Phosphorus Availability in Sand and Silt Loam Soils from Six Wisconsin Biosolids

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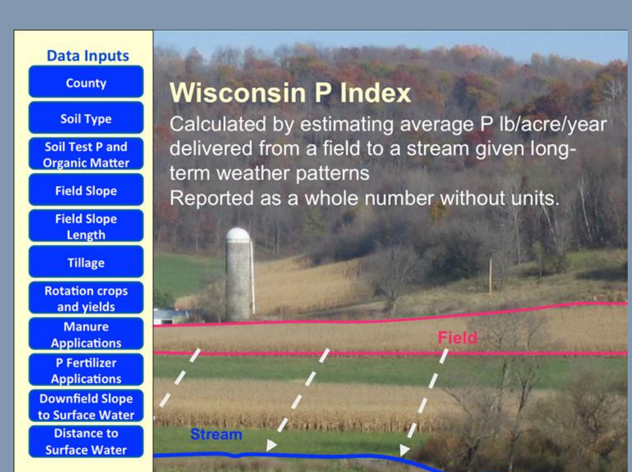
Abstract

Tighter phosphorus regulations in Wisconsin will cause wastewater treatment plants to be required to remove even more phosphorus from wastewater. The resulting biosolids will have increased phosphorus levels. Understanding how different treatment processes affect phosphorus availability from biosolids is important for biosolids to be included in the Wisconsin Phosphorus Index. The goal of this research is to quantify differences in phosphorus availability among six biosolids collected from wastewater treatment plants in southeastern Wisconsin. Two eleven week soil incubations were completed using a Kewaunee silt loam and a Plainfield sand soil incubated with six biosolids treatments (2 liquids, 4 solids), ammonium phosphate, and a control. Soil amendments were applied at 40 kg P/ha and incubated at 60% water holding capacity and 25°C. Biosolids were characterized for pH, total solids, total nitrogen and phosphorus, as well as total minerals. Soil was analyzed at the end of the incubation (week 11) for total P, Bray P1, water extractable P, P saturation, and total minerals. These results should illuminate and quantify differences in phosphorus availability from biosolids applied to soil and provide P source factors necessary for biosolids to be included in the Wisconsin Phosphorus Index. This will allow agricultural producers to appropriately credit biosolids when land applied and supply adequate nutrients while protecting water quality.

Introduction

- Why is this research important?
  - biosolids are a valuable resource containing nutrients important in agriculture
  - water quality needs to be protected, thus farmers need to understand their amendments to maximize yields and improve soil quality
- What are the issues?
  - biosolids (byproduct of waste water treatment), are often land applied
  - eutrophication is accelerated by excess P entering freshwater, and appropriately managing biosolids and other soil amendments can reduce P losses
  - biosolids are applied to soil to supply nutrients, but differences in P availability from biosolids generated at different treatment plants are not well understood and not yet incorporated into the Wisconsin Phosphorus Index
- GOAL
  - investigate P availability and improve understanding of biosolids from southeast Wisconsin, ultimately including biosolids in the Wisconsin P Index



http://wpindex.soils.wisc.edu/

Therefore the PURPOSE of this study was to quantify differences in phosphorus availability among six biosolids collected from wastewater treatment plants in southeastern Wisconsin on a sand and a silt loam soil

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BIOSOLIDS and SOIL: Sample Collection and Analysis

Biosolids from six cities in southeast Wisconsin (Fig. 1) were collected in spring 2014.
Bulk biosolids samples were stored at 4°C upon collection. Smaller quantities were separated and frozen until use in the incubations. See Table 1 for biosolids characteristics.

