

# Water Treatment Residual to Reduce Nutrients in Surface Runoff from Agricultural Land

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## ABSTRACT

Application of animal manures in excessive amounts can result in surface runoff of nutrients and degradation of surface water. Best management practices that use chemical or by-products to sorb nutrients can reduce nutrient loss from agricultural land. The objective of this work was to determine the ability of water treatment residual (WTR) to reduce N and P runoff from land treated with poultry litter. Different WTR (ABJ or WISTER) were used in two experiments at different locations. Three WTR treatments were applied to plots that received poultry litter at 6.72 Mg ha<sup>-1</sup> broadcast on bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture. Treatments were broadcast (11.2 or 44.8 Mg ha<sup>-1</sup>), and a buffer strip (44.8 Mg ha<sup>-1</sup>) to the bottom 2.44 m of the plot. Experimental plots received simulated rainfall for 75 min at 6.35 cm h<sup>-1</sup> within 24 h of litter and WTR application. Nitrogen, NH<sub>4</sub>, P, Al, and dissolved solids in surface runoff were determined. Mean dissolved P of 15.0 mg L<sup>-1</sup> was reduced to 8.60 mg L<sup>-1</sup> by the high broadcast and to 8.12 mg L<sup>-1</sup> by the buffer strip ABJ treatments. Reductions in runoff P were attributed to amorphous Al in the WTR. Soluble NH<sub>4</sub>-N was reduced from 33.7 to 11.3 mg L<sup>-1</sup> (high broadcast) and to 17.9 mg L<sup>-1</sup> (buffer strip) by ABJ. WISTER did not, however, reduce soluble NH<sub>4</sub>-N or total N. Reduction in NH<sub>4</sub>-N was related to cation-exchange capacity of the WTR. Land application of WTR did not increase dissolved solids or Al in surface runoff.

**S**URFACE RUNOFF of nutrients (N and P) from agricultural land is a major source of water quality impairments in surface waters in the USA (Parry, 1998). Application of animal manures in amounts that exceed agronomic rates based on the N requirement for crop production often results in increased loss of P from agricultural land in surface runoff and potential eutrophication of surface waters (Sharpley et al., 1994). Excessive concentration of soluble P is the most common source of eutrophication in freshwater surface waters (Correll, 1998). The greatest potential for surface runoff of nutrients from agricultural land and eutrophication to occur is in regions of intense animal production (Duda and Finan, 1983; Sharpley et al., 1994). Intensive poultry production in eastern Oklahoma has contributed to economic growth (Oklahoma Agricultural Statistics Service, 1998) but raised concerns about surface water pollution. Poultry litter is an inexpensive N fertilizer and often applied to permanent pastures without incorporation. Surface application of poultry litter increases NH<sub>4</sub> and P concentrations in surface runoff (Liu et al., 1997; Sharpley, 1997).

Several best management practices (BMPs) have potential to reduce nutrients in surface runoff. One BMP involves decreasing soluble P by mixing poultry litter with Ca, Al, or Fe chemical amendments (Moore and Miller, 1994). Soluble P in poultry litter was reduced from >2000 to <1 mg P kg<sup>-1</sup> by mixing CaO, CaCO<sub>3</sub>, alum, or FeSO<sub>4</sub> with poultry litter (Moore and Miller, 1994). Land application of poultry litter treated with chemical amendments (1:5 amendment/litter) had lower soluble P in runoff than untreated poultry litter (Shreve et al., 1995). Alum treatment of poultry litter reduced runoff P from 90 to 10 mg L<sup>-1</sup> while FeSO<sub>4</sub> treatment reduced runoff P from 90 to 20 mg L<sup>-1</sup>. Another approach to reduce P in surface runoff involves mixing chemical amendments with soil. Addition of 80 g kg<sup>-1</sup> of fluidized bed combustion flyash to soil reduced Mehlich-III P from >200 to <100 mg kg<sup>-1</sup> (Stout et al., 1998).

