Effect of biosolids P removal treatment on P soil test and availability to corn

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Abstract
A field research study was conducted in Wisconsin, USA for three years to determine the relative P availability of municipal biosolids. Sewage treatment plants use a variety of methods to sequester P in biosolids so that a very low P effluent can be discharged to surface water. This study compared fertilizer and biosolids that used lime, alum, iron, and biological methods to remove P from sewage and tested their effect on soil test P and availability to corn at two rates of application. Biosolids produced from the use of alum and iron required more total P applied to increase soil test P compared to those using lime and a biological method. Plant P uptake was not affected by material, but was higher at the high rate of application. Corn grain yield was higher in some years where lime and biological biosolids were applied. This research demonstrates that biosolids treatment does affect P availability and should be a component of nutrient management recommendations.

Key Words
Sewage sludge, nutrient management, P runoff, maize.

Introduction
Recently approved nutrient management rules (USDA-NRCS Conservation Practice Standard 590 2006) prescribes the application of nutrients based on the P need of crops compared to the traditional N-based strategy. Studies have shown that high soil test P is correlated with elevated soluble P concentration of runoff, causing the reduction of water quality (Sharpley 1995; Hooda *et al.* 2000). Currently biosolids (municipal sewage sludge) have been granted an exemption from following a P-based strategy, but many believe that such an exemption is short-sighted. Managing the application of biosolids with a P-based strategy will require a more precise understanding of P availability compared to that understood for fertilizer and animal manure.

Research has shown that the P availability from biosolids is lower than that found in fertilizer and manure because of strong binding between P and compounds added during sewage treatment that are intended to sequester P in the solids so that a very low P effluent can be discharged to surface water (O'Connor *et al.* 2004). This binding may continue after materials have been applied to the land, increasing the amount of applied total P needed to increase soil test P. The research discussed in this paper describes a three-year field study designed to estimate the P availability from several municipal biosolids that have been processed by different P removal methods.

Methods
A small plot study was established at the University of Wisconsin Arlington Agricultural Research Station (43.30, -89.35) in 2005 on a Plano silt loam soil (Typic Argiudoll, fine, silty, mixed, mesic) using corn (*Zea mays*, L.) as the test crop. The site selected for the study had a Bray P_1 test in the optimum soil test category (Laboski *et al.* 2006). Small plots of 3 x 9 m, containing four 0.75-m rows were used and all treatments were replicated three times in a randomized factorial treatment arrangement.

Treatments included rates of triple super phosphate fertilizer (0-46-0) applied in 2005 to establish soil test P levels ranging from the initial level to an excessively high category near 100 mg/kg. Biosolids were collected from nearby municipalities and included materials that used P removal methods of: 1) lime-amendment; 2) biological treatment; 3) alum treatment; and, 4) iron treatment. Biosolids materials were hand-applied at rates estimated to supply 112 and 224 kg total P/ha to separate plots in 2005 to 2007. The actual P loading was calculated from a sample of the biosolids collected the day of application.

All treatments were applied to existing corn stubble in late April each year and were incorporated with two passes with a coulter chisel plow followed by two passes with a field cultivator. A full-season corn hybrid was planted in early May each year at a population of 86,500 seeds/ha. All non-P fertilizers and crop protection chemicals were uniformly applied at University of Wisconsin recommended rates (Laboski *et al.* 2006). Glyphosate was applied twice post-emergence for weed control.

Measurement taken during the term of the study included:

1. Total P of the biosolid materials.
2. Annual soil test (Bray P_1) for individual plots prior to treatment and following grain harvest.
3. Total dry matter accumulation and mineral nutrient uptake at physiological maturity.
4. Corn grain yield reported at 15.5 g/kg moisture.

Data were subjected to a analysis of variance for a factorial treatment arrangement using the statistical procedures of SAS (Statistical Analysis System, Cary, North Carolina). Where significance was found at p=0.05 a Fisher's LSD was calculated.

Results

The amount of total P supplied by the various materials is shown in Table 1. Rates of application for the biosolids were estimated from historic analysis supplied by the treatment plant operators. The rates used in this study bracket those that are commonly used to supply the N need for corn. The actual rate of application was determined from the analysis of a sample collected at application. The tabular data should be doubled to provide the 224 kg P/ha rate (2X). The 2X rate of fertilizer resulted in the application of 399 kg P/ha.

Table1. Actual total P loading to biosolid treated plots in the P availability study at Arlington, Wis., 2005 to 2007.

P source †	2005 (kg P/ha)	2006 (kg P/ha)	2007 (kg P/ha)
Fertilizer	133	--	--
Lime biosolids	133	107	160
Biological biosolids	131	121	128
Alum biosolids	58	55	81
Iron biosolids	125	87	121

† Loading represents the rate estimated to supply 112 kg P/ha (1X). Double values for the 2X rate, which is estimated to supply 224 kg P/ha. The 2X amount of fertilizer supplied 399 kg P/ha.