Parameter[a]	Brookfield	Delafield	East Troy	Fort Atkinson	Mukwonago	Whitewater
pH	7.5	6.1	6.8	6.3	6.6	7.6
Total Nitrogen (mg g^{-1})[b]	2.55	20.82	10.37	11.40	9.54	1.98
Total Phosphorus (mg g^{-1})	3.09	1.09	1.60	0.98	0.42	2.91
Total Potassium (mg g^{-1})	0.24	0.07	0.12	0.33	0.01	0.33
Dry Matter (%)	3.0	75.7	19.2	14.8	26.5	2.4
Type	liquid	solid	solid	solid	solid	liquid
Digestion[c]	anaerobic	anaerobic	aerobic	aerobic	anaerobic	anaerobic
Phosphorus Treatment[d]	alum	TBD	alum	biological	ferrous chloride	alum

Table 1. **Characteristics measured on each biosolids.** [a]All values in the table are the average of duplicate analyses and all analyses performed at SPAL (UW Madison's Soil and Plant Analysis Lab, Marshfield, WI). [b]Total Nitrogen, Total Phosphorus, and Total Potassium given for "as is" biosolids. [c]TBD, to be determined – still sorting out the details of the biosolids treatment processes. [d] For removal of P from wastewater; alum: aluminum sulfate

Figure 1. Google map locations of the six cities in Wisconsin where the biosolids were collected.

Soil Characteristic	Plainfield sand	Kewaunee silt loam
P (mg kg^{-1} soil)	84(3)	71(4)
K (mg kg^{-1} soil)	121(3)	280(7)
pH	6.2(.2)	7.1(.1)
O.M (%)	0.9(0)	3.7(.1)

Table 2. **Selected soil characteristics for each soil used in the incubations.** All values are the mean of samples sent to the UW Madison Soil and Plant Analysis Lab for routine field analysis (n=3); standard deviation is given in parenthesis.

SOIL INCUBATION: Methods

1. Two soils (a Plainfield sand and a Kewaunee silt loam) were collected, air dried, crushed with a rubber mallet, and passed through a 6 mm screen. Soil characteristics described in Table 2. Equal masses of soil (90.53g) were weighed into each incubation cup (Figs. 2 & 3).
2. The six biosolids were added "as is" to each incubation cup to provide 110 kg P ha^{-1} (based on a 15 cm plow layer) which is ~70 mg P kg^{-1} soil. A fertilizer ($(NH_4)_2HPO_4$) was included as a treatment as well as a control with no P addition. Treatments were replicated four times (four incubations cups per treatment).
3. After mixing, deionized water was added to each cup to provide 60% water-filled pore space (accounting for the water added with the biosolids).
4. Incubation cups were capped with lids that had small pin holes to allow for air exchange and incubated at 25°C for 11 weeks (simulating one Wisconsin growing season). A completely randomized design was used to assign incubation cups to a specific location in the incubator.
5. Incubation cups were checked weekly. When average water loss reached >2% (by mass), water was added to bring each cup back to 60% water filled pore space.
6. After incubation, soils were removed from the incubator, transferred into a paper bag, air dried, ground with a mortar and pestle, passed through a 2 mm sieve, and stored until soil analysis was completed.

Note: these methods are the same as those used for the Amnicon-Cuttre complex soil incubation completed and presented last fall (2014).

Soil Incubation Analyses

- Total P: A small mass of incubation soil (~0.025g) was digested with sulfuric acid, potassium persulfate, and water in an autoclave (Getinge vacuum steam sterilizer model 53325) for an hour at 130° C on the liquid cycle (modified Nelson, 1987). Supernatants were analyzed by ortho-P analysis.
- Water Extractable P: Samples (incubation soils) were shaken with deionized water for 1 hour at 180 rpm, after which samples were centrifuged for 10 min at 2500 rpm, filtered with Fisher P5 filter paper (modified Pote et al., 1996) and analyzed the supernatant by ortho-P analysis. (1:50 and 1:10 ratios were used.)
- Bray P1: Soil (2.500g) and BP1 solution (25ml) were shaken for 5 min at 180 rpm, after which samples were centrifuged for 10 min at 2000 rpm, filtered with Fisher P5 filter paper and analyzed the supernatant by ortho-P analysis. (Bray and Kurt, 1945)
- Mehlich 3: Soil (2.500g) and M3 solution (25ml) (Mehlich, 1984) were shaken for 5 min at 180 rpm, after which samples were centrifuged for 10 min at 2000 rpm, filtered with Fisher P5 filter paper and sent to UW Madison's Soil and Plant Analysis Lab in Madison, WI for ICP-OES analysis or measured by ortho-P analysis.
- Ortho P: The supernatant of the TP, BP1, M3, and WEP methods were analyzed for ortho-phosphate colorimetrically by the molybdenum-blue (ascorbic acid) Murphy Riley method (Dick and Tabatabai, 1977) on a Beckman spectrophotometer (model DU-640).
- Degree of P Saturation: DPS = P/(Al + Fe)*100, where P, Al, and Fe are the soil concentrations of each of those elements. This calculation can provide an estimation of P runoff from soil.