Water treatment residuals (WTR) are primarily sediment, aluminum oxide, activated C, and polymer removed from the raw water (Elliott and Dempsey, 1991). Residual by-products from the drinking water treatment process contain chemical constituents capable of adsorbing or precipitating dissolved P (e.g., Al and Fe oxides, resins). Incorporation of WTRs with soil reduces dissolved and extractable P in soil (Cox et al., 1997; DeWolfe, 1990; Peters and Basta, 1996). Lake Wister WTR (WISTER) at 100 g WTR kg<sup>-1</sup> reduced Mehlich-III P from 296 to <200 mg kg<sup>-1</sup> in soil that had excessive levels of available P from poultry litter application (Peters and Basta, 1996). Residual from the AB Jewell reservoir (ABJ) at 100 g WTR kg<sup>-1</sup> reduced Mehlich-III P from 553 to 250 mg kg<sup>-1</sup>. Incorporation of WTR into soil with WTR will reduce dissolved P and consequently runoff P from permanent pastures treated with poultry litter. Incorporation may, however, damage pasture vegetation and is discouraged. Surface application of WTR to pasture land treated with poultry litter may reduce N and P nutrients in surface runoff. The objectives of this work was to determine the ability of WTR to reduce N and P runoff from land treated with poultry litter under field conditions and to evaluate potential environmental impacts associated with land application of WTR.

## MATERIALS AND METHODS

### Experimental Design

Field experiments were conducted at Adair County, Oklahoma, and at LeFlore County, Oklahoma. Different WTR

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**Abbreviations:** WTR, water treatment residual; BMPs, best management practices; WISTER, Lake Wister; ABJ, AB Jewell reservoir; EC, electrical conductivity; CCE, calcium carbonate equivalence; CEC, cation-exchange capacity; ICP, inductively coupled plasma atomic emission spectroscopy.

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were used for each field experiment. Water treatment residual from ABJ was used at the Adair County experiment and WISTER was used at the LeFlore County experiment. Water treatment residuals were collected from storage lagoons and were air dried before use. The experimental design was a randomized block with three treatments and control replicated four times. Each of the 16 experimental plots was 1.8 m × 9.8 m. Adair County experimental plots were placed on a Dickson silt loam (fine-silty, siliceous, thermic Glossic Fragiu-dult). Plant available nutrients in the Dickson soil were 5.12 mg NO<sub>3</sub>-N kg<sup>-1</sup>, 22 mg P kg<sup>-1</sup>, and 104 mg K kg<sup>-1</sup>. LeFlore County experimental plots were placed on a Pirum fine-sandy loam (fine-loamy, siliceous, thermic Typic Hapludult). Plant available nutrients in this soil were 6.03 mg NO<sub>3</sub>-N kg<sup>-1</sup>, 11 mg P kg<sup>-1</sup>, and 131 mg K kg<sup>-1</sup>. All plots were placed on similar slopes of <5%. All plots received poultry litter at 6.72 Mg ha<sup>-1</sup> on a wet weight basis broadcast on bermudagrass vegetation cut to a height of 7.6 cm. Poultry litter moisture contents were 14% in the Adair County experiment and 19% in the LeFlore County experiment. Plots were constructed to channel surface runoff downslope into collection troughs made of 150 mm in diam. PVC pipe split length-wise (Cole et al., 1997). Three WTR treatments were applied across the litter-treated plots. Treatments were high broadcast of 44.8 Mg ha<sup>-1</sup> (72.6 kg plot<sup>-1</sup>), low broadcast of 11.2 Mg ha<sup>-1</sup> (18.2 kg plot<sup>-1</sup>), and a buffer strip of 44.8 Mg ha<sup>-1</sup> (18.2 kg plot<sup>-1</sup>) to the bottom 2.44 m of the plot. The control plot received poultry litter but did not receive WTR.

### Chemical Characterization of Residuals and Poultry Litter

Drinking water treatment processes and source waters that produced the WTR used in this study were different. Drinking water treatment coagulation process for ABJ included addition of alum, polymer, and sodium carbonate but WISTER used alum, and Ca hydroxide addition. Chemical properties and metal content of the WTR were determined (Table 1). The pH was determined in 1:2 WTR/0.01 M CaCl<sub>2</sub>. Salinity (EC) was measured in 1:2 WTR/deionized water. Calcium carbonate equivalence (CCE) was determined by boiling WTR in 0.5 M HCl and back-titrating the excess HCl with standardized 0.25 M NaOH (Rund, 1984). Cation-exchange capacity (CEC) of WTR was determined by sodium saturation

