Soil phosphorus distribution in a crop production system with long-term compost amendment

Leandro Bortolon[A], John L. Kovar[B], Cynthia A. Cambardella[C], Jeremy W. Singer[D], Clesio Gianello[E]

[A]Soil Scientist, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil, Email leandro.bortolon@ufrgs.br
[B]Soil Scientist, USDA-ARS, National Laboratory for Agriculture and the Environment, Ames, IA, United States, Email John.Kovar@ARS.USDA.GOV
[C]Soil Scientist, USDA-ARS, National Laboratory for Agriculture and the Environment, Ames, IA, United States, Email Cindy.Cambardella@ARS.USDA.GOV
[D]Research Agronomist, USDA-ARS, National Laboratory for Agriculture and the Environment, Ames, IA, United States, Email Jeremy.Singer@ARS.USDA.GOV
[E]Faculty of Soil Science, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil, Email cgianello@hotmail.com

Abstract
Excessive fertilization with inorganic or organic phosphorus (P) amendments, such as compost, increases the risk of P losses to surface waters. To properly manage fertilizer amendments, an understanding of P distribution in soil is essential. The objective of this research was to evaluate P distribution in soil with and without long-term compost amendment in a maize (*Zea mays* L.)-soybean (*Glycine max* L. Merr.)-wheat (*Triticum aestivum* L.)/clover (*Trifolium repens* L.) crop rotation managed with moldboard plow (MP), chisel plow (CT), or no-tillage (NT), with all phases present each year since 1988. Soil (Clarion silt loam and Canisteo silty clay loam) samples were collected in 2007 from three depth increments (0-7.5; 7.5-15; 15-30 cm) of each plot. Water-extractable P, Bray-1 extractable P, total P, and degree of P saturation (DPS) were determined from subsamples. Long-term compost application increased all P forms in the soil profile. The low C:P ratio of the compost likely increased soil P mineralization, leading to the differences we measured. The intensity of tillage affected all measures of P in the surface soil more than the crop that was grown. Water-extractable P was higher in the CT and NT treatments relative to the MP treatment, and tended to be higher following soybean. Similar results were found for Bray 1 P and total P. Compost applications can increase soil P, mainly P forms most susceptible to losses, thereby increasing the risk of P losses by leaching and runoff. Conservation tillage can reduce P leaching by keeping P in topsoil layers where root activity is higher. To decrease the risk of P losses from these cropping systems, compost applications should be P based.

Key Words
Soil phosphorus, water quality, compost amendment.

Introduction

Tillage practices and soil amendments play an important role in P dynamics and distribution in the soil profile. Conservation tillage systems tend to concentrate plant-available P in topsoil layers where root activity is higher. Application of organic amendments, such as compost, to cropland increases soil organic carbon, as well as the content of P and other plant nutrients. Thus, compost amendments can be an economical alternative for P supply to crops, given the high cost of inorganic P sources and the large amount of organic material available to use as fertilizer in areas near animal production. The beneficial influence of long-term compost applications on the physical, chemical, biochemical, and microbiological properties of soils and crop yields has been well documented (Singer *et al*. 2004, 2007, and 2008). Singer *et al.* (2008) found that compost applications may eliminate yield differences between conventional and minimum tillage. On the other hand, when compost application supplies P that exceeds crop removal, P levels will build in topsoil (Sharpley 1996; Lehmann *et al.* 2005). Phosphorus removals depend on the crop that is grown, and whether grain and/or biomass are harvested (Johnson *et al.* 2009). If soil P levels are allowed to build, the risk of P losses to ground and surface water increases as soil P sorption capacity approaches saturation (Novak *et al*. 2000; Schoumans and Groenendijk 2000). Although the amount of P lost per year in runoff is generally inconsequential from an agronomic perspective, small increases in P concentration in surface water often result in eutrophication of water bodies (Hart *et al.* 2004).

To complement agronomic soil tests, several methods have been devised to assess the risk of P loss from soil to surface water. The degree of P saturation (DPS) is an environmental index that has been used to assess the potential for P release to runoff and leaching (Zhou and Li 2001). Several studies have reported highly significant correlation of DPS with the forms of P most susceptible to runoff and leaching losses (Pote *et al*. 1996, Pote *et al.* 1999, Ige *et al.* 2005). The objective of this research was to evaluate: i) the distribution of added P among various P forms in soil following long-term compost application associated with tillage-cropping systems; and ii) the relationship of various P forms with potential P losses by leaching and runoff.