Figure 2: Materials for soil incubation prep

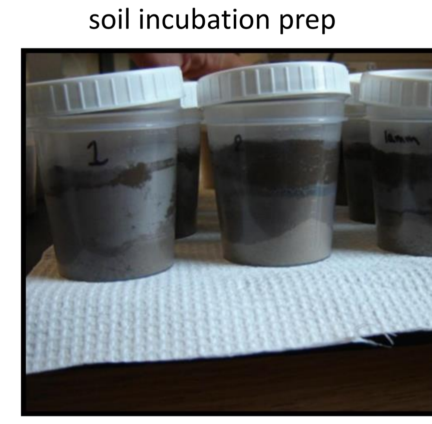

Figure 3: Incubation cups

Soil Incubation Results

- Fort Atkinson biosolids (biological P treatment) consistently had the highest soil test P (STP) (M3, BP1, WEP, and DPS, Tables 3&4)
- Delafield biosolids (anaerobic and highest dry matter content) consistently produced the lowest STP, sometimes no different than the control (Tables 3&4)
- Most of the biosolids did not statistically increase WEP in the Kewaunee silt loam soil (Table 3), only Fort Atkinson biosolids had increased WEP compared to the control
- WEP results in the Plainfield sand indicated Fort Atkinson was most available, with the two liquid biosolids (Brookfield and Whitewater) the next most available (Table 4)
- M3 and BP1, as expected, trends indicate similar biosolids treatment effects in the Kewaunee silt loam (Table 3), in the Plainfield sand, there was less agreement between the two tests (Table 4)

Kewaunee Silt Loam

Table 3. **Soil test P results of the incubation with Kewaunee silt loam soil.**

	M3[a] (mg/kg)	BP1 (mg/kg)	WEP (mg/kg)	TP (mg/kg)	DPS (%)
Fertilizer	206(7)b[b]	137(2)b	26.6(3)ab	411(47)a	20bc
Fort Atkinson	294(11)a	187(15)a	37.8(9)a	196(84)b	28(2)a
Brookfield	218(10)b	134(6)b	18.3(1)b	208(36)b	21(1)b
Whitewater	219(13)b	137(7)b	16.0(2)b	364(51)a	18(2)bc
East Troy	201(4)bc	127(4)bc	19.9(1)b	268(44)ab	19(.3)bc
Mukwonago	184(10)c	116(7)c	14.4(2)b	279(49)ab	17(1)cd
Delafield	159(5)d	98(2)d	15.0(0.4)b	195(35)b	15(0.4)de
Control	135(0.7)e	87(1)d	21.7(16)b	161(129)b	14(0.08)e

Plainfield Sand

Table 4. **Soil test P results of the incubation with Plainfield sand soil.**

	M3[a] (mg/kg)	BP1 (mg/kg)	WEP (mg/kg)	TP (mg/kg)
Fertilizer	48(5)c[b]	143(5)bc	28(.9)b	319(26)ab
Fort Atkinson	80(4)ab	175(4)a	46(3)a	420(27)ab
Brookfield	56(3)bc	144(3)bc	23(.8)c	447(134)ab
Whitewater	57(4)bc	153(4)b	20(.7)cd	380(32)ab
East Troy	70(7)abc	131(7)d	19(.9)de	274(28)b
Mukwonago	47(7)c	141(7)e	16(.9)ef	483(110)a
Delafield	91(3)a	95(3)e	14(.6)fg	288(36)b
Control	83(2)a	91(2)e	13(1)g	382(106)ab

[a] M3, Mehlich 3; BP1, Bray P1; WEP, water extractable P (1:10); TP, total P; DPS, Degree of P saturation
[b] Soil test P values after incubation with biosolids and fertilizer (biosolids and fertilizer applied at same total P rate – 110 kg P ha^{-1}). Means within the same column with the same letter are not significantly different at the 5% significance level. Values in parentheses are standard deviations.

