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SW—Soil and Water

Effect of Poultry Litter to Water Ratios on Extractable Phosphorus Content and its Relation to Runoff Phosphorus Concentrations

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Source factors with regard to phosphorus (P) loss in runoff waters are often soil test P and P content of fertilisers applied. More recently, water extractable P (WEP) fractions in fertilisers and animal manure have been the focus of many field and plot-scale studies. This study evaluated changes in the WEP content of six poultry litters by varying the extraction ratio from 1:10 (20 g fresh poultry litter to 200 m*l* water) to 1:200 (1 g fresh poultry litter to 200 m*l* water), and also the relation between WEP content determined at these different ratios and P concentrations in runoff water collected during rainfall simulations. Six different poultry litters were surface-applied at equivalent total P (TP) application rates ($\sim$67 kg [TP] ha^{-1}) to 1·52 by 6·10 m grass plots on a 5% slope which received artificial rainfall at 5 cm h^{-1} until 30 min of continuous runoff was observed. Four plots were used per treatment including four control plots (no poultry litter application). Water-extractable P content of the various poultry litters increased with a decrease in the amount of poultry litter used in the extraction, *i.e.* from an extraction ratio of 1:10 to 1:200. However, these results also suggest that the 1:10 extraction ratio may extract different fractions of WEP compared to the 1:200 extraction ratio, and that some variability in dry weight extraction ratios existed when using fresh poultry litter. Water-extractable P application rates were positively correlated to P concentrations in runoff waters from the small plots. This study reaffirmed the importance of WEP content of poultry litter when determining the potential for P loss in surface runoff but demonstrated differences in the relation between runoff soluble reactive P (SRP) concentrations and WEP application rates related to the runoff to rainfall ratio.
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1. Introduction

The development of field-based phosphorus (P) indices to manage animal manure and commercial fertiliser applications has identified many potential P source and transport factors, and the importance of individual factors may differ within and between various countries around the world. The intent of these P indices is to manage and reduce the risk of P loss from land application of animal manure and commercial fertilisers containing P. The P source factor of these various indices often includes soil test P content and water extractable P (WEP) and/or total P (TP) application rates. The positive correlation between soil test P measurements and P concentrations in runoff waters from small plot studies has been well documented (Pote *et al*., 1999; Hansen *et al*., 2003). Recent evidence from small plots studies has shown the importance of manure or fertiliser WEP application rate and its effect on P concentrations in runoff water (DeLaune *et al*., 2004; Haggard *et al*., 2004; Kleinman *et al*., 2002a; Sauer *et al*., 2000). When manure or fertilisers containing P are applied, the effect of manure and fertiliser WEP often inhibits the traditional relation observed between soil test P and P concentrations in runoff waters.

Various methods exist to measure WEP content of manures or commercial fertilisers, and each method may extract different amounts of WEP from the source. Variation in manure to water extraction ratios may result in differences in estimates of manure WEP content, with the fraction of WEP increasing with this ratio (Kleinman *et al.*, 2002b). The fraction of WEP in manures also increased with an increase in agitation or shaking time, and greater than 70% of WEP was extracted within 1 h (Kleinman *et al.*, 2002b). Thus, a 1 h extraction time during manure analysis may provide a good estimate of the amount of P susceptible to loss in surface runoff after surface application (Dou *et al.*, 2000).

Differences in manure WEP extraction techniques, particularly the manure to water ratio, may result in substantially different relations between P concentrations in runoff waters and manure WEP application rate. However, these different extraction methods all have produced significant positive relations between manure WEP content and P concentrations in runoff water (*e.g.* see Kleinman *et al.*, 2002b). The objective of this study was to: (1) determine the effect of extraction ratios (poultry litter to water) on WEP content of various poultry litters; (2) compare WEP content and runoff P concentrations from six poultry litters; and (3) evaluate the relation between WEP application rate at the various ratios and P concentrations in runoff waters from a small plot study.

