Water Extractable Phosphorus in Raw, Heated, and Granulated Poultry Litters

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Introduction

In the southwestern Ozarks, poultry operations are highly concentrated in many environmentally sensitive watersheds, such as the Eucha-Spavinaw Watershed, the Illinois River basin, and the White River Basin. DeLaune et al. (2006) noted that approximately 70% of the poultry litter produced annually in the Eucha-Spavinaw Watershed will need to be exported in order to meet phosphorus (P) management practices as defined in the lawsuit settlement agreement. The Illinois River Basin will be the focus of a second lawsuit in the Ozarks, which might ultimately result in a similar need to export poultry litter to other P deficient areas. The long-term solution to solve P imbalance in intensive animal production regions may involve the development of off-farm uses of poultry litter. One of the possible alternative may involve use of poultry litter in turf, lawn, and gardens. However, this may require the processing of poultry litter to reduce moisture content, prevent odor, and to increase the consistency of particle sizes to ease application constraints. In the past, poultry litters have been pelletized and more recently poultry litters have been granulated in the Ozarks. To successfully implement these approaches, the effect of granulation on litter P chemistry, particularly water extractable P (WEP) in the final product needs to be evaluated because WEP application rates in surface applied litters have been positively correlated with dissolved P concentrations in runoff. This suggests that WEP content in litters can be used as an indicator of the potential for P loss when litters are land applied.

Our study objectives were to determine P solubility in unprocessed raw and granulated poultry litters using water extraction at five different litter (dry weight equivalent) to water ratios and to elucidate other water extractable elements related to WEP in poultry litters.

Laboratory Methods

Poultry Litter Granulation

Poultry litters were collected from two poultry farms in Northwest Arkansas and granulated at facilities located in PA and AR. Poultry litter from one farm near Decatur, AR, was ground to pass through a 5.8 mm mesh screen and thoroughly mixed. The ground and mixed poultry litter was delivered to Mars Mineral, Inc. in PA and was placed in a holding bin. Feed grade urea and dicyandiamide (DCD) were placed in an adjacent blend and used during the process to produce some of the granulated products. DCD is a nitrification inhibitor, often used in agricultural practices to reduce nitrate losses. The poultry litter (and additives) were fed into a bench scale granulator with vibrating screw feeders; water was used as the binding agent in the granulation process. After granulation, granulates were moved to a vibrating fluid bed dryer at 232ºC, and dried to 121ºC. Dried granulates were screened to pass a 4.75 mm mesh screen, but not a 0.85 mm mesh screen. Five treatments resulted from this litter source: 1) raw poultry litter (*raw litter no. 1*); 2) ground poultry litter (*ground litter no. 1*); 3) granulated poultry litter (*granulated no. 1*); 4) granulated mixture of poultry litter plus urea (*granulated no. 1 with urea*); and 5) granulated mixture of poultry litter plus urea and DCD (*granulated no. 1 with urea and DCD*). The raw poultry litter was heated at 180 ^{0}C for 2 hrs (*heated litter no. 1*) in our laboratory.

A second poultry litter source was obtained from Organic-Gro, Inc. in Northwest AR. At this facility, poultry litter was passed through a 2.5 mm vibrating screen and then mixed with hydrolyzed feathermeal before granulation. Two treatments resulted from this litter source: 1) ground poultry litter (*ground litter no. 2*); and 2) granulated mixture of poultry litter and hydrolyzed feathermeal (*granulated no. 2 with feathermeal*). This facility dried granulates to less than 8% moisture to avoid composting during storage, because *granulated no. 2 with feathermeal* is a commercially available product (lawn and turf fertilizer) from Organic-Gro, Inc.

Poultry Litter Extraction and Analyses

Total P, K, Ca, Mg, Fe, Al, and Zn in the raw and granulated poultry litters were determined, in triplicate, using concentrated HNO_3 and H_2O_2 digestion followed by inductively coupled plasma- optical emission spectroscopy (ICP-OES) analysis.

