DAIRY MANURE TREATMENT EFFECTS ON SOIL TEST PHOSPHORUS

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Introduction

Because of increasing environmental concerns related to manure disposal, some farms are adopting manure handling systems that diminish the potential environmental problems associated with the large amount of manure produced in relatively small areas. For example, in Wisconsin as of 2007, there were 20 farms with fully operational anaerobic manure digesters with an average of 1,474 cows in each farm (USDA, 2010). Manure liquid-solid separation is another alternative option to manure handling. The separated liquid can be reused in barns as flush water, a crop nutrient source, or irrigation water; whereas, the separated solids can be recycled as bedding, used as nutrient source for crop production, or sold off farm as a horticultural amendment (personal communication with farmers). Manure composting has been used as an alternate manure handling process. Composting decreases the total amount of manure through water loss and also eliminates most of the pathogens in manures (Rynk et al., 1992). In-barn composted bedded packs are an alternative option to complete composting and consist of bedding layers (e.g., saw dust) that are constantly added to the barn floor without removal of the older layer. The bedded pack is aerated daily to stimulate microbial decomposition.

There has been little or no research that investigated and compared the effects of manure in-barn composted bedded pack, anaerobic digestion, or liquid-solid separation on the forms of inorganic and organic manure P. It is possible that manipulation systems that are known to use microorganism to mediate the process, such as composting or anaerobic digestion, can affect the distribution of the organic and inorganic P fractions in manure. For example, Sharpley and Moyer (2000) used sequential fractionation to quantify the change in the P fractions when dairy and poultry manure are composted. Composting increased the inorganic P fraction in dairy manure by reducing both the organic and residual fractions.

Anaerobic digestion of animal manure is mediated by bacteria, which degrade organic compounds and release inorganic compounds during the digestion. This process could alter the mechanisms controlling P solubility from treated manures. However, in a laboratory bench-scale study, anaerobic digestion of dairy manure was reported to have no effect on manure P solubility (Güngör and Karthikeyan, 2005). In a different study, when raw and anaerobically digested swine manure samples were applied to a silty clay loam soil, similar increases in STP were observed with both manures (Loria and Sawyer, 2005). The authors concluded that the anaerobic digestion of swine manure did not affect the mechanisms controlling P solubility and, therefore, no significant differences were observed in the increase in STP after raw and treated manure application (Loria and Sawyer, 2005). These two studies show that anaerobic digestion of animal manure, may not alter the manure P interactions with soil with regard to increases in STP after manure addition.

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In liquid-solid separation systems most of the changes would be expected to be a result of the mechanical manipulation of the manure. For example, if all manure inorganic P is in a dissolve (Møller et al., 2000), which indicates that the dissolved and precipitated forms of P in manure are in dynamic equilibrium. form, liquid-solid separation could concentrate most of the inorganic P in the liquid fraction. Or if most of the P in manure is in the precipitated form, then liquid-solid separation could concentration the P in the solid fraction. However, liquid-solid separation of cattle and swine manure has been reported to result in liquid and solid fractions that have similar P concentrations

There are no peer-reviewed publications that report the effects of dairy manure treatment on the manure P fractins and subsequently on soil test phosphorus (STP). Therefore, this research was conducted to evaluate the effect of manure treatment (in-barn composted bedded pack, liquid-solid separation without digestion, and anaerobic digestion with liquid-solid separation) on the increase in STP after manure application.