2. Materials and methods

2.1. *Manure soluble phosphorus*

Six different poultry litters were used in this study (Table 1) and extracted for WEP content using various mass ratios of fresh poultry litter to water. The mass ratios used were 1:10, 1:20, 1:50, 1:100, and 1:200 where the 1:10 mass ratio is the standard ratio used in this method for determining WEP in relatively dry solid manures, *i.e.* poultry litter (Self-Davis & Moore, 2000). All mass ratio extractions were shaken in a reciprocating shaking for 2 h and then centrifuged at relative centrifugal force of 2900 times the gravitational acceleration g for 20 min. An aliquot of the supernatant was filtered (0·45 μm nylon or Metrical membrane) and acidified to $pH < 2$ using concentrated HCl. The filtered, acidified aliquot was analysed for soluble reactive P (SRP) using the automated ascorbic acid reduction method, *i.e.* WEP_{SRP} (APHA, 1992). The filtered, acidified portion was also analysed using an inductively coupled argon plasma (ICP) spectrometry to determine total dissolved P (WEP_{ICP}). Total P content of the poultry litters were determined using HNO_3 and H_2O_2 digestion with ICP analysis (Zarcinas *et al.*, 1987). Water extractable P and TP content were determined on three replicate samples from each poultry litter treatment and are reported on a percentage dry weight basis.

2.2. *Small plot runoff study*

At the University of Arkansas Agricultural Experiment Station, Fayetteville, Arkansas, USA, 28 small plots (1·52 m by 6·10 m) with a tall fescue (*Festuca arundincea* Shreb.), bermudagrass and clover mix on a Captina silt loam soil (fine-silty, siliceous, active, mesic Typic Fragiudult) were selected. The plots were established in 1998 with a 5% slope and were hydrologically isolated using 0·15 m metal borders inserted vertically into the soil so that 0·05 m of the metal borders were above the soil surface. An Al trough at the down slope

Table 1
Six different poultry litter treatments used in laboratory study on extraction ratios and in the field study with artificial rainfall simulation and small plots

Treatment name	*Litter source and description*	*Chemical amendments*	*Actual Application, kg plot^{-1}*	*TP, %*	*TN, %*	*Dry matter, %*
Pelleted compost	Pelleting plant: pelleted composted poultry litter	None	3·9	1·71	4·41	92·1
Pelleted litter	Pelleting plant: pelleted raw poultry litter	None	3·7	1·85	4·51	90·4
Raw litter	Pelleting plant: raw, unprocessed poultry litter	None	4·0	1·91	4·37	82·7
Alum treated	Local farm: alum treated raw poultry litter	Alum ($Al_2(SO_4)_3$)	6·1	1·36	5·19	75·5
Pelleted alum	Local farm: pelleted alum treated raw poultry litter	Alum ($Al_2(SO_4)_3$)	4·6	1·61	4·37	84·2
Untreated litter	Local farm: raw, unprocessed or untreated poultry litter	None	5·3	1·48	—	72·7

TP, total P; TN, total N.

end was used to collect surface runoff. Poultry litter treatments were applied at equivalent rates of manure TP, about 67 kg [TP] ha^{-1}, to the small plots using a completely randomised design. Rainfall simulations were conducted immediately following land application of the various poultry litters in July 2002. Small plots received artificial rainfall at a rate of 5 cm h^{-1} from large simulators using eight TeeJet 1/2HH-SS30WSQ nozzles (Spraying Systems, Wheaton, Illinois, USA) at approximately 3 m above the soil surface until 30 min of continuous runoff was observed. Discrete runoff water samples were collected 2 min after initiation of continuous runoff and every 5 min thereafter until 30 min of continuous runoff was observed. A single flow-weighted composite runoff water sample was made from six discrete samples from each plot and used in subsequent laboratory analyses. Soil samples were collected from each plot before land application of the various poultry litters and also following the rainfall simulation. Soils were analysed for Melich-3 soil test P (Mehlich, 1984). A small portion of the composite runoff water was filtered through a 0·45 μm membrane, acidified with concentrated HCl to pH < 2, and analysed for SRP using the automated ascorbic acid reduction method (APHA, 1992). Total P was determined on an unfiltered, acidified portion of the composite runoff sample using HNO_3 and H_2O_2 digestion with ICP analysis (Zarcinas *et al.*, 1987).

Specific comparisons between poultry litter treatments are discussed in a previous report (Haggard *et al.*, 2004), and this manuscript focuses on the effect of manure extraction ratios on WEP content and its relation with runoff P concentrations.

2.3. *Statistical analysis*

Statistical analyses were performed using ANOVA, simple linear regression and the software program, Statistix 8·0. Manure WEP content were natural logarithm (ln) transformed, and means of ln-transformed values were separated using Fisher's protected least significant difference (LSD). Simple linear regression was used to relate runoff P concentrations with manure WEP application rates at the various extraction ratios.