**Table 1. Chemical properties, chemical components, and nutrient content of water treatment residuals.**

Property or Component	Water treatment residual	
	AB Jewell	Wister
<b>Chemical Property</b>		
pH	7.6	7.0
EC, dS m <sup>-1</sup>	0.58	0.31
CCE, g kg <sup>-1</sup>	148	18.7
CEC, cmol kg <sup>-1</sup>	54.7	16.4
OC, g kg <sup>-1</sup>	66.8	39.3
<b>Chemical Components</b>		
Al oxide, g kg <sup>-1</sup>	50.5	11.7
Fe oxide, g kg <sup>-1</sup>	4.2	5.0
Total N, g kg <sup>-1</sup>	8.98	4.53
<b>Aqueous Components, mg L<sup>-1</sup></b>		
Al	0.08	0.10
Ca	375	60.0
Mg	4.70	7.65
P	0.27	0.10
<b>Nutrients, mg kg<sup>-1</sup></b>		
NH <sub>4</sub> -N	58.4	31.2
NO <sub>3</sub> -N	240	34.2
P	11.9	16.8

(Rhoades, 1982). Organic C content and total N of the WTR was determined by dry combustion (Schepers et al., 1989). Amorphous reactive Al and Fe oxide content of WTR were determined using the acid ammonium oxalate method (Ross and Wang, 1993). Aqueous Al, Ca, Mg, and P were determined by shaking 1:2 WTR/deionized for 1 h and subsequent analysis using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP). Plant available N (NO<sub>3</sub> and NH<sub>4</sub>) in KCl extracts of WTR were determined by automated colorimetric methods (Mulvaney, 1996). Plant available P was determined using Mehlich-III extraction (Mehlich, 1984) and ICP analysis.

Eight samples of poultry litter used at the Adair or the LeFlore County locations were collected and analyzed for total N, P, and K. Total N was determined by dry combustion (Bremner, 1996), total P and K by wet digestion followed by ICP analysis (Kuo, 1996). The mean nutrient content of oven-dried litter used in the Adair County experiment was 29.5 g N kg<sup>-1</sup>, 15.6 g P kg<sup>-1</sup>, and 15.6 g K kg<sup>-1</sup>. The mean nutrient content of the oven-dried litter used in the LeFlore County experiment was 34.6 g N kg<sup>-1</sup>, 17.4 g P kg<sup>-1</sup>, and 11.2 g K kg<sup>-1</sup>.

### Surface Runoff Collection and Chemical Analysis

Experimental plots received simulated rainfall for 75 min at a rate of 6.35 cm h<sup>-1</sup> within 24 h of poultry litter and WTR application. Runoff samples were collected from the plots at 5- to 10-min intervals. Total runoff volume for each time interval was used to prepare a flow-weighted sample for each plot. Runoff composites were split into two different samples, unfiltered and filtered through a 0.45-μm membrane filter.

Total N and P was determined by wet digestion of the unfiltered surface runoff samples (APHA, 1992). Dissolved NH<sub>4</sub>-N and P were determined using filtered surface runoff and the Indophenol blue method (Keeney and Nelson, 1982) and the modified Murphy-Riley ascorbic acid method (Kuo, 1996), respectively. Dissolved Al in filtered surface runoff was determined by ICP analysis.

## RESULTS

### Effect of Water Treatment Residual on Volume of Surface Runoff

Hydrologic variability of experimental plots resulted in a wide range of runoff volumes within treatments (Table 2). Treatments did not affect runoff volumes ( $P < 0.05$ ) at either experimental location. We used nutrient concentration for data analysis because of the variability in the hydrologic response of the experimental plots.

**Table 2. Mean runoff volume for treatments at each experiment location.**

Location	Parameter	Treatment†			
		Br-High	Br-Low	Buffer	Control
Adair County	mean	315	138	444	210
	sd‡	293	112	312	64
LeFlore County	mean	907	846	855	872
	sd	160	167	111	426

† Treatments are broadcast high application (Br-High, 44.8 Mg ha<sup>-1</sup> or 72.6 kg plot<sup>-1</sup>), broadcast low application (Br-Low, 11.2 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), buffer strip (Buffer, 44.8 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), and control.

### Effect of Water Treatment Residual on Phosphorus in Surface Runoff

The high broadcast and buffer strip treatments of WTR applied reduced dissolved P ( $P < 0.05$ ) in the surface runoff compared with the control plots in the Adair County experiment (Fig. 1A). Mean dissolved P was 88.3% of the mean total P in the surface runoff for the Adair County site. Because most of the total P was dissolved P, total P results were similar to dissolved P results for all treatments. Mean concentration of total P was 8.60 mg L<sup>-1</sup> (42.7% reduction compared with control) in the high broadcast treatment and 8.12 mg L<sup>-1</sup> (45.9% reduction compared with control) for the buffer strip treatment (Fig. 1A). Small reductions in dissolved P were found for the low broadcast treatment, but these reductions were not significant ( $P < 0.05$ ). Reductions in dissolved P in the surface runoff due to WTR application in LeFlore County (Fig. 1B) were smaller than the results from Adair County (Fig. 1A). In general, WTR treatments showed small but significant reductions in dissolved P ( $P < 0.05$ ) in the LeFlore County experiment. Further reductions in soluble P in the surface runoff were not seen when higher amounts of WTR were applied to the plots (Fig. 1B). Mean dissolved P was 93.6% of the mean total P in the surface runoff from LeFlore County. Because most of the total P was dissolved P, total P and dissolved P results were similar within treatments.