- Looking only at Bray P1, biosolids behaved similarly on the sand (Plainfield) and the silt loam (Kewaunee) (Figure 4)
- Further analysis will completed on water extractable P, Mehlich 3, and degree of phosphorus saturation

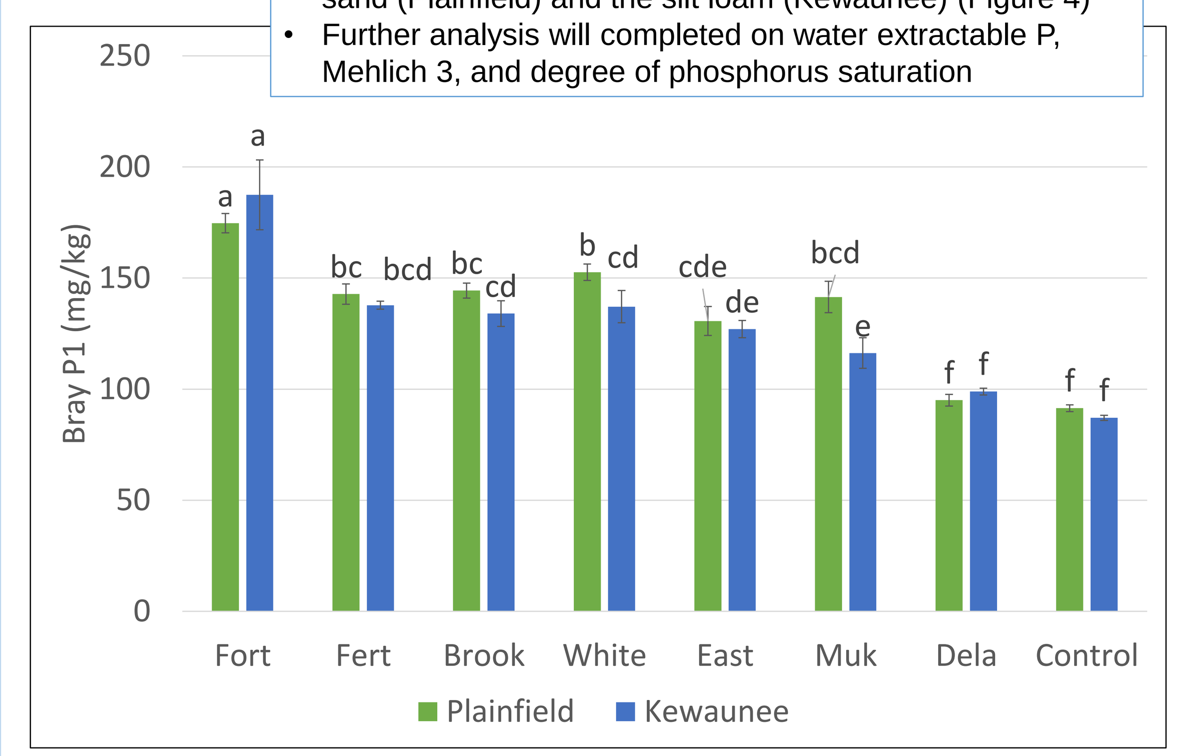

Figure 4. **Bray P1 comparison of biosolids treatments on Plainfield sand and Kewaunee silt loam soils.** Two-way anova was conducted with soil and P source as factors. Interactions were significant so a Tukey pairwise comparison of means (n=4) was conducted. Bars with the same letter are not statistically different at the 95% significance level.

Interesting relationships to explore further (Figure 5):
- Fort Atkinson (biological P removal) – high WEP
- Mukwonago (ferric chloride for P removal) – low WEP

