0.03	394	2.30	194	-11.9	0.78	n/a	24.4	n/a
	130-135	0.03	58.9	0.62	98.9	-1.74	0.80	n/a	10.8[†]	n/a
A4	11[‡]	0.11	317	1.82	248	-40.0	1.00	7.7	41.3	592
	50-55[‡]	0.01	812	3.77	235	-10.2	0.89	7.39	10.4	408
	70-75	0.01	1066	4.66	251	-11.3	0.90	7.15	31.6	402
	100-105	0.01	849	4.45	208	-8.87	0.70	7.0	39.6	480
	110-115	0.02	761	4.50	199	-15.6	0.95	6.74	35.3	n/a
	130-135	0.00	125	0.94	134	-0.03	0.99	8.53	1.62[†]	149

[†] Due to the higher pH values and the possible $CaCO_3$ content at these depths, the Bray P-1 extraction may not have been fully effective and the results may be suspect.

[‡] These samples were taken from above the septic system chamber and should not be directly compared to core F1.

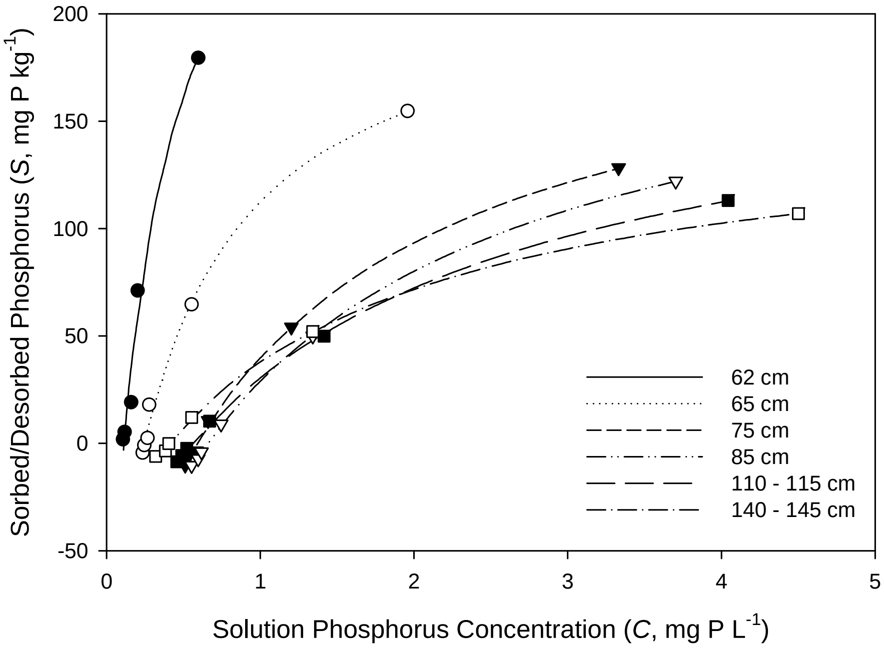


Figure 4. Langmuir soil phosphorus sorption isotherms for core F1, sampled directly below the septic system chamber.