Poultry litter (dry weight equivalent) were extracted, in triplicate, at deionized water ratios of 1:10, 1:50, 1:100, 1:200, and 1:250 to determine water soluble elements. For example, the 1:10 ratio had 20 g dry weight equivalent of poultry litter mixed with 200 ml of water (including ambient moisture in the poultry litter), and this volume of water (200 mL) was used in all extracts. The mixture was shaken for 2 h in a reciprocating shaking followed by centrifugation at 2900 rpm for 20 min before filtration through a 0.45 µm nylon membrane or a Whatman 40 filter. The filtered aliquots (0.45 µm and Whatman 40) were analyzed for P using the automated ascorbic acid reduction method (APHA, 1992) and are referred as $WEP_{SRP-0.45\mu m}$ or $WEP_{SRP-W40}$, respectively. The difference between WEP measured in the filtered (0.45 µm) aliquot via ICP-OES ($WEP_{ICP-0.45\mu m}$) and ascorbic acid reduction method ($WEP_{SRP-0.45\mu m}$) was assumed to represent water extractable organic P ($WEP_{ORG-0.45\mu m}$). This manuscript focuses on WEP and its relation to several water extractable elements measured via ICP-OES, but it does not present data on elements that did not significantly affect WEP. The filtered (0.45 µm) aliquot from the various ratios was also analyzed for water extractable elements (Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Ni, P, S, Se, Ti, and Zn) by ICP-OES.

Statistical Analyses

Effects of treatments and extraction ratios on litter WEP was calculated using Genstat 4.2. Stepwise linear regression using *Statistix 8.0* was preformed to relate WEP with other water extractable elements in poultry litters.

Results

Total Elemental Contents

- Granulation of poultry litter significantly reduced total P compared with raw and ground litters (Table 1).
- Addition of urea, DCD, and feathermeal during the granulation resulted in lower contents of K, Ca, Mg, Fe, Al, and Zn than ground litters.

Table 1. Total elemental analyses for poultry litters.

Poultry litter treatment	P	K	Ca	Mg	Fe	Al	Zn
	----------g kg^{-1}----------				----------mg kg^{-1}----------		
Raw Litter No. 1	22.7	40.3	31.6	7.5	561	649	615
Ground Litter No. 1	23.6	40.1	33.2	7.7	561	712	642
Granulated Litter No. 1	21.9	39.1	32.3	7.4	636	666	620
Granulated Litter No. 1 with Urea	17.7	30.5	25.7	5.8	475	535	517
Granulated Litter No. 1 with Urea and DCD	16.8	29.3	25.5	5.6	419	482	490
Ground Litter No. 2	18.3	26.9	28.8	5.8	544	949	417
Granulated Litter No. 2 with Feathermeal	15.5	24.0	25.1	4.9	697	866	364
LSD (0.05)	1.3	1.7	4.2	0.3	201	72	21

Water Extractable Phosphorus

- Contents of WEP in poultry litters varied as a function of extraction ratio. The sequential increase in WEP content from 1:10 to 1:250 suggests that the equilibrium between aqueous P and litter solids limits the dissolution of P compounds (Table 2).
- At 1:10 to 1:100 extraction ratio, granulated products had significantly greater amounts of WEP compared to raw or ground poultry litters.
- However, at 1:200 to 1:250 extraction ratio, WEP was not significantly different among granulated products and raw or ground litters.

Table 2. Contents of water extractable P at different ratios for poultry litters.

Poultry litter treatment	1:10	1:50	1:100	1:200	1:250
	$WEP_{SRP-0.45\mu m}$				
	----------mg kg^{-1}----------				
Raw Litter No. 1	959	2280	3690	5588	6439
Ground Litter No. 1	1135	2401	3935	5953	6471
Heated Litter No. 1	5756	6301	6366	6473	6425
Granulated Litter No. 1	2669	4684	6048	6440	6393
Granulated Litter No. 1 with Urea	3645	4328	4614	4691	4769
Granulated Litter No. 1 with Urea and DCD	2908	4290	4501	4707	4809
Ground Litter No. 2	1035	2816	4042	4711	4758
Granulated Litter No. 2 with Feathermeal	2826	3552	3852	4135	4228
LSD (0.05)			210		

- Percentage of WEP was more variable between raw or ground litters and granulated products at the lower extraction ratios (1:10 to 1:50) (Table 3).
- Whereas, percentage of WEP was very similar (26 to 29%) for all poultry litters at the 1:250 extraction ratio.

Table 3. Percentage of water extractable P at different ratios for poultry litters.

Poultry litter treatment	1:10	1:50	1:100	1:200	1:250
	$WEP_{SRP-0.45\mu m}$				
	----------% of total P----------				
Raw Litter No. 1	4	10	16	25	28
Ground Litter No. 1	5	10	17	25	27
Heated Litter No. 1	25	28	28	29	28
Granulated Litter No. 1	12	21	28	29	29
Granulated Litter No. 1 with Urea	21	24	26	26	27
Granulated Litter No. 1 with Urea and DCD	17	25	27	28	29
Ground Litter No. 2	6	15	22	26	26
Granulated Litter No. 2 with Feathermeal	18	23	25	27	27
LSD (0.05)			1.8		

Effect of Filtration Techniques

- WEP in 0.45 µm membrane and Whatman 40 filter was significantly correlated (r = 0.998**) (Fig. 1).
- Slope of the linear relation showed that $WEP_{SRP-0.45\mu m}$ was approximately 98% of $WEP_{SRP-W40}$.
- Greater pore size (1.0 µm) in Whatman 40 filters compared to 0.45 µm membranes resulted in slightly higher WEP in Whatman 40 filtrates.