Methods

The soil for the study was collected from research plots at the Iowa State University Agronomy and Agricultural Engineering Research Farm near Ames, Iowa, USA. The soils were classified as Canisteo silty clay loam (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludolls). The experimental site had been in continuous maize production since 1987, with tillage main plots consisting of moldboard plow (MP), chisel plow (CT), and no-till (NT) since 1988. In 1997, the entire site was planted to soybean. In 1998, a maize–soybean–wheat/clover rotation was initiated with all phases represented each year in each tillage system. Additional information about the management practices can be found in Singer *et al*. (2004) and Singer *et al.* (2010). During the first six years of the study (1998-2003), an average of 6000 kg C/ha/yr were applied via compost. Although compost application rates changed to a P removal basis in 2004, an average of 157 kg P/ha/yr were applied since 1998. On average, the C:N ratio of the compost was 13.9, and the C:P ratio was 33.5. The experimental design was a randomized complete block in a split-plot treatment arrangement with four replicates. Plots were 22.8 m wide by 26.1 m long. Fall moldboard plow depth prior to maize and soybean crops was approximately 20 cm. Fall chisel plow depth, using twisted shanks, was approximately 25 cm for the same crops. Spring secondary tillage operations prior to maize and soybean included an early spring disking and a pre-plant field cultivation in MP and CT systems. Subplots, 7.6 m (10 rows with a 0.76-m row spacing) wide by 13.1 m long, consisted of fall-applied compost or no compost.

Representative soil samples were collected periodically to a depth of 18 cm during the first nine years of the study, and analyzed for Bray-1 extractable P. To better characterize nutrient levels in the surface soil, samples were collected in 2007 from three depth increments (0-7.5; 7.5-15 and 15-30 cm) of each plot. All soils were air dried, sieved (2 mm), and stored at 23^{o}C prior to analysis. For the soil surface layer (0-7.5 cm), water-extractable P, Bray-1 extractable P, total P, and degree of P saturation (DPS = (extractable P/P sorption index) x 100) were determined. For the subsoil layers, only Bray-1 extractable P was determined. Analysis of variance (ANOVA) was used to evaluate differences in the distribution of P in the soil profile as affected by compost application and tillage-crop rotation.

Results and Discussion

The compost P applied during the first nine years of the study increased Bray-1 extractable P in the top 18 cm of the profile to levels well in excess of crop needs (Figure 1a). Tillage had little effect on Bray-1 P until 2006 when mean values in the CT and NT treatments were 50% higher than those in the MP treatments. The high values observed with compost-amended soils may be due to the low compost C:P ratio, which can increase P mineralization. Similar results were reported by Motavalli and Miles (2002) in a study of soil P fractions after 111 years of animal manure and fertilizer applications, as well as by Eghball (2003) in a study of P leaching following manure or compost application. Generally, the P in the compost used in our work is 70% inorganic, which is readily available for plant absorption, microbial turnover, and soil adsorption. In the last case, when the P sorption capacity reaches saturation, P can be lost by leaching or surface runoff, if the amounts applied exceed crop removal.

When compared with subsoil layers, the topsoil had the highest P levels with or without compost application (Figure 1b). Compost application, however, increased soil profile P to a depth of 30 cm. This suggests that surface soil P levels increased sufficiently to allow P to move into the profile when compost was applied. There was less subsoil P in the NT system compared with the MP and CT systems. Almost 50% of the P applied with the compost was found in the subsoil layers under the MP system. The distribution of P in the soil profile is an important aspect to consider in areas with shallow groundwater or a fluctuating water table that moves close to the soil surface (Eghball 2003).