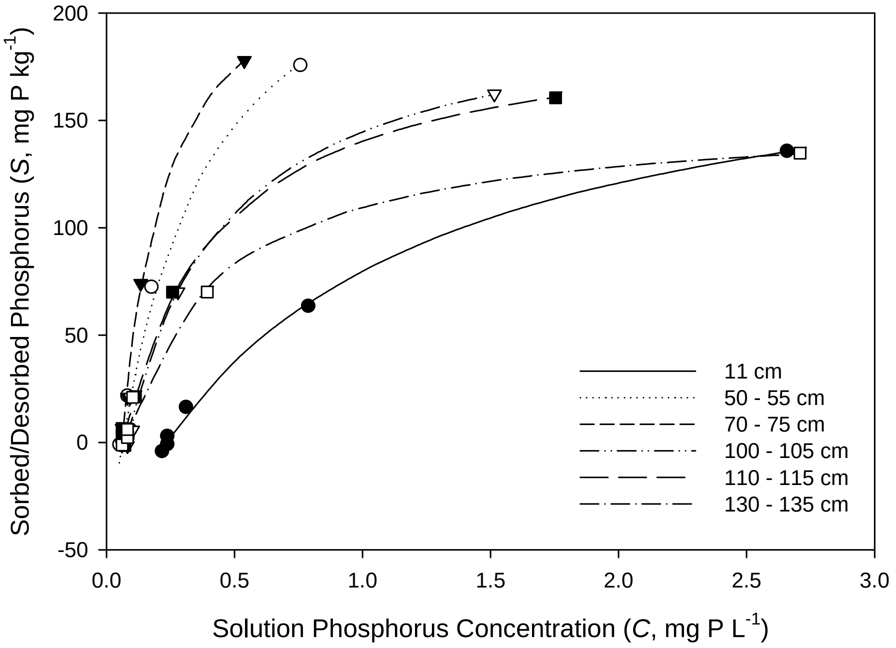


Figure 5. Langmuir soil phosphorus sorption isotherms for core A1, sampled just outside the septic system chamber.

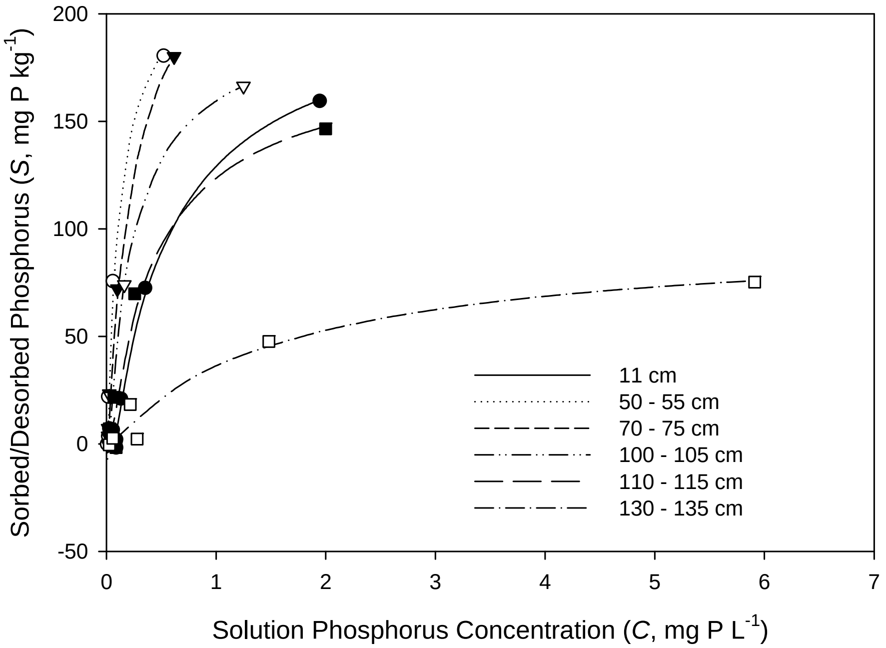


Figure 6. Langmuir soil phosphorus sorption isotherms for core A2, sampled 25 cm from A1.

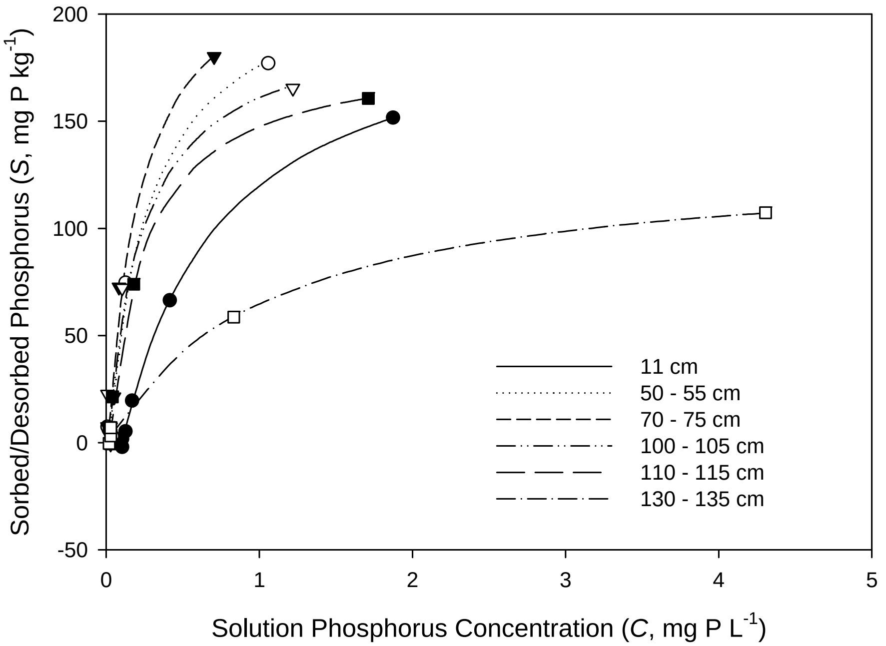


Figure 7. Langmuir soil phosphorus sorption isotherms for core A4 sampled 100 cm from A1.