### Effect of Water Treatment Residual on Nitrogen in Surface Runoff

Nitrogen measured in surface runoff included NH<sub>4</sub>-N, NO<sub>3</sub>, and total N. The relative amounts of the three types of dissolved N in surface runoff were total N > NH<sub>4</sub> >> NO<sub>3</sub>. Therefore only NH<sub>4</sub>-N and total N values are shown. Significant reductions of soluble NH<sub>4</sub>-N for

the high broadcast treatments and the buffer strip treatments compared with control plots were observed at the Adair County site (Fig. 2A). Total N was not reduced ( $P < 0.05$ ) for any of the treatments compared with the control plots (Fig. 2A). Mean soluble NH<sub>4</sub>-N was 49.9% of the mean total N indicating almost one-half of the dissolved N was in organic forms in surface runoff. WTR treatments did not reduce soluble NH<sub>4</sub>-N or total N at the LeFlore County location (Fig. 2B). Both locations had similar amounts of dissolved NH<sub>4</sub>-N in the surface runoff from the control plots; however, only 37.1% of total N in surface runoff was NH<sub>4</sub>-N indicating most of the dissolved N was in organic forms.

### Potential Environmental Impacts

Surface application of WTR on pasture land and increased sediment runoff into nearby water bodies from plots treated with WTR may be a concern. Mean dissolved solids in runoff water in the Adair County experiment for the high broadcast, low broadcast, and the buffer strip treatments of 0.8, 0.4, and 0.6 g kg<sup>-1</sup>, were not different ( $P < 0.05$ ) than the 0.4 g kg<sup>-1</sup> from control plots. Mean dissolved solids in the runoff water in the LeFlore County experiment for the high broadcast, low broadcast, and the buffer treatments of 0.6, 0.6, and 0.5 g kg<sup>-1</sup>, respectively, were not different ( $P < 0.05$ ) than the 0.5 g kg<sup>-1</sup> from control plots. Land application of WTR did not increase sediment present in surface runoff.

Mean soluble Al (in mg L<sup>-1</sup>) for the control plots (0.023), the high broadcast plots (0.025), the low broadcast plots (0.027), and the buffered plots (0.029) were not different ( $P < 0.05$ ) in the Adair County experiment (Fig. 3). Similarly, mean soluble Al in surface runoff in the LeFlore County experiment (in mg L<sup>-1</sup>) from the control plots (0.060), the high broadcast plots (0.048),

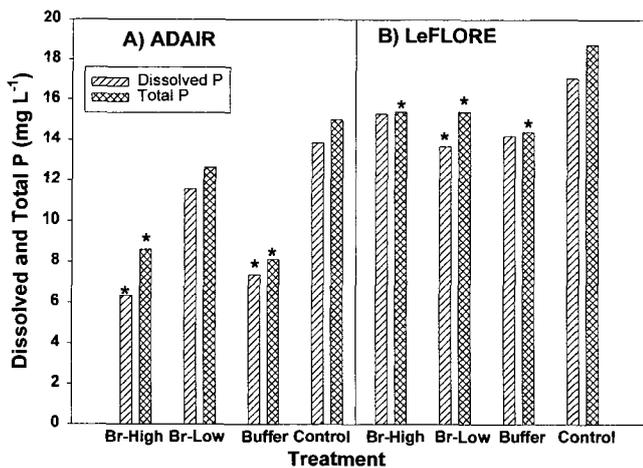


Fig. 1. Dissolved and total P in surface runoff from plots treated with poultry litter in the (A) Adair County experiment and the (B) LeFlore County experiment. Treatments are broadcast high application (Br-High, 44.8 Mg ha<sup>-1</sup> or 72.6 kg plot<sup>-1</sup>), broadcast low application (Br-Low, 11.2 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), buffer strip (Buffer, 44.8 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), and control. Asterisks above bars indicate the treatment is different ( $P < 0.05$ ) than the control plot.