When compost was applied, WEP, Bray-1 P, total P, and DPS increased in the topsoil (0-7.5 cm) layer (Table 1) regardless of crop or tillage system. The intensity of tillage affected all measures of P in the surface soil more than the crop that was grown. Water-extractable P was higher in the CT and NT treatments relative to the MP treatment, and tended to be higher when soybean was grown (Table 1). Similar results were found for Bray 1 P and total P, and suggest that soybean harvest removed less P from the surface soil than was removed by the maize and wheat harvests. Several authors have reported a significant correlation between dissolved reactive P concentration in surface runoff and WEP (Pote *et al.* 1996, Pote *et al.* 1999), indicating that WEP can be used as an index of soil P that is readily lost to runoff. In addition, mean DPS under NT was the highest value observed. As the DPS increases, the capacity of the soil to retain P decreases, suggesting that the NT treatment posed the greatest risk of P losses by either leaching into soil profile and/or surface runoff. On the other hand, conservation tillage maintains cover on the soil surface, reducing raindrop impact and subsequent soil erosion. No-till can also increase soil aggregation, and consequently soil water infiltration, which can reduce erosion and soil P losses with runoff. Tillage will mix the compost P into the profile (Sharpley 2003); however, the increases in WEP and the reduction of soil P sorption capacity with time must be considered.

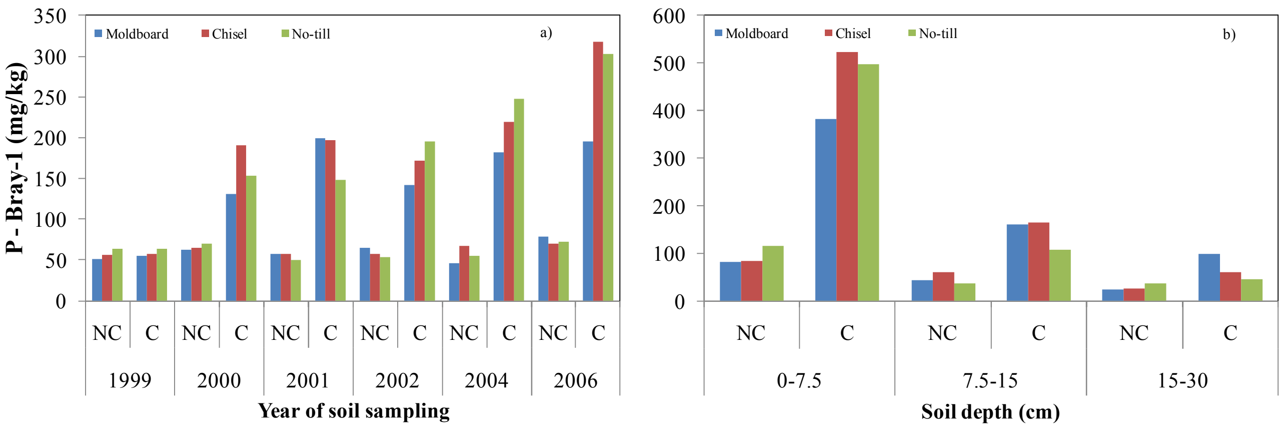

Figure 1. Soil phosphorus extractable with Bray-1 during a 9-year period in a crop production system with long-term compost amendment: (a) 0-18 cm soil depth and (b) soil profile sampled within 3 soil depths in fall 2007. Optimum Bray-1 P range is 16-20 mg/kg. NC=no compost; C=compost application.

Table 1. Water extractable P (WEP), Bray-1 extractable P (Bray-1), total P (Total), and degree of P saturation (DPS) as affected by tillage, compost application, and cropping system in the top soil layer (0-7.5 cm).

Factor	Soil P							
	WEP		Bray-1		Total		DPS	
	---------------------- mg/kg ----------------------						%	
Moldboard	C†	NC‡	C	NC	C	NC	C	NC
Bean	7.4	1.7	373	83	860	682	53	12
Maize	8.2	2.4	408	88	908	676	61	13
Wheat	7.6	1.7	366	74	843	721	54	11
Mean	*7.7*	*1.9*	*382*	*82*	*870*	*693*	*56*	*12*
Chisel								
Bean	12.9	4.5	523	96	1059	772	79	14
Maize	11.1	2.5	494	65	973	660	74	12
Wheat	11.1	3.0	477	93	955	711	71	14
Mean	*11.7*	*3.3*	*498*	*85*	*996*	*714*	*75*	*13*
No-till								
Bean	17.0	3.4	612	106	1222	795	91	16
Maize	10.6	3.1	477	120	1153	772	72	18
Wheat	9.7	2.8	482	119	967	701	72	18
Mean	*12.4*	*3.1*	*523*	*115*	*1114*	*756*	*79*	*17*
ANOVA	---------------------------------- P > F ----------------------------------							
Amendment	<0.01		<0.01		<0.01		<0.01	
Tillage	0.03		0.04		0.02		0.04	
Am x Till	0.90		0.86		0.23		0.80	
Crop	0.07		0.05		<0.01		0.06	
Am x crop	0.38		0.21		0.02		0.32	
Till x crop	0.18		0.25		<0.01		0.41	
Am x Till x crop	0.32		0.33		0.67		0.57	