Methods and Materials

Manure and Soil Collection

Eighteen dairy (*Bos taurus*) manure samples (a mix of feces + bedding + urine) were collected from five commercial farms in Wisconsin with three different treatment systems: in-barn composted bedded pack, liquid-solid separation, and mesophilic anaerobic digestion with liquid-solid separation. Each of the treatment system is illustrated in Figures 1 and 2. Three samples were collected from an in-barn compost bedded pack (system 1) including a sample from the top (0 to 1 ft), the middle (1to– 2 ft), and the bottom layers (2 to 3 ft). In the in-barn composted bedded pack system, new layer of bedding is added daily, after which, an aeration practice mixes the new bedding and existing bedding + manure + urine to a depth of 8 to 10 inches. As the depth of the bedded pack increases because of deposition of feces, urine, and addition of new bedding layer, the lower layers are not aerated. Seven samples were collected from two liquid-solid separation systems, system 2 and system 3. For system 2, the separation system was composed of four stages, starting with a Mclanahan coarse sand separator, then passing through Mclanahan hydrocyclones fine sand separator, following the samples go through a fan separator and in the last stage samples pass through dissolved air floatation, which separates the manure liquid and solid fractions. The manure samples collected from system 2 included raw samples before entering the system, and liquid and solid samples after they passed through the dissolved air flotation. For system 3, the separation system is similar to that of system 2, but includes an additional centrifugation system, which separates the separated liquid into two fractions, tea water and concentrate. Samples collected from system 3 included the raw manure prior to separation, separated solid, concentrate, and tea water. Eight samples were collected from two anaerobic mesophilic digestion systems, system 4 and system 5. In these systems, raw manure is fed into the digester, after manure is digested it passes through a screw press system that separates the digested manure into liquid and solid fractions. The samples taken from these systems included one raw (prior to entering the digester), one post digestion but prior to liquid-solid separation, one liquid after separation (digested separated liquid), and one solid after separation (digested separated solid). After collection, samples were stored at -20°C until use. Dry matter content, electrical conductivity (EC), pH, total N, total potassium (K), and total dry ash P (P_t) were measured according to Peters et al. (2003) (Table 1). Total carbon (C), was measured by dry combustion using a Leco CNS-2000 analyzer (Leco, 2000). Water extractable P was measured after equilibrating manure with water in a 1:100 (manure dry matter to water) ratio for four hours He et al. (2006).

Five soil series that represent a range in soil properties under agricultural production in Wisconsin were collected from fields that had not received manure applications for at least 5 years (Table 3). Soil samples were collected from each site to a depth of 0 to 6 inches. After collection, the soils were moist sieved to pass through a 5-mm sieve, air-dried on a greenhouse bench, and stored in a sealed container until needed. A subsample of each soil was ground to pass through a 2-mm sieve and used for chemical analysis. Soil pH was measured in water (1:1 ratio w/w); organic matter (OM) content was measured by loss on ignition; electrical conductivity (EC) was measured using the water saturated paste method (Brown, 1998). In addition, particle size analysis was performed using the hydrometer method of Bouyoucos (1962). Extractable P was measured using the Bray P-1 test (Brown, 1998), and determined by the molybdate blue method of Murphy and Riley (1962). Calcium, Mg, potassium (K), and sodium (Na) were extracted using ammonium acetate (NH_4OAc, pH buffered at 7.0, Brown, 1998) and determined by atomic absorption. Cation exchange capacity (CEC) was estimated according to Brown (1998).

Manure and Soil Incubation Study

All 18 manures, triple superphosphate fertilizer (TSP), and a control (no fertilizer or manure) were applied to each soil in a full factorial, completely randomized design with four replications. Manure or fertilizer was manually mixed with 50 g of the sieved and air-dried soil at a rate of 40 mg P kg $soil^{-1}$ (183 lb P_2O_5/a). The dry matter content of the tea water manure was very low and it was not possible to supply 40 mg P kg $soil^{-1}$ without adding water in excess of field capacity. Therefore, the application of this manure was based on an amount of irrigation water (10 inches) that might typically be applied in a growing season in Wisconsin and resulted in a 16 mg P kg^{-1} (73 lb P_2O_5/a) application rate. Each individual sample was incubated at 25°C for 70 days in a specimen cup covered with a perforated cover to allow for air exchange. Soil moisture content was maintained between 40 to 60% of gravimetric water content by weighing the cups on a weekly basis and adding deionized water as required. After 70 days, samples were oven-dried at 35°C for 48 hours, ground to pass through a 2-mm sieve, and extracted with Bray P-1. The increase in soil test phosphorus (STP) was determined by subtracting the mean Bray P-1 in the control treatment of each soil from the Bray P-1 determined in each replication of the different treatments applied to that same soil. The soil P buffer capacity PBC was calculated by dividing the P application rate by the increase in soil test P.