3. Results

3.1. *Manure soluble phosphorus*

The relationship between WEP_{SRP} content and extraction ratio was similar for the various poultry litters where WEP_{SRP} content increased with a reduction in the amount of poultry litter used in the extraction with 200 m*l* water (from 1:10 to 1:200 poultry litter to water extraction ratios) (Table 2). The relative increase in WEP_{SRP} content from the 1:10 to 1:200 extraction ratios was 5–13-fold for the various poultry litters. While gross increase in WEP_{SRP} was variable between the various poultry litters, the relative ranking from least to greatest WEP_{SRP} content in the various poultry litters remained the same for each extraction ratios. In general, the ranking was in this order (from least to greatest): alum treated, pelleted alum, untreated litter, raw litter, pelleted raw, and then pelleted compost.

The fraction of dissolved P released during the extractions generally increased in a linear fashion (*Fig. 1*), assuming the 1:200 extraction ratio represented total WEP_{SRP} content. This relation was generally consistent between extraction ratios based on fresh, wet weight of poultry litter or based on dry weight of poultry litter. Owing to the variability in moisture content of the poultry litters, the extraction ratios were quite different when based on dry weight of poultry litter. Water extractable P_{SRP} at the 1:200 ratio represented 10–74% of the TP content of the various poultry litters.

These comparisons produced similar gradients and differences when comparing WEP_{ICP} content that is when P in the extraction water was determined *via* ICP analysis (Table 2). As expected, WEP_{ICP} content was greater than WEP_{SRP} because the analytical technique was different where WEP_{SRP} (*via* ascorbic acid reduction and spectrometry) is a fraction of WEP_{ICP}. WEP_{SRP} content was on average 88% of the WEP_{ICP} content, but the proportion was slightly different for the various poultry litters ranging from 79% for pelleted alum to 100% for alum treated. The coefficient of variation generally increased for WEP_{SRP} and WEP_{ICP} content as the amount of poultry litter used in the extraction ratio decreased from 1:10 to 1:200 (Table 2), suggesting variability increased with smaller amounts of poultry litter.

3.2. *Relation between manure soluble P and runoff P concentrations*

Significant differences were observed in runoff SRP and TP concentrations from the plots receiving the various poultry litters at equivalent TP applications rates (*Fig. 2*), and these differences are discussed further in Haggard *et al.* (2004). Poultry litter application increased P concentrations compared to those measured in runoff from control plots (plots without poultry litter application). All the treatments had similar Mehlich-3 soil test P (M3P) content, ranging from an average of 107–124 mg [M3P] kg^{-1} dry soil for the various

Table 2

Water extractable P (WEP) content in the various poultry litters at different extractions ratios (by weight) of fresh poultry litter to water where colorimetric analysis of soluble reactive P (SRP) determined WEP_{SRP} and inductively coupled argon plasma spectrometry (ICP) analysis of total dissolved P determined WEP_{ICP} [the data represent the average of three replicates, and the coefficient of variation is presented in parentheses]

Treatment name	*Water extractable P content, %*				
	1:10	*1:20*	*1:50*	*1:100*	*1:200*
Poultry litter WEP_{SRP} content, %					
Pelleted compost	0·24 (2·5)	0·28 (0·8)	0·42 (5·4)	0·43 (2·7)	1·27 (33·4)
Pelleted litter	0·15 (0·9)	0·22 (3·2)	0·32 (0·8)	0·49 (5·1)	1·17 (16·7)
Raw litter	0·07 (6·5)	0·14 (1·7)	0·28 (4·8)	0·43 (2·3)	0·92 (21·3)
Alum treated	0·02 (5·1)	0·03 (10·2)	0·05 (5·0)	0·06 (5·7)	0·13 (13·4)
Pelleted alum	0·05 (6·5)	0·08 (3·2)	0·17 (3·7)	0·32 (15·0)	0·61 (29·6)
Untreated litter	0·06 (5·1)	0·11 (2·4)	0·22 (2·5)	0·38 (4·0)	0·60 (4·5)
Poultry litter WEP_{ICP} content, %					
Pelleted compost	0·26 (2·2)	0·34 (0·8)	0·44 (7·1)	0·48 (0·9)	1·36 (32·3)
Pelleted litter	0·18 (2·2)	0·26 (1·7)	0·38 (2·4)	0·57 (4·5)	1·35 (15·9)
Raw litter	0·09 (10·9)	0·16 (0·2)	0·31 (5·1)	0·49 (3·7)	1·02 (24·1)
Alum treated	0·02 (3·9)	0·03 (12·9)	0·05 (4·7)	0·06 (26·4)	0·14 (8·6)
Pelleted alum	0·08 (10·4)	0·10 (3·8)	0·20 (5·4)	0·36 (15·1)	0·69 (30·4)
Untreated litter	0·08 (3·7)	0·14 (2·7)	0·26 (2·7)	0·43 (2·9)	0·65 (5·7)