Conclusions

It has been shown that beneath the septic system chamber there is an increase of Bray P-1 and soil solution phosphorus as well as a decrease in soil sorption capacity with depth. As the P profile increases vertically, the potential for downward leaching in this system increases, especially when a large amount of soluble P is associated with the increased levels of P in the labile pool. The increase in phosphorus to depth under core F1 shows that leaching may be occurring, considering the high C_0 values and low buffer capacity numbers. Since the groundwater table is quite deep in this location, this system should not impact the water quality if the assumption that the infiltrating wastewater flowed primarily downward, which differs from other research at different locations, is correct; beneath the 1.5-m sampling depth employed here, however, lateral flow to nearby surface water in roadside drainage ditches is possible. Finally, it appears that the ability of the soil to sorb additional phosphorus beneath the septic chamber is not great and the addition of phosphorus at this location may cause potential environmental hazards. Further research regarding phosphorus beneath septic systems in the United States should be undertaken to determine any potential environmental ramifications.

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References

Avila-Segura, M., J.W. Lyne, J.M. Meyer, and P. Barak. 2004. Rapid spectrophotometric analysis of soil phosphorus with a microplate reader. Commun. Soil Sci. Plant Anal. 35:547-557.

Barrow, N.J. 1978. The description of phosphate adsorption curves. J. Soil Sci. 29:447-462.

Bowman, R.A. 1988. A rapid method to determine total phosphorus in soils. Soil Sci. Soc. Am. J. 52:1301-1304.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Erickson, J.L. 2002. Soil oxygen surrounding wastewater infiltration surfaces. I. Models of soil oxygen diffusion to onsite wastewater infiltration surfaces. II. Soil and wastewater oxygen in onsite wastewater infiltration surfaces. MSc, University of Wisconsin, Madison.

Graetz, D.A., and V.D. Nair. 2000. Phosphorus sorption isotherm determination, p. 102, *In* G. M. Pierzynski, ed. Methods for P analysis for soils, sediments, residuals, and waters, 396 ed. North Carolina State University.

Keys, J.R., E.J. Tyler, and J.C. Converse. 1998. Predicting life for wastewater absorption systems, pp. 167-176. *In* Proc. Natl. Symp. on Individual and Small Community Sewage Systems, Orlando, FL. 8-10 Mar. 1998. ASAE, St. Joseph, MI.

Kuo, S. 1996. Phosphorus, *In* D. L. Sparks, ed. Methods of soil analysis. Part 3. Chemical methods. SSSA Book Series no. 5, Madison, WI.

Lyne, J.W. 2002. The vertical distribution of phosphorus due to long-term nutrient management practices. M.S. Thesis, University of Wisconsin-Madison, Madison, WI.

Milner, M., E.J. Tyler, and J.C. Converse. 1991. Wastewater infiltration from chamber and gravel systems., pp. 214-222. *In* Proc. Natl. Symp. on Individual and Small Community Sewage Systems, Chicago, IL. 16-17 Dec. 1991. ASAE, St. Joseph, MI.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination fo phosphate in natural waters. Anal. Chim. Acta. 27:31-36.

Nair, P.S., T.J. Logan, A.N. Sharpley, L.E. Sommers, M.A. Tabatabai, and T.L. Yuan. 1984. Interlaboratory comparison of a standardized phosphorus adsorption procedure. J. Environ. Qual. 13:591-595.

Robertson, W.D. 2003. Enhanced attenuation of septic system phosphate in noncalcareous sediments. Ground Water 41:48-56.

Robertson, W.D., and J. Harman. 1999. Phosphate plume persistence at two decommissioned septic system sites. Ground Water 37:228-236.

Zanini, L., W.D. Robertson, C.J. Ptacek, S.L. Schiff, and T. Mayer. 1998. Phosphorus characterization in sediments impacted by septic effluent at four sites in central Canada. J. Contam. Hydrol. 33:405-429.

Zurawsky, M.A., W.D. Robertson, C.J. Ptacek, and S.L. Schiff. 2004. Geochemical stability of phosphorus solids below septic system infiltration beds. J. Contam. Hydrol. 73:129-143.