Statistical Analysis

All statistical analysis was performed in JMP 9.01. The effect of manure treatment for a given soil and treatment system and the effect of soil for a given manure treatment were evaluated with a mixed model with Tukey means separation at the P-value <0.05. All manure PBCs were compared to the fertilizer treatment for the appropriate soil using a Dunnett's test.

Results

The PBC determined when fertilizer was incubated with soil ranged between 9 and 13 lb P_2O_5/a/ppm. The PBCs that are currently used in determining fertilizer rate guidelines (A2809) are 18 lb P_2O_5/a/ppm for silt loam soils (groups A – D) and 12 lb P_2O_5/a/ppm for coarse-textured soils (group E) (Laboski, et al., 2006). The present PBC are generally lower than values in A2809, which is typical of incubation studies compared to field studies. The Waymor soil had a significantly higher PBC compared to the other soils while the Mahtomedi (group E) tended to have the lowest PBC.

For the composted bedded pack system, the middle layer tended to have a lower PBC compared to the top and bottom layers, though not always significant. In system 2 liquid-solid separation, a PBC could not be calculated for the separated solids because soil test P decreased or increased very minimally. In the Dodgeville and Mahtomedi soils, the separated liquid had a significantly lower PBC compared to raw manure, but was not different for the other soil series. In system 3 liquid-solid separation, tea water generally had the lowest PBC, but was only significant in the Waymor and Dodgeville soils. On the other hand, separated solids had the greatest PBC though not always significantly different than other manures in this treatment system.

For the anaerobic digestion and separation system 4, there were no differences in PBC for raw slurry, digested slurry, digested separated liquid, or digested separated solid for any soil except Hortonville where the digested separated solid had a significantly lower PBC compared to digested separated liquid. Similarly for system 5 anaerobic digestion and separation, there were no differences in PBC for raw slurry, digested slurry, digested separated liquid, or digested separated solid for any soil except Dodgeville and Antigo. Digested separated solids had a significantly lower PBC compared to raw slurry in the Dodgeville while on the Antigo soil, digested separated liquid had significantly lower PBC compared to raw slurry.

The PBC for each manure treatment on each soil were compared to the PBC for fertilizer on that soil to determine if P source affects PBC. For the top layer of the compost bedded pack manure, PBC was always significantly greater than fertilizer. In 47% of the comparisons, PBC for manure was significantly greater than fertilizer on the Dodgeville soil. Manure PCB was greater than fertilizer on the Hortonville soil in 35% of the comparisons. On the whole, manure PBC is not different than fertilizer PBC, though there is some variation.

Additional data analysis is needed to determine if soil and/or manure properties can be used to predict when manure will increase soil test P less than fertilizer (greater PBC).