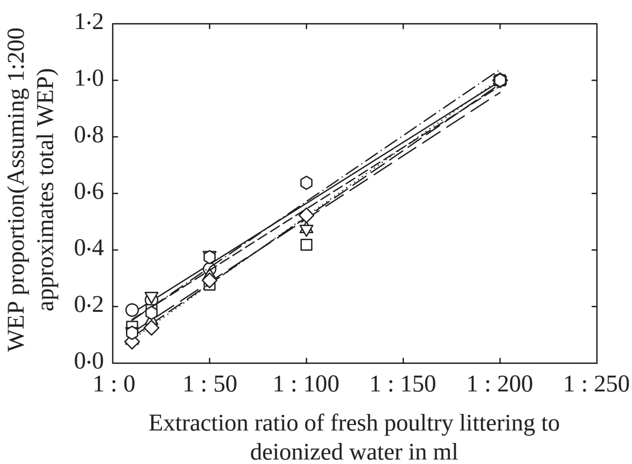

Fig. 1. Relation between water extractable P determined using colorimetric analysis of soluble reactive P (WEP_{SRP}) and inductively coupled argon plasma spectrometry (ICP) analysis of total dissolved P (WEP_{ICP}) content in the various poultry litters and different extractions ratios (by weight) of poultry litter to water (symbols represent mean of three replicates): ○, pelleted compost; □, pelleted raw; △, raw litter; ▽, alum treated; ◇, pelleted alum; and ⬡, normal litter

treatments. Average runoff, rainfall and runoff to rainfall ratio for the treatment plots ranged from 3 to 7 mm, 43 to 57 mm, and 0·07 to 0·16 per plot and showed no significant differences between treatments.

Phosphorus concentrations in runoff water increased with an increase in the WEP_{SRP} application rate of the various poultry litters. Results between P concentrations and WEP_{ICP} application rates of the poultry litter treatments were very similar. Water extractable P_{SRP} application rates from the various extraction ratios explained 69–84% and 68–82% of the variability in SRP and TP concentrations in runoff waters, and WEP_{ICP} application rates explained 72–87% and 68–84% of the variability (Table 3). Interestingly, there were slight differences in the relation between WEP_{SRP} (and WEP_{ICP}) application rates and runoff P concentrations between the sources of the poultry litters used in this study. Average runoff P concentrations from plots receiving poultry litters from the local farm increased at a greater rate with increasing WEP_{SRP} (and WEP_{ICP}) application rates than plots receiving poultry litters from the pelleting plant.

The relations were apparently linear between P concentrations in runoff water and WEP content of the various poultry litters despite differences in the extractions ratios (Table 3). The slope of this relation between decreased sequentially with a decrease in the extraction ratio (from 1:10 to 1:200) reflecting the increase in WEP content. However, no consistent patterns were observed in the Y intercept of this relation. The observations held true when considering all poultry litters or poultry litters from individual sources, as well as with WEP_{SRP} and WEP_{ICP}.

The differences observed between the relation between runoff P concentrations and WEP application rates were likely because of small (but non-significant) differences in time to runoff, total rainfall and runoff and the ratio of runoff to rainfall (see Haggard *et al.*, 2004). Multi – linear regression of WEP_{SRP} or WEP_{ICP} application rates and the runoff to rainfall ratio against