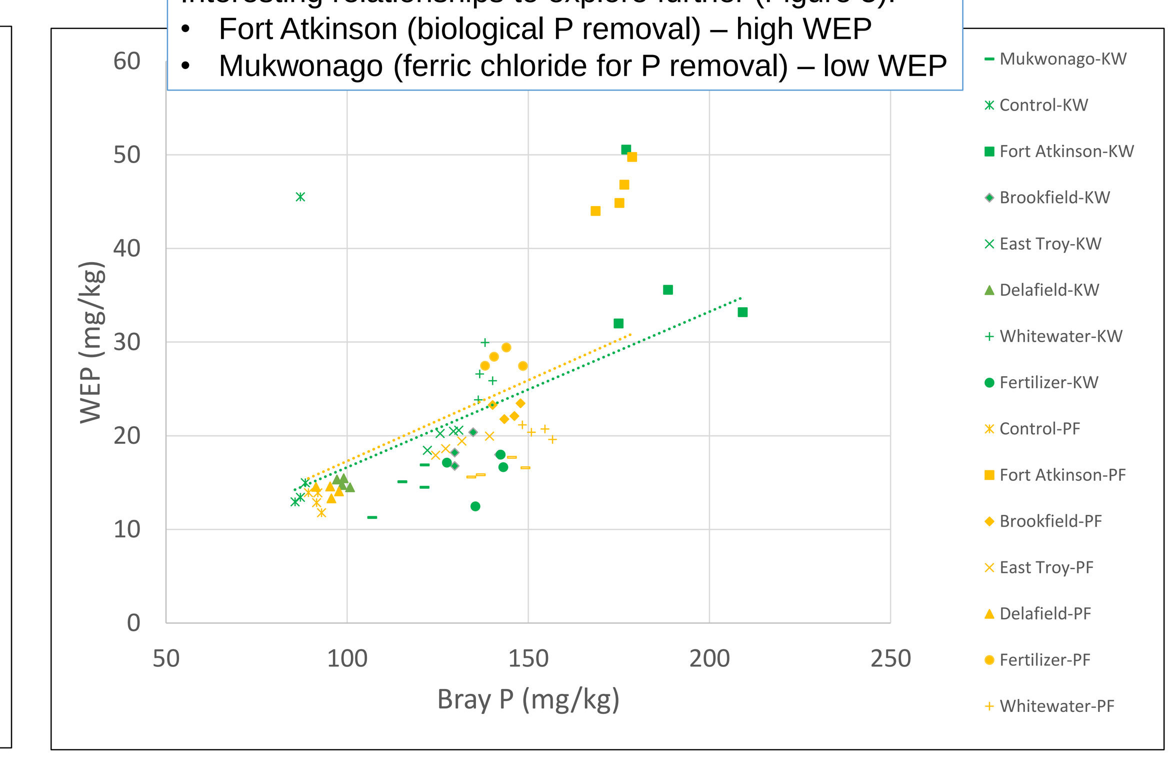

Figure 5. **Regression of Bray P1 and WEP (water extractable P) on both soils (Kewaunee silt loam (green) and Plainfield sand (yellow)).** Dotted lines are linear regressions of each soil forced through zero. Statistical analysis has not yet been completed. KW=Kewaunee, PF=Plainfield

Statistical Analysis

Statistical analyses were performed in the open source statistical program R (R Development Core Team, 2010). Differences in P availability (WEP, BP1, M3P, TP, and DPS) due to treatment in each soil was determined using one-way ANOVA at α=0.05 (Tables 3 and 4). A Tukey separation of the means was also performed in R. Normality assumptions for ANOVA were assessed and found acceptable. Two-way ANOVA analysis (soil and P source) for Bray P1 on both soils was conducted (Figure 4).

Conclusions

Overall, this data provides the beginning of an understanding of the differences in biosolids P availability in Wisconsin. More analysis needs to be done to sort out these differences. In general, the biosolid with biological phosphorus removal (Fort Atkinson) resulted in the highest soil test phosphorus measurements. The two liquid biosolids (Whitewater and Brookfield) often behaved similarly. Effects of digestion (anaerobic and aerobic) and chemical treatment of wastewater (alum and ferrous chloride) still need to sorted out. With further analysis, biosolids will hopefully be able to be included in the Wisconsin phosphorus index to allow farmers to appropriately credit biosolids additions and protect water quality.

Future Work

- Continue incubations with the same biosolids on different soils that are agriculturally important in Wisconsin
- Incubate these soils with other biosolids (from Wisconsin)
- Compare P availability of these biosolids to biosolids investigated in Wisconsin previously
- Determine P water solubility factors to allow inclusion of biosolids in the Wisconsin P Index
- Continue statistical analyses to evaluate biosolids effects on different soils with different soil test phosphorus measures

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