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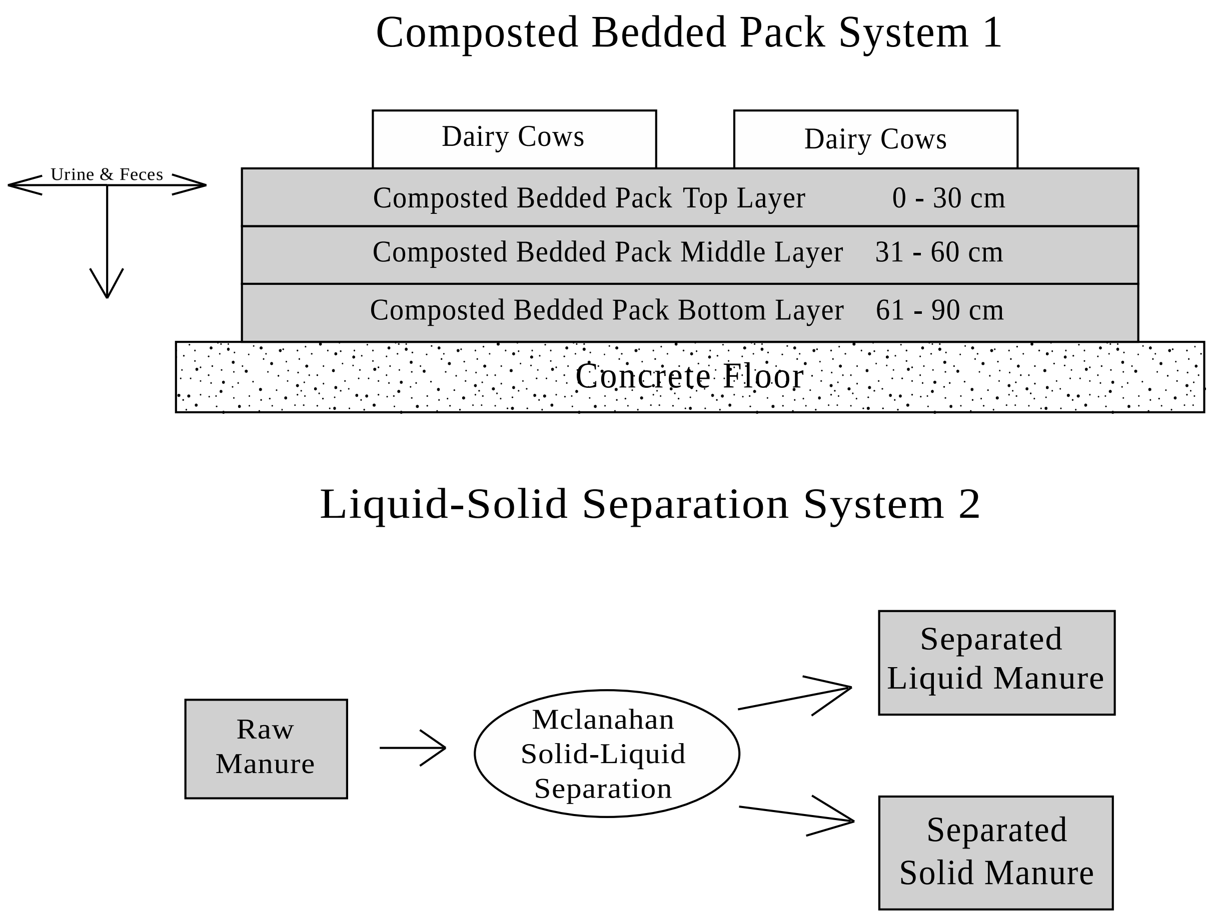

Figure 1. Schematics for the manure treatment systems 1 and 2 studied in this research. Gray box indicate stage where manure samples were collected.