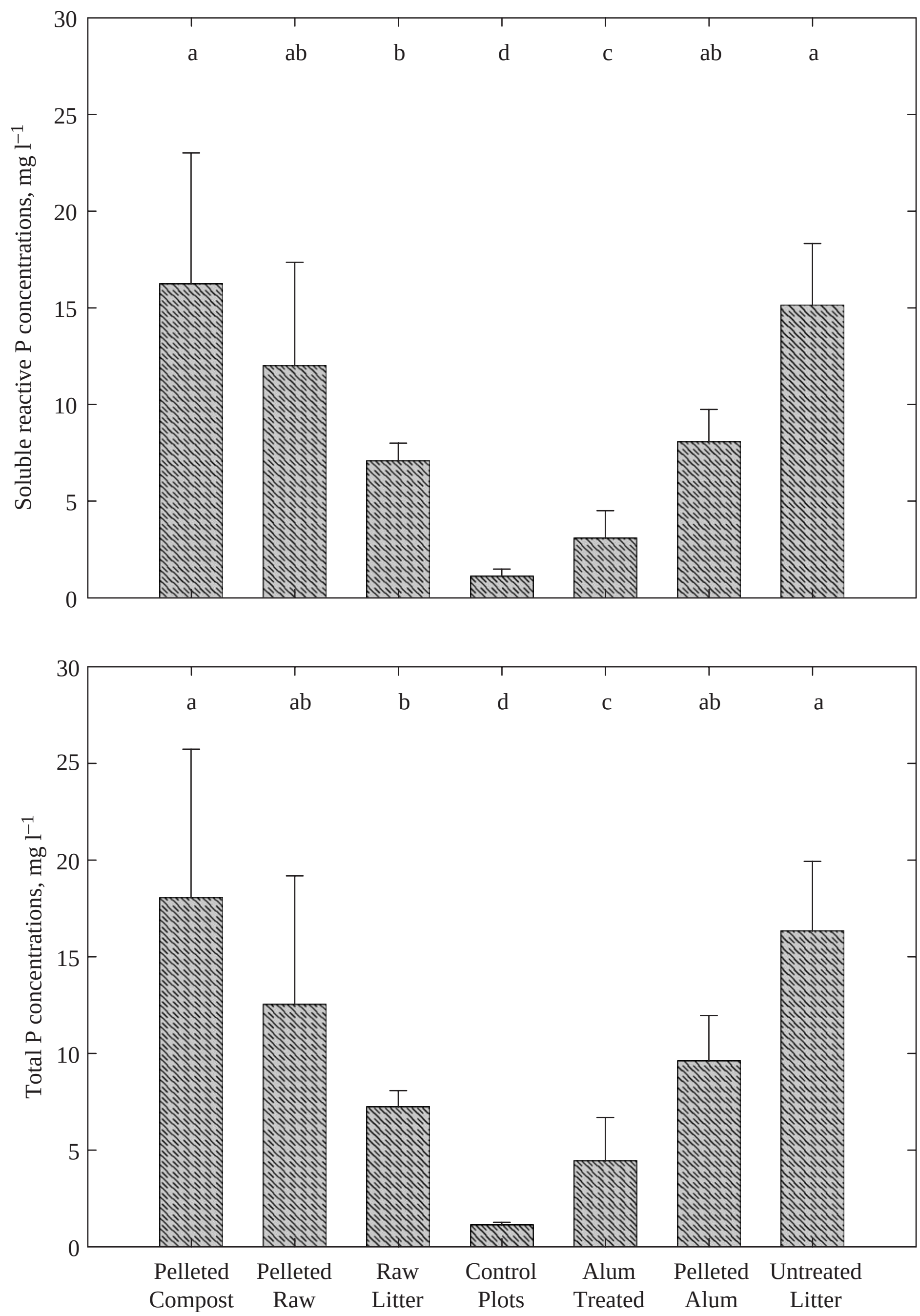

Fig. 2. Effect of the various poultry litters on soluble reactive (SRP) and total P (TP) concentration (mean ± standard deviation) in runoff water from small plots when applying poultry litters at ~67 kg [TP] ha^{-1} [different letters among the treatments designate significant differences between treatments]

runoff P concentrations was significant at all extraction ratios (Table 4), explaining greater than 87% of the variability in runoff P concentrations. However, the slope coefficients for WEP_{SRP} or WEP_{ICP} application rates or the runoff to rainfall ratio were not always significant, especially at the extraction ratios using the least amount of poultry litter, *i.e.* 1:100 and 1:200.

4. Discussion

4.1. *Extraction ratios and manure soluble phosphorus*

The relation between WEP content of the various poultry litters and the poultry litter to water extraction ratio was similar across all treatments, where WEP

Table 3

Linear relation between water extractable P (WEP) application rates from the various extraction ratios in kg ha^{-1} and average P concentrations in mg l^{-1} in runoff from small plots receiving poultry litter at equivalent total P application rates of ~67 kg ha^{-1},

$$C_{SRP} = k_1 P_{WEP} + k_2 \text{ and } C_{TP} = k_3 P_{WEP} + k_4$$

where: C_{SRP} is runoff soluble reactive P (SRP) concentrations; C_{TP} is runoff total P (TP) concentrations; P_{WEP} is the application rate of WEP determined using colorimetric analysis of SRP (WEP_{SRP}) or inductively coupled argon plasma spectrometry (ICP) of total dissolved P (WEP_{ICP}); and k_1 to k_4 are regression coefficients