† Compost; ‡ No compost

Conclusion

Long-term compost applications can build up soil P, mainly the forms most susceptible to losses, so that the risk of P losses by leaching and runoff increases. Conservation tillage practices can reduce P leaching and keep P in topsoil layers where root activity is more concentrated. This promotes P cycling in the soil-plant system, but may increase the risk of P losses in surface runoff. Intensive tillage will mix applied P into the profile, but increases WEP and reduces soil P sorption capacity with time, which poses a threat to groundwater, even though lower P levels in surface soil decrease P losses in runoff. To decrease the risk of P losses from these cropping systems, compost applications should be P based.

References

Eghball E (2003) Leaching of Phosphorus Fractions Following Manure or Compost Application. *Communications in Soil Science and Plant Analysis* **34**, 2803-2815.

Hart MR, Quin BF, Nguyen ML (2004) Phosphorus runoff from agricultural land and direct fertilizer effects: a review. *Journal of Environmental Quality* **33**, 1954-1972.

Ige DV, Akinremi OO, Flaten, DN (2005) Environmental index for estimating the risk of phosphorus loss in calcareous soils of Manitoba. *Journal of Environmental Quality* **34**, 1944-1951.

Lehmann J, Lan Z, Hyland C, Sato S, Solomon D, Ketterings QM (2005) Long-term dynamics of phosphorus forms and retention in manure-amended soils. *Environmental Science Technology* **39**, 6672-6680.

Motavalli PP, Miles RJ (2002) Soil phosphorus fractions after111years of animal manure and fertilizer applications. *Biology and Fertility of Soils* **36**, 35-42.

Novak JM, Watts DW, Hunt PG, Stone KC (2000) Phosphorus movement through a Coastal Plain soil after a decade of intensive swine manure application. *Journal of Environmental Quality* **29**, 1310-1315.

Pote DH, Daniel TC, Nichols DJ, Sharpley AN, Moore PA, Miller DM, Edwards DR (1999) Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. *Journal of Environmental Quality* **28**, 170-175.

Pote DH, Daniel TC, Sharpley AN, Moore PA, Edwards DR, Nichols DJ (1996) Relating extractable soil phosphorus to phosphorus losses in runoff. *Soil Science Society of America Journal* **60**, 855-859.

Schoumans OF, Groenendijk P (2000) Modeling soil phosphorus levels and phosphorus leaching from agricultural land in the Netherlands. *Journal of Environmental Quality* **29,** 111-116.

Sharpley AN (2003) Soil mixing to decrease surface stratification of phosphorus in manured soils. *Journal of Environmental Quality* **32**, 1375-1384.

Sharpley AN (1996) Availability of residual phosphorus in manured soils. *Soil Science Society of America Journal* **60**, 1459-1466.

Singer JW, Kohler KA, Liebman M, Richard TL, Cambardella CA, Buhler DD (2004) Tillage and compost affect yield of corn, soybean and Wheat and Soil Fertility. *Agronomy Journal* **96**, 531-537.

Singer JW, Logsdon SD, Meek DW (2007) Tillage and compost effects on corn growth, nutrient uptake, and grain yield. *Agronomy Journal* **99,** 80-87.

Singer JW, Logsdon SD, Meek DW (2008) Soybean growth and seed yield response to tillage and compost. *Agronomy Journal* **100**, 1039-1046.

Singer JW, Chase CA, Kohler KA (2010) Profitability of cropping systems featuring tillage and compost. *Agronomy Journal* **102,** (in press).

Zhou M, Li Y (2001) Phosphorus-sorption characteristics of soils and limestone from the Southern Everglades and adjacent farmlands. *Soil Science Society of America Journal* **65**, 1404-1412.