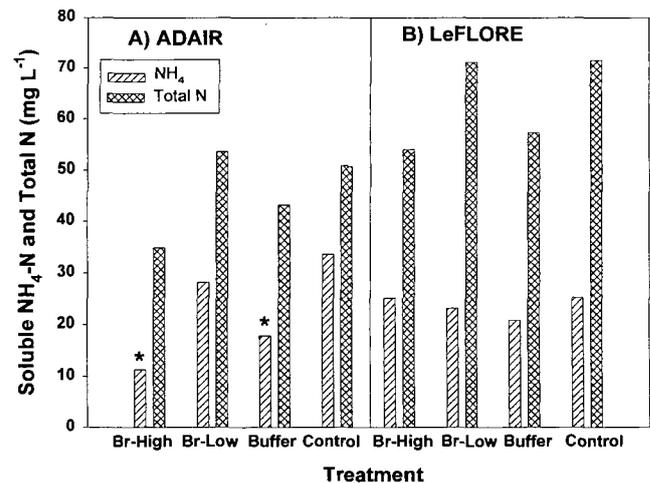


Fig. 2. Total N and soluble NH<sub>4</sub>-N in surface runoff from plots treated with poultry litter in the (A) Adair County experiment and the (B) LeFlore County experiment. Treatments are broadcast high application (Br-High, 44.8 Mg ha<sup>-1</sup> or 72.6 kg plot<sup>-1</sup>), broadcast low application (Br-Low, 11.2 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), buffer strip (Buffer, 44.8 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), and control. Asterisks above bars indicate the treatment is different ( $P < 0.05$ ) than the control plot.

the low broadcast plots (0.055), and the buffer strip plots (0.049) were not different ( $P < 0.05$ ) (Fig. 3). Land application of WTR did not increase soluble Al in the surface runoff.

## DISCUSSION

Treatment of plots with WTR did not affect volume of surface water runoff or affect the hydrologic properties of the plots (Table 2). Comparison of buffer and low broadcast treatments (Fig. 1A) shows buffer strips were more effective than the broadcast treatments in reducing dissolved P in runoff. The buffer strip treatment required 18.2 kg plot<sup>-1</sup> of WTR, which was the same amount applied in the low broadcast treatment; however, dissolved P in surface runoff for the buffer strip treatment was lower than results from the low broadcast plots. The buffer strip may have provided greater contact between the surface runoff water and the WTR than the broadcast treatment resulting in more P removal from surface runoff solution. The high broadcast treatments showed similar reductions in dissolved P as the buffer strip treatment, but the high broadcast treatment required four times the amount of WTR (72.6 kg plot<sup>-1</sup>).

Application of WTR as buffer strips was more effective than broadcast in reducing nutrients in surface runoff in this study, but larger scale field operations may produce different results. Our field study used small plots with even surfaces and constant slopes. The water was channeled to flow directly through the entire width of the buffer strip and into the collection troughs. Application of WTR to a much larger field scale with less homogenous surfaces and slopes may result in "short-circuiting" of surface runoff where runoff flows preferentially through only part of the buffer strip. Short-circuiting may result in a large amount of the buffer strip not interacting or adsorbing nutrients while some of the buffer strip may be saturated with nutrients by

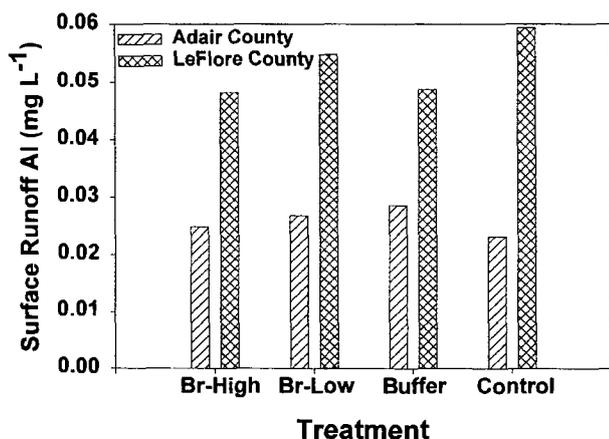


Fig. 3. Soluble Al in surface runoff from plots in the Adair and LeFlore County experiments. Treatments are broadcast high application (Br-High, 44.8 Mg ha<sup>-1</sup> or 72.6 kg plot<sup>-1</sup>), broadcast low application (Br-Low, 11.2 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), buffer strip (Buffer, 44.8 Mg ha<sup>-1</sup> or 18.1 kg plot<sup>-1</sup>), and control. Asterisks above bars indicate the treatment is different ( $P < 0.05$ ) than the control plot.

the surface runoff. In this case, a broadcast application of WTR may provide more interaction with nutrients in surface runoff and reduce nutrient runoff more effectively than the buffer strip application of WTR.