Extraction ratios	*Soluble reactive P (SRP)*				*Total P (TP)*			
	k_1	k_2	r^2	*P*	k_3	k_4	r^2	*P*
Water extractable P_{SRP}								
1:10	1·52	3·99	0·69	0·021	1·62	4·60	0·69	0·022
1:20	1·34	2·58	0·75	0·012	1·42	3·16	0·73	0·014
1:50	0·95	1·02	0·84	0·004	1·01	1·53	0·82	0·005
1:100	0·70	0·59	0·78	0·008	0·73	1·20	0·74	0·013
1:200	0·28	1·63	0·74	0·013	0·29	2·23	0·71	0·017
Water extractable P_{ICP}								
1:10	1·43	3·34	0·74	0·013	1·53	3·91	0·74	0·014
1:20	1·14	2·34	0·79	0·008	1·21	2·90	0·77	0·009
1:50	0·88	0·80	0·87	0·002	0·93	1·33	0·84	0·004
1:100	0·70	0·86	0·76	0·010	0·73	1·51	0·72	0·016
1:200	0·25	1·78	0·72	0·016	0·26	2·41	0·68	0·022

r^2, coefficient of determination.

Table 4

Multi–linear regression between water extractable P (WEP) application rates from the various extraction ratios in kg ha^{-1} and the runoff to rainfall ratio (R_O/R) during the first simulation in cm cm^{-1} against average P concentrations in mg l^{-1} in runoff from small plots receiving poultry litter at equivalent total P application rates of ~67 kg TP ha^{-1}

$$C_{SRP} = k_1 P_{WEP} + k_2 R_O R + k_3 \text{ and } C_{TP} = k_4 P_{WEP} + k_5 R_O R + k_6$$

where: C_{SRP} is runoff soluble reactive P (SRP) concentrations; C_{TP} is runoff total P (TP) concentrations; P_{WEP} is the application rate of WEP determined using colorimetric analysis of SRP (WEP_{SRP}) or inductively coupled argon plasma spectrometry (ICP) of total dissolved P (WEP_{ICP}); R_O/R is the runoff to rainfall ratio; and k_1 to k_6 are regression coefficients

Extraction Ratios	*Soluble Reactive P (SRP)*					*Total P (TP)*				
	k_1	k_2	k_3	R^2	*P*	k_4	k_5	k_6	R^2	*P*
Water extractable P_{SRP}										
1:10	0·93	*62·99	*0·18	0·90	0·009	0·93	*73·42	*0·015	0·94	0·003
1:20	0·86	*57·14	*−0·35	0·92	0·006	0·84	*68·66	*−0·36	0·95	0·002
1:50	0·66	*44·28	−0·54	0·92	0·006	0·62	*57·82	*−0·51	0·94	0·004
1:100	0·44	48·98	−0·81	0·87	0·017	0·73	65·65	−0·68	0·88	0·014
1:200	0·18	*57·00	−0·86	0·91	0·009	0·17	*69·67	*−0·82	0·93	0·005
Water extractable PICP										
1:10	0·90	*57·99	*0·11	0·91	0·007	0·90	*68·61	*0·08	0·95	0·002
1:20	0·75	*53·70	*−0·28	0·93	0·005	0·73	*65·36	*−0·29	0·95	0·002
1:50	0·63	*40·86	−0·59	0·94	0·004	0·58	*55·26	*−0·55	0·95	0·003
1:100	0·37	51·65	*−0·77	0·87	0·016	0·32	67·89	−0·65	0·88	0·014
1:200	0·15	*59·53	*−0·93	0·90	0·009	0·14	*72·17	*−0·89	0·93	0·006

*Denotes that the slope coefficient was significant at $P < 0{\cdot}05$.

content increased with a decrease in the amount of poultry litter used in the extraction. Kleinman *et al.* (2002b) showed similar results with poultry manure, dairy manure and swine slurry (see also Vadas *et al.*, 2004) and suggested this was due to dissolution of insoluble Ca phosphates. The dilution of poultry litters with extraction ratios from 1:10 to 1:200 promoted the dissolution of additional P from the solid phase into the aqueous phase. The increase in WEP content was between 5 and 13 times depending upon the poultry litter used, suggesting some variability existed in the dissolution of insoluble P forms. The fraction of WEP released from the poultry litter followed a linear relation, similar to that observed by Vadas *et al.* (2004) for poultry manure (see *Fig. 1*). These linear relations showed that 1:10 extraction ratio dissolved only 8–20% of WEP observed at the 1:200 extraction ratio. Vadas *et al.* (2004) showed that almost 30% of the total amount of WEP was extracted at a 1:10 extraction ratio.