Effect of Method of Analysis

- WEP analyzed by the colorimetric method ($WEP_{SRP-0.45\mu m}$) was significantly linearly (r = 0.980**) related with ICP ($WEP_{ICP-0.45\mu m}$), with a slope of 0.87, suggesting that on average $WEP_{SRP-0.45\mu m}$ was 87% of $WEP_{ICP-0.45\mu m}$ (Fig. 2).

Relations between Water Extractable Elements

- Contents of water extractable P and Al, Ca, Fe, K, Mg, Zn increased from the 1:10 to 1:250 extraction ratios for all poultry litters (Fig. 3).
- WEP had the highest significant (P<0.001) correlation with water extractable Mg.
- The other elements that significantly (R^2 = >0.75) affected variation in WEP were different for $WEP_{ICP-0.45\mu m}$ (Fe, Zn, Ca, K, Al) and $WEP_{SRP-0.45\mu m}$ (Cu, S, Zn) (Table 4).

Table 4. Stepwise linear regression of $WEP_{ICP-0.45\mu m}$ or $WEP_{SRP-0.45\mu m}$ and other total water extractable elements (mg kg^{-1}) at different ratios for poultry litters.

Step	Stepwise regression equation	R^2	P
	$WEP_{ICP-0.45\mu m}$ and other water extractable elements		
1	1688.3+2.8[Mg]	0.7976	<0.01
2	-90.3+2.9[Mg]+24.8[Fe]	0.9414	<0.01
3	-805.7+2.9[Mg]+52.8[Fe]-41.4[Zn]	0.9651	<0.01
4	-526.5+3.3[Mg]+ 49.3[Fe]-32.8[Zn]-0.84[Ca]	0.9782	<0.01
5	-1197.7+3.1[Mg] +45.5[Fe]-35.4[Zn]-0.71[Ca]+0.05[K]	0.9811	<0.03
6	-1185.1+2.9[Mg] +39.6[Fe]-32.8[Zn]-0.71[Ca] +0.06[K]+2.86[Al]	0.9842	<0.02
	$WEP_{SRP-0.45\mu m}$ and other water extractable elements		
1	1683.4+2.3[Mg]	0.7538	<0.01
2	-118.2+2.5[Mg]+9.9[Cu]	0.8981	<0.01
3	1594.2+2.6[Mg]+11.4[Cu] -0.3[S]	0.9382	<0.01
4	745.9+2.7[Mg] +22.1[Cu]-0.3[S]-34.3[Zn]	0.9698	<0.01

Fig. 1 Relation between water extractable P in 0.45 µm membrane and Whatman 40 filtered aliquots analyzed by Colorimetric method.

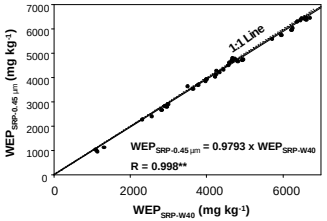

Fig. 2 Relation between water extractable P in 0.45 µm membrane filtered aliquots analyzed by Colorimetric and ICP-OES.

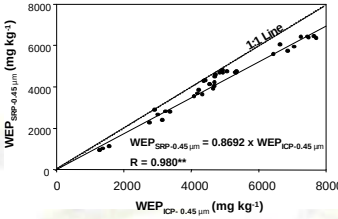
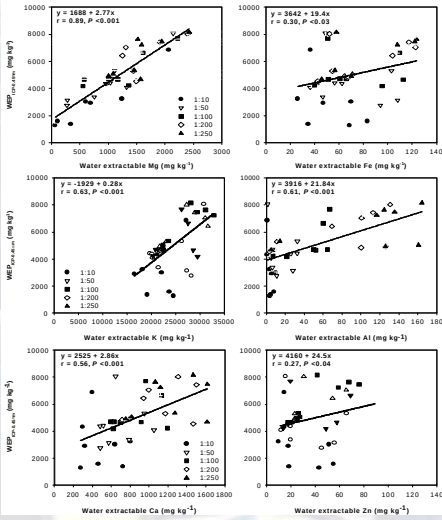
Fig. 3 Relation between water extractable P ($WEP_{ICP-0.45\mu m}$) and water extractable Mg, Fe, K, Al, Ca, and Zn at the different extraction ratios for all poultry litter treatments.