Differences in dissolved P in runoff between locations can result from different sources of poultry litter or different WTR. The poultry litters used at the two locations were from different sources. Laboratory analysis showed the P content of the Adair County litter of 15.6 g P kg<sup>-1</sup> was similar to the LeFlore County litter of 17.4 g P kg<sup>-1</sup>. Furthermore, total P concentrations in runoff from the control plots from Adair County (15.0 mg L<sup>-1</sup>) and control plots from LeFlore County (18.8 mg L<sup>-1</sup>) were similar. Different WTR were used for each experiment; WISTER was used in LeFlore County, while ABJ was used in Adair County. Laboratory P adsorption studies show WISTER removes less P from solution than ABJ WTR (Peters and Basta, 1996). Nonlinear Freundlich distribution constant ( $K_d$ ) values were 2870 L kg<sup>-1</sup> for ABJ and 35.3 L kg<sup>-1</sup> for WISTER. Moore and Miller (1994) found that Ca has a tremendous ability to bind P via adsorption and/or precipitation. The Ca content of ABJ was 21.9 g kg<sup>-1</sup> while WISTER was 2.1 g kg<sup>-1</sup>. Analysis of WTR solution data by the geochemical model MINTEQA2 (Allison et al., 1991), however, indicated WTR solutions were undersaturated with respect to Ca minerals. Other studies have shown amorphous Al was correlated with P adsorption capacity of WTR (Elliott et al., 1990). Amorphous Al content of ABJ of 50.5 g kg<sup>-1</sup> was much greater than the WISTER amorphous Al content of 11.7 g kg<sup>-1</sup>. Our results suggest adsorption of soluble P by amorphous Al in WTR was an important mechanism for reduction of soluble P in surface runoff.

Soluble NH<sub>4</sub> in surface runoff was decreased by WTR in both experiments. Soluble NH<sub>4</sub> can be absorbed by the CEC of the WTR. The ABJ WTR used at the Adair County site has a CEC of 54.7 cmol kg<sup>-1</sup> capable of adsorbing significant amounts of NH<sub>4</sub>. Soluble NH<sub>4</sub>-N can be absorbed by the CEC of the WTR, but NO<sub>3</sub> and organic forms of N have little affinity for WTR CEC sites. The WISTER WTR used at the LeFlore County site has a CEC of 16.4 cmol kg<sup>-1</sup> which is much smaller than the ABJ WTR CEC of 54.7 cmol kg<sup>-1</sup>. Larger decreases of soluble NH<sub>4</sub> in surface runoff from plots treated with ABJ than plots treated with WISTER suggest adsorption of soluble NH<sub>4</sub> by CEC sites in WTR.

Because alum-based WTR contains Al, there may be concern that land application of WTR will increase soil solution Al and may increase the potential for Al phytotoxicity. Because alum WTRs used in this experiment were alkaline (Table 1), WTR Al most likely occurs as insoluble amorphous oxide. Application of alkaline ABJ WTR at 100 g kg<sup>-1</sup> to an acidic Dickson soil (pH 5.3) increased soil pH to 7.0 (Peters and Basta, 1996). Similarly, application of WISTER WTR at 100 g kg<sup>-1</sup> to the same acidic soil raised the pH to 5.6. Land application of alum-based WTR did not increase dissolved Al in surface runoff (Elliott et al., 1988; Peters and Basta, 1996,) or extractable Al in soil (Peters and Basta, 1996). Aluminum in WTRs exists as an insoluble form of alumi-

num oxide and does not dissolve in soil environments that are not strongly acidic (pH > 5).

## CONCLUSION

The ability of WTR to reduce P in surface runoff depends on the amorphous Al content of the WTR. Drinking water treatment plants that use different source water and different treatment chemicals will probably produce WTR that have different chemical composition and nutrient adsorption capacities (Basta et al., 1999). Because various WTR will likely have a wide range of chemical properties, further studies are needed to evaluate the potential of land application of WTR to reduce nutrients in surface runoff. Land application of WTR serves as an alternative to land-filling and will provide financial savings to water treatment plants and protects surface water quality.

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