Some distinct differences were noted in the absolute per cent of WEP in these poultry litters. First, the least WEP content was observed in the alum litter at the various extraction ratios. Moore and Miller (1994) found the addition of $Al_2(SO_4)_3$ to poultry litter significantly reduced the amount of water extractable P (see also Sims & Luka-McCafferty, 2002). The authors suggested the addition of Al reduced P solubility because of the formation of Al hydroxides with which PO_4 either adsorbed to or coprecipitated with. The addition of $Al_2(SO_4)_3$ to poultry litter not only reduces P solubility but provides another environmental benefit by decreasing NH_3 volatilisation. Several studies have shown that $Al_2(SO_4)_3$ reduced the pH of poultry litters, thus reducing the loss of NH_3 into the atmosphere (Moore *et al.*, 1995). Al amendments to liquid manures or slurries have also been shown to reduce P availability and NH_3 loss (Smith *et al.*, 2001, 2003, 2004).

Second, the greatest WEP content was observed in pelleted poultry litters at the various extraction ratios suggesting that the pelleting process some how increases water extractable P in poultry litter. One difficulty with this study is that the pelleted poultry litters and raw poultry litter from the nearby facility may be from different sources where variability in P solubility may exists from differences in diet, management, *etc.* Sims and Luka-McCafferty (2002) showed that WEP_{ICP} content (1:10 extraction ratio) varied from 0·07 to 0·36% on a dry poultry litter basis, and all poultry litters used in the present study were within this range. However, the direct comparison between alum litter and pelleted alum litter does indicate an increase in water extractable P at the various extraction ratios. The pelleting process uses heat (80–90 °C; Gray, 1999) and pressure when forming pellets, and heat drying animal manure can increase WEP by converting organic P into inorganic P (Ajiboye *et al.*, 2004). Thus, the effect of pelleting poultry litters on soluble P content needs additional investigation, and the use of Al or other chemical amendments during this process may be an option to mitigate any increase in P solubility resulting from the pelleting processes.

4.2. *Relation between extraction ratios and runoff study*

Several studies have shown that soil test P content was strongly related to P concentrations in runoff during rainfall simulations (Pote *et al.*, 1999; Hansen *et al.*, 2003; Kleinman *et al.*, 2004). However, P release from land-applied poultry litter during rainfall simulations often overwhelms the amount of P lost from the soil breaking down this strong relation (DeLaune *et al.*, 2004). Total P application rates of poultry litters and other manure have a positive effect on P concentrations in runoff water (Kleinman & Sharpley, 2003; Tarkalson & Mikkelsen, 2004). This study surface applied various litters at the same TP application rate (~67 kg [TP] ha^{-1}) where WEP application rates differed because of the variability in WEP content between the poultry litter treatments. Under this situation, WEP application rates were a relatively strong predictor of P concentrations in runoff waters during the rainfall simulations. Recently, other studies have focused on the importance of WEP content in animal manure (Vadas *et al.*, 2004; DeLaune *et al.*, 2004, Kleinman *et al.*, 2002a). Often, P management tools such as the P Index (*e.g.* see DeLaune *et al.*, 2004) give strong consideration to WEP content of animal manure that are to be used as an organic fertiliser on pastures.

This study also looked at the WEP content estimated at various poultry litter to water extraction ratios and its relation with P concentration in runoff waters. Kleinman *et al.* (2002b) also evaluated this relation using different animal manures and presented a standard method for WEP content in animal manure using a 1:200 ratio of dry weight equivalent of fresh manure to water. The authors suggested that a 1:10 extraction ratio (see Self-Davis & Moore, 2000) resulted in rather poor relations with runoff P concentrations compared to a 1:200 extraction ratio (see Sharpley & Moyer, 2000) when evaluating relatively dry to liquid animal manure. In this study, WEP_{SRP} (or WEP_{ICP}) estimated using a 1:50 extraction ratio explained the greatest proportion of variability in runoff P concentrations (over 84%). Furthermore, the coefficient of variation of WEP content generally increased from 1:10 to 1:200 extraction ratios in this study, demonstrating that using relative small amounts (*i.e.*, 1–2 g) of poultry litter increases variability in estimates of WEP content substantially, likely because poultry litter is a very heterogeneous material (Dou *et al.*, 2000; Sims & Luka-McCafferty, 2002).