A portion of the applied P of any P-containing material is bound by soil minerals in forms that are not plant available according to calibrated soil testing procedures. This phenomenon is known as buffering and for this soil the accepted value is 9 kg P needed to increase the soil test P level 1 mg/kg. If sewage treatment decreases the availability of P in biosolids, then a higher buffering value would be observed. Table 2 shows the buffer value for the various materials in the year of application. These values are not adjusted for crop P removal. The soil test P value of the control was 16 mg/kg. Differences were observed in both 2005 and 2007 relative to source and showed that alum and iron amended biosolids required more applied P to increase soil test compared to lime treatment and the method that used biological sequestration to remove P. In fact, the fertilizer and biological removal method had a similar buffering value suggesting that P from these sources is similar in its reaction in soils.

The effect of treatment on the P uptake and grain yield is shown in Table 3. If sewage treatment substantially reduced the phyto-availability of P in any of the materials then the total uptake and potentially grain yield could be reduced in crops grown on P responsive soils. The soil test P at the experimental site is characterized as moderately responsive by local soil test calibration. Source did not affect the P uptake in any year; however, as expected, the higher rate of material did affect uptake in 2005 and showed a strong trend for the same response in 2007. Although the control treatment was not included in the analysis of variance, the alum and iron treatments showed lower P uptake than the control in a few cases. Grain yield was affected by source in 2007 and showed a trend for response in 2006. In both situations, yield tended to be higher in the lime-amended and biological treatments compared to the alum and iron treatments, as well as the fertilizer treatment. More detailed statistical analysis will be conducted to compare the differences between the control and P sources, and between various biosolids.

Table 2. Effect of P source and rate on the amount of applied P needed to increase the soil test P 1 mg/kg, Arlington, Wis., 2005 to 2007†.

P source	2005 (kg P/ha)	2006 (kg P/ha)	2007 (kg P/ha)
Fertilizer – 1X	4.0	4.3	7.7
Fertilizer – 2X	3.5	5.4	5.1
Lime biosolids – 1X	3.2	4.7	15.1
Lime biosolids – 2X	4.6	6.5	8.7
Biological biosolids – 1X	4.8	4.3	5.4
Biological biosolids – 2X	4.4	5.8	5.8
Alum biosolids – 1X	12.5	6.7	17.1
Alum biosolids – 2X	4.7	13.0	10.2
Iron biosolids – 1X	9.7	8.0	15.1
Iron biosolids – 2X	10.1	10.7	12.7
Pr>F			
Source	<0.01	0.21	0.02
Rate	0.10	0.15	0.09
Source * Rate	0.02	0.82	0.60

† Formula: Total P applied (kg/ha)/(soil test P – 16) (mg/kg).

Table 3. Whole-plant P uptake at physiological maturity and corn grain yield as affect by P source and rate, Arlington, Wis., 2005 to 2007.

	P uptake (kg P/ha)			Grain yield (Mg/ha)		
P source †	2005	2006	2007	2005	2006	2007
Control	32.3	29.7	31.1	11.6	12.1	12.2
Fertilizer – 1X	45.0	29.8	31.5	11.5	12.4	12.5
Fertilizer – 2X	44.3	29.7	36.0	12.2	12.7	11.5
Lime biosolids – 1X	39.1	28.8	32.3	12.4	13.6	13.2
Lime biosolids – 2X	46.0	29.5	36.1	12.1	13.2	13.7
Biological biosolids – 1X	38.7	36.3	33.4	12.4	13.7	13.0
Biological biosolids – 2X	40.4	31.0	38.9	12.4	13.6	13.3
Alum biosolids – 1X	36.7	25.8	32.2	11.6	12.8	12.9
Alum biosolids – 2X	44.5	32.3	32.3	12.1	12.3	12.6
Iron biosolids – 1X	31.6	36.1	31.5	12.9	12.8	12.4
Iron biosolids – 2X	39.9	37.2	32.4	12.6	13.2	13.4
Pr>F						
Source	0.14	0.10	0.47	0.37	0.07	<0.01
Rate	0.03	0.64	0.07	0.84	0.85	0.69
Source * Rate	0.57	0.55	0.75	0.80	0.78	<0.01

† Control yield value not included in analysis of variance.

Conclusion

Future nutrient management regulations will require P-based application of organic waste materials such as municipal biosolids. Biosolids have increased P content because their treatment concentrates P in the material; therefore an over-application of P occurs when attempting to supply a significant portion of the crop N requirement. It is important to have an understanding of P availability of various biosolids to account for the variety of sewage treatment methods that sequester P in the biosolids. It is likely that certain methods result in binding in the soil after application in forms that are not plant available, potentially reducing P availability to the crop. This study showed that alum and iron treatment increased the P buffer value such that more total applied P was required to increase the soil test P one mg/kg compared to the lime and biological treatments. This will reduce the rate at which the soil test P will increase with these treatments so that more material must be applied to obtain a similar soil test. Total P uptake by the corn was not affected by material, but uptake was higher at the 2X rate as might be expected. Grain yield was higher in the lime-amended and biological treatments compared to the alum and iron treatments. This research demonstrates that the treatment of sewage by different means to sequester P results in biosolids that have different relative P availability. When applied to the land biosolids created with alum and iron have a higher P buffering value, which in some cases may reduce the plant availability of P. The biosolids treatment method is a factor that should be considered when selecting rates of biosolids application in the development of a nutrient management plan.

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