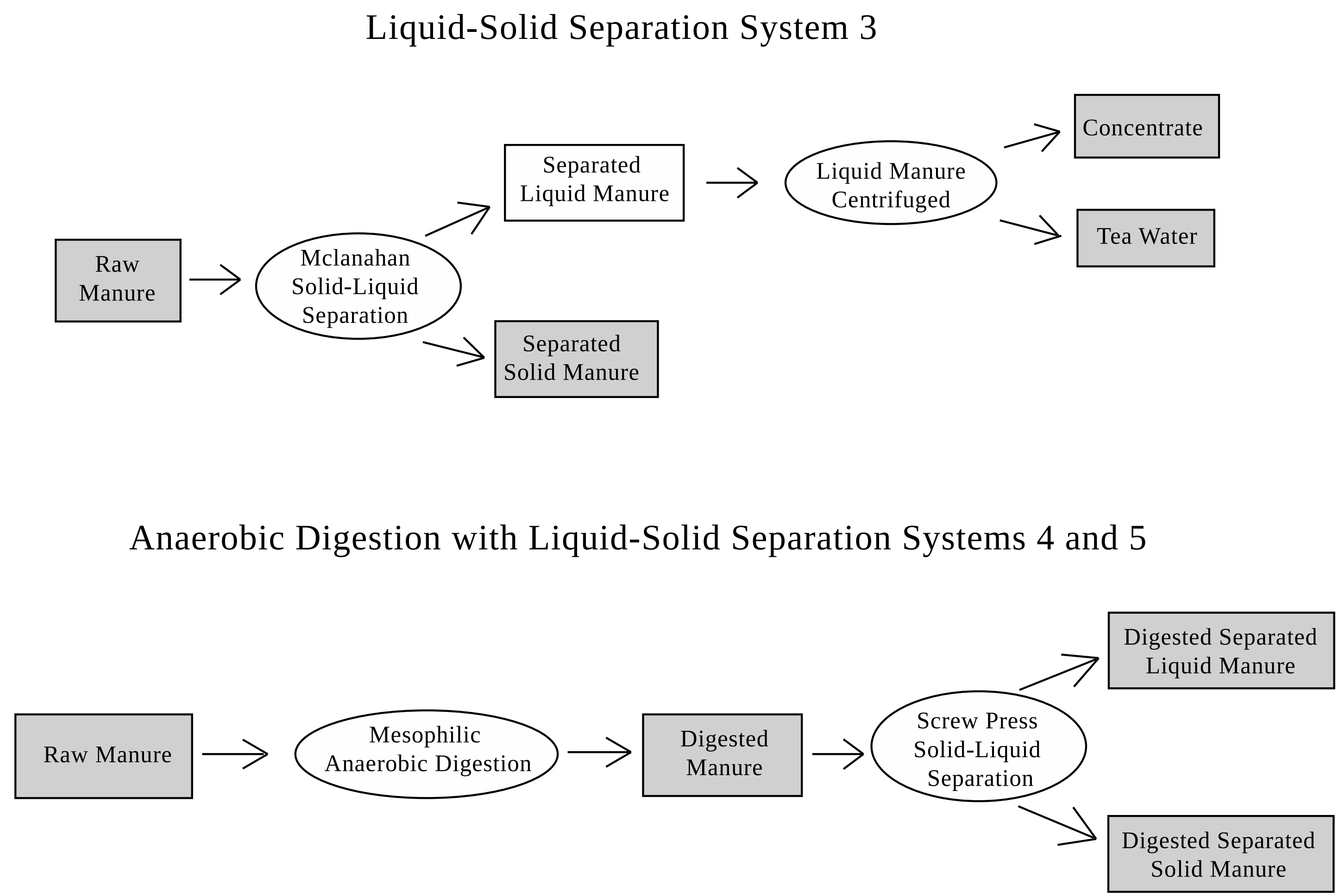

Figure 2. Schematics for the manure treatment systems 3, 4, and 5 studied in this research. Gray box indicate stage where manure samples were collected.

Table 1. Selected physical and chemical properties of manure.

System	Manure†	DM	pH	EC	C:N	Total N	NH_4-N	Total K_2O	Total P_2O_5	WSP_2O_5‡	WSP_2O_5/ Total P_2O_5
		%		dS/m		——	——	lb/T §	——	——	%
Composted Bedded Pack											
1	Top layer	33.7	9.3	2.9	38	8.1	1.3	14.6	2.8	1.32	48
	Middle layer	33.4	9.4	2.7	33	9.4	3.3	13.6	5.7	1.87	33
	Bottom layer	31.4	9.7	2.5	29	10.0	2.5	13.6	5.3	1.62	30
Liquid-Solid Separation											
2	Raw-2	10.6	6.8	9.8	12	7.0	3.8	5.1	2.6	0.64	25
	SL-2	3.6	6.8	14.1	5	4.3	1.7	3.0	1.6	0.95	60
	SS-2	28.6	6.7	2.1	15	17.2	0.6	4.8	2.0	0.03	1
3	Raw-3	7.0	8.3	7.9	14	3.8	1.8	4.2	1.6	0.31	20
	Concentrate-3	6.1	6.9	11.9	6	8.9	3.1	4.1	3.6	0.64	18
	Tea water-3	1.0	8.0	10.4	3	2.0	1.7	5.4	0.1	0.05	71
	SS-3	23.2	8.3	1.3	13	14.4	0.9	3.9	3.1	1.68	55
Anaerobic Digestion / Separation											
4	Raw-4	4.0	8.1	6.8	7	4.8	2.8	3.0	2.2	0.19	9
	Digested-4	5.4	7.5	9.9	6	6.9	4.2	4.4	2.7	0.21	8
	DSL-4	3.9	7.5	17.3	5	6.4	3.3	4.5	2.7	0.15	6
	DSS-4	24.8	8.3	1.5	18	12.4	3.5	6.5	8.1	1.54	19
5	Raw-5	6.0	8.7	10.9	7	7.1	4.3	5.6	3.0	0.19	7
	Digested-5	5.1	9.8	8.8	6	6.4	4.3	5.1	2.4	0.16	7
	DSL-5	3.1	7.8	19.4	3	6.5	4.5	5.5	1.9	0.08	4
	DSS-5	32.8	8.2	1.8	18	15.7	3.9	7.9	14.3	2.20	15