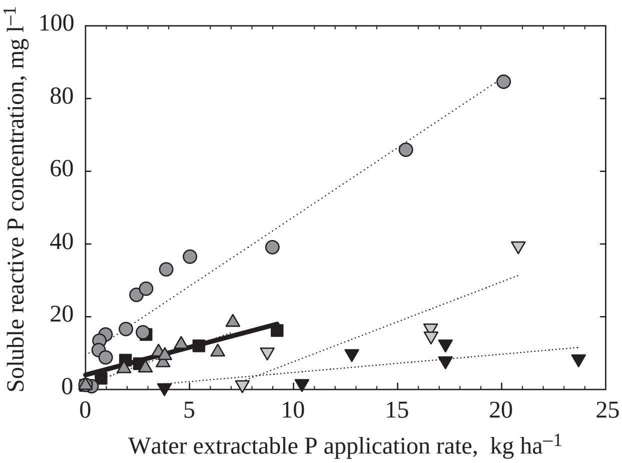

Fig. 3. The relation between water extractable P (WEP_{SRP}) application rates determined using a 1:10 extraction ratio (by weight) of fresh poultry litter to deionised water and soluble reactive P (SRP) concentrations in runoff from small plots receiving the various poultry litters (symbols represent treatment means from each study): ■, the current study; ▼ and ▽, data from two rainfall simulations during a compost study (DeLaune et al., 2002); ●, data from a rainfall simulation used to develop source coefficients for a phosphorus index for pastures (DeLaune et al., 2004); and ▲, data from a rainfall simulation evaluating the effects of poultry diets on runoff P loss (Smith et al., 2004).

The small plots used in this study have been previously used for other studies evaluating P loss in runoff from surface applied poultry litters (*e.g.* DeLaune *et al.*, 2002, 2004; Smith *et al.*, 2004). These studies used poultry litter from various sources including the local farm used in the current study. When SRP concentrations in runoff water from the first artificial rainfall simulation were plotted as a function of WEP_{SRP} application rate (based on a 1:10 extraction ratio), the data produced multiple linear relations that could be separated by rainfall simulation studies (*Fig. 3*). Thus, the ability of artificial rainfall and runoff to dissolve and transport P in surface applied poultry litter was quite variable among different studies, but the relation between runoff SRP concentration and WEP application rate was generally linear for each rainfall simulation in the various studies. Although plots and soils were the exact same in the current study and the aforementioned citations, the runoff to rainfall ratio has been show to influence variability in runoff SRP concentrations from small soil boxes (Vadas *et al.*, 2004). The runoff to rainfall ratio was often a significant factor when predicting average P concentrations in the current study; multi–linear regression using WEP application rates and the runoff to rainfall ratio generally explained greater than 90% of the variability in runoff P concentrations. Kleinman *et al.* (2004) also normalised SRP concentrations by box area, runoff depth and rainfall depth to account for variation related differences in surface runoff from packed soil boxes. Thus, variability in antecedent moisture conditions, time to runoff and runoff volumes relative to rainfall may influence P concentrations from rainfall simulations and small plots such as those used in the current study. It seems that simply using WEP_{SRP} or WEP_{ICP} application rates does not consider plot–scale hydrologic variability which can contribute to discrepancies in runoff P concentrations.

5. Conclusions

This study further demonstrated that changes in the amount of poultry litter mixed with a constant volume resulted in an increase in water extracted P (WEP) content increased as the amount of poultry litter used decreased, *i.e.* from a 1:10 to 1:200 extraction ratio. Water extracted P content and runoff P concentrations from the small plots were variable depending on the various poultry litter. Overall, the amount of WEP applied to small plots was a strong predictor of P concentrations in runoff water from plots, regardless which extraction ratio was used to determine WEP content. Thus, WEP application rates of poultry litters were an important source factor when evaluating the potential for P loss in surface runoff, especially in this study because all poultry litters were applied at equivalent total P (TP) application rates. However, some variability exists in the relation between runoff P concentrations and WEP application rates of poultry litter, likely because of slight differences in runoff to rainfall ratio and the timing of when runoff occurred. Thus, plot–scale hydrologic variability must be included into studies evaluating P loss as a function of WEP application rates.

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