† DSL, digested separated liquid; DSS, digested separated solids; SL, separated liquid; SS, separated solid

‡ WSP_2O_5, water soluble phosphate

§ Units are pounds per ton of “as is” manure. For liquid manures, multiple by 4.165 to convert to pounds per 1,000 gallons.

Table 2. Selected soil physical and chemical properties.

	Soil series				
Soil properties	Antigo	Dodgeville	Hortonville	Mahtomedi	Waymor
A2809 Soil Group	D	B	C	E	A
pH	5.6	5.7	6.9	6.7	6.6
OM, %	3.4	3.4	2.9	1.5	2.9
Sand, %	55.9	18.2	17.9	87.9	48.9
Silt, %	41.0	66.0	70.0	9.0	40.0
Clay, %	3.1	15.8	12.1	3.1	11.1
Bray P-1, %	24	18	43	16	30
CEC, $cmol_c\ kg^{-1}$	4	12	11	6	13

Table 3. Phosphorus buffer capacity of manure and fertilizer when applied to five Wisconsin soils in a laboratory incubation.

System	Treatment	Waymor		Dodgeville		Hortonville		Antigo		Mahtomedi	
		lb/a P_2O_5 applied per ppm soil test P									
Fertilizer	TSP	13	A	10	B	9	B	9	B	8	B
Composted Bedded Pack											
1	Top layer	29*‡	a AB†	73*	a A	28*	a AB	19*	a B	18*	a B
	Middle layer	15	b AB	16	a A	16*	b A	11	b AB	8	b B
	Bottom layer	25*	a A	23	a A	10	b B	15*	ab B	14	ab B
Liquid-Solid Separation											
2	Raw-2	20*	a A	22	a A	18	a AB	17	a B	12	a B
	SL-2	18	a A	16	b A	14	a AB	10	a B	10	b B
	SS-2	na§		na		na		na		na	
3	Raw-3	17	ab B	38*	a A	9	a B	13	a B	12	b B
	Concentrate-3	15	ab B	20*	bc A	12	a B	14	a B	8	b C
	Tea water-3‡	11	b A	12	c A	10	a A	6	a B	9	b A
	SS-5	25*	a AB	31*	ab A	11	a B	16	a AB	25*	a AB
Anaerobic Digestion / Separation											
4	Raw-4	16	a AB	18*	a AB	21*	ab A	13*	a AB	9	a B
	Digested-4	14	a B	13	a BC	18	ab A	10	a BC	9	a C
	DSL-4	13	a B	17*	a AB	27*	a A	11	a B	10	a B
	DSS-4	15	a A	16	a A	12	b A	11	a A	14	a A
5	Raw-5	16	a B	28*	a A	13	a BC	13*	a BC	11	a C
	Digested-5	17	a B	26*	ab A	17*	a B	11	ab C	12	a C
	DSL-5	15	a B	26	ab A	15	a B	10	b B	12	a B
	DSS-5	15	a AB	20	b A	17*	a AB	11	ab B	13	a AB

† Within a soil series and manure treatment system, means with the same lower case letters are not significantly different (P-value<0.05). Within a manure treatment (row), means with the same uppercase letters are not significantly different.

‡ Within a soil series, means followed by an * are significantly different from the fertilizer treatment.

§ na, not applicable. Soil test P either decreased or increased very minimally when manure was applied; P buffer capacity could not be calculated.