Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

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TABLE OF CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

Introduction

Poultry, swine and dairy production has grown significantly across the region and represents an important economic opportunity. However, this increase in production has led to an increase in the potential for surface and ground water contamination resulting from improper manure application rates, timing and placement. The implementation of best management practices (BMPs) for manure management systems is critical to water quality protection. For producers and the animal industry to accept and implement BMPs, their utility must be demonstrated under field conditions. This demonstration project provided the mechanism to disseminate and demonstrate state-of-the-art recommendations and technologies for land application of animal manure to permanent pastures.

This project demonstrated the effectiveness of BMP recommendations and technologies in reducing nitrogen and phosphorus losses in surface runoff from land application of animal manure to permanent pastures in two critical watersheds in eastern Oklahoma. Using a portable rainfall simulator, three rainfall simulator demonstrations were conducted. Two demonstrations were conducted in LeFlore County at the Kerr Center for Sustainable Agriculture, Poteau, Oklahoma, one on June 18-19, 1996 and the second on August 6-7, 1996. The third demonstration was conducted in Adair County, at the Hudson Farms Chance Complex Number 8, just outside Chance, Oklahoma, on July 9-10, 1996. BMP factors demonstrated included:

1) manure application rate
2) pasture aeration
3) water treatment residual (alum sludge) to reduce P and NH_4 surface runoff losses from poultry litter
4) vegetation height
5) filter/buffer strips
6) fertilizer comparison: commercial, poultry, swine, dairy.

Conclusions and Recommendations

The following conclusions and recommendations are based on the demonstrated BMPs that had replicated plots, i.e. manure application rate, pasture aeration, water treatment residuals (alum sludge), vegetation height, commercial fertilizer and poultry litter comparison.

Traditional BMPs

For the conditions studied, plot slope had a significant effect for all response variables except solids and organic N. In previous Oklahoma State University rainfall simulator studies, slope was found to be insignificant or occasionally marginally significant. In the current and previous studies the effect of slope was found to be very complex. Thus we do not recommend adjusting BMP recommendations for slope without further studies. We also found that, for the conditions studied, the aeration and vegetation height treatments does not have a significant effect.

Based on the Kerr-August and Hudson Farms data, as well as previous studies, we found that increasing litter application rate increases nutrient loss (N and P) in surface runoff. When the P and N response variables were normalized by the N or P application rate, the high and low litter application rates were not significantly different. This indicates there was a linear response to litter application rate for P and N.

The commercial fertilizer treatment response was different from the litter application treatments. The normalized surface runoff P concentrations for the commercial fertilizer treatments were always significantly higher than the litter application treatments. This indicates that on a per unit application basis commercial fertilizer has significantly higher losses to surface runoff than poultry litter. Therefore, poultry litter is the preferred P fertilizer source for permanent pasture.

Nitrogen showed mixed results. For the Hudson Farms demonstration, the normalized surface runoff total N, ammonium, and organic N concentrations were significantly higher from commercial fertilizer than poultry litter. However, these normalized N response variables were not significantly different for the Kerr-August demonstration, and the normalized mean concentrations were lower for the commercial fertilizer treatment. Therefore we have no recommendation at this time on use of poultry litter vs commercial fertilizer (ammonium nitrate) for N losses to surface runoff.

Based on these demonstrations the following conclusions can be made:

1. Slope should be considered when developing BMP recommendations. However, additional studies are needed to make specific recommendations.
2. Aeration has no significant effect and should not be considered a BMP.
3. For the conditions studied, i.e. good vegetation stand with 1.5 to 20 inch height, vegetation height has no significant effect.
4. Increasing litter application rate increases nutrient losses. Therefore, litter application rates should be minimized to reduce potential off-site water quality impacts.
5. P from triple super phosphate fertilizer is more mobile than P from poultry litter, and thus the use of tripe super phosphate would result in higher losses in surface runoff. Therefore, when P fertilization is recommended for agronomic reasons, poultry litter would be the preferred source of P from a water quality perspective.
6. Based on current information, no recommendation can be made at this time between commercial N fertilizer (ammonium nitrate) and poultry litter.

Water Treatment Residuals

Two WTRs were used in three treatments: an edge of plot buffer strip and two broadcast rates. One WTR reduced P and NH_4 in surface runoff significantly, whereas the other WTR did not. No significant difference was found between broadcast and buffer strip treatments. In addition, soluble Al in surface runoff ranged from 0.02 to 0.09 mg/L, and WTR treated plots were not significantly different from the control. Therefore, land application of alum-based WTR does not increase dissolved Al in surface runoff. Related studies showed that these WTRs did not increase soil extractable Al.

The ability of WTRs to reduce P and NH_4 in runoff depends on the Ca content, amorphous Al content and cation exchange capacity of the WTR. Drinking water treatment plants use different source waters and different treatment chemicals and produce WTRs with different chemical compositions and properties. Therefore, further studies on specific WTRs are needed to evaluate their potential to reduce nutrients in surface runoff.

The following can be concluded for WTRs from these demonstrations:

1. Some WTRs can reduce P and NH_4 in surface runoff, and thus have potential as a BMP.
2. Land application of alum-based WTR does not increase dissolved Al in surface runoff or extractable Al in soil

Education Activities

For the June19, 1996 demonstration approximately 80 people attended, for the July 10, 1996 demonstration approximately 40 people attended, and for the August 7, 1996 demonstration approximately 40 people attended. Three facts sheets on animal waste were developed. As one measure of success, a follow up survey to non-governmental attendees was conducted, i.e. agricultural producers. The results of the survey were very encouraging. The producers thought the presented BMPs were very practical and could be easily implemented. Although we did not completely convince everyone that there can be problems with excessive land application of nutrients, all were convinced that they could effectively use a combination of poultry litter and commercial fertilizer. Quite a few practices were implemented as a result of information obtained at the demonstrations. Each producer implemented at least one additional BMP following the demonstration.

Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

INTRODUCTION

Poultry, swine and dairy production has grown significantly across the region and represents an important economic opportunity. However, this increase in production has led to an increase in the potential for surface and ground water contamination resulting from improper manure application rates, timing and placement. The implementation of best management practices (BMPs) for manure management systems is critical to water quality protection. This project demonstrates the effectiveness of selected BMPs in two critical watersheds in eastern Oklahoma.

Information and recommendations resulting from these and other studies are useful only if they are implemented. For producers and the animal industry to accept and implement these BMPs, their utility must be demonstrated under field conditions. This demonstration project provided the mechanism to disseminate and demonstrate state-of-the-art recommendations and technologies for land application of animal manure to permanent pastures.

Using a portable rainfall simulator, this project demonstrated the effectiveness of BMP recommendations and technologies in reducing nitrogen and phosphorus losses in surface runoff from land application of animal manure to permanent pastures. This project enhanced the effectiveness of existing water quality programs by the State of Oklahoma, USDA Hydrologic Unit Area (HUA) Projects, and the NRCS-ASCS Special Water Quality Improvement Projects and Water Quality Incentive Program (WQIP) in the Illinois River Basin, Grand Lake Basin, Poteau River Basin, and the Little River Basin. BMP factors demonstrated included:

1) manure application rate
2) pasture aeration
3) water treatment residual (alum sludge) to reduce P and NH_4 surface runoff losses from poultry litter
4) vegetation height
5) filter/buffer strips
6) fertilizer comparison: commercial, poultry, swine, dairy.

PROJECT AREA DESCRIPTION

Two demonstration areas were selected reflecting high concentrations of animal feeding operations that are located in high priority watersheds in northeastern and southeastern Oklahoma. During the summer of 1996 one rainfall simulator demonstration was conducted in Adair County, Oklahoma and two rainfall simulator demonstrations were conducted in LeFlore County, Oklahoma. The Adair County demonstration was located in Planning Basin Number 1 of the Middle Arkansas River where there were high concentrations of poultry and dairy operations. The LeFlore County demonstrations were conducted in Planning Basin Number 2 of the Lower

Arkansas River or Planning Basin Number 4 of the Lower Red River where high concentrations of poultry and swine operations were located. The location of Adair and LeFlore Counties are shown in Figure 1.

FIELD MATERIALS AND METHODS

Site Preparation

Rainfall simulator demonstrations were conducted during the summer of 1996 to permanent pastures in a mix of common Bermuda grass and tall fescue. Two demonstrations were conducted in LeFlore County at the Kerr Center for Sustainable Agriculture, Poteau, Oklahoma, one on June 18-19 and the second on August 6-7. The third demonstration was conducted in Adair County, at the Hudson Farms Chance Complex Number 8, just outside Chance, Oklahoma, on July 9-10. The soil at Kerr was a Bengal-Pirum-Clebit Complex fine sandy loam and the soil at Hudson Farms was a Dickson silt loam.

Differential leveling techniques were used to define contour lines to determine suitable locations for rainfall simulator setups. Plots were located to ensure surface runoff was parallel to the slope and that they contained no significant surface depressions. The layout for the rainfall simulator setups is given in Figures 2 and 3 for Kerr and Hudson Farms, respectively. There were a total of 24 rainfall simulator setups, with 16 setups at Kerr and 8 setups at Hudson Farms for a total of 96 plots. Plot slopes are given in Tables 1 through 3 and summarized by setup in Table 4.

Rainfall Simulator

A portable rainfall simulator was used to apply controlled rainfall simultaneously to four 1.8 by 9.8 m plots. The rainfall simulator is based on the Nebraska rotating-boom design (Swanson, 1979) which wets a 15.2 m diameter area. The nozzles are located on a rotating boom 2.7 m above the ground and spray continuously and move in a circular pattern. The rainfall simulator boom was rotated at approximately 7 revolutions per min. A central alley 3 m wide allowed room for simulator placement between plots 2 and 3 with at least a 1.5 m boom overhang at all plot corners to ensure uniform rainfall coverage (Figure 4). Plots were constructed to channel surface runoff downslope into collection troughs made of 150mm-diameter PVC pipe split length-wise (Cole et al., 1997). A cross-section view of the surface runoff collection system is shown in Figure 5.

The rainfall simulator was set parallel to the land surface with the rotating boom held at a constant height above the ground. A setup consisted of four plots, with plot pairs separated by 0.3 m (Figure 4). The rainfall simulator was calibrated before the experiment; however, as a check three rain gauges were installed in the center alley at 2.4, 4.0, and 5.5 m from the boom center to measure delivered rainfall. Each rainfall simulation experiment required approximately 15,000 L of water. A series of gasoline engines with pumps were used to deliver water through a 5 cm diameter high-pressure vinyl hose to the rainfall simulator. The pumping system provided a mast pressure of 207 kpa at the rainfall simulator, which delivered 2.5 in/hr of rainfall for 75 minutes. Water was obtained from the local Rural Water District for the Hudson Farms demonstration, and a pond was the water source for the Kerr demonstrations.

Experimental Design

BMPs and factors demonstrated for the project included poultry litter application rate, alum hydro-solids (alum sludge) application to land applied poultry litter, vegetation height, pasture aeration (Kerr), commercial fertilizer comparison, vegetative buffers, and dairy (Hudson Farms) and swine (Kerr) manure. We used eight rainfall simulator setups per demonstration for a total of 32 plots per demonstration. A summary of the treatments, average slope by treatment, and number of replications is given in Table 5. Additional treatment details are given in Table 6. We used a randomized block design, and for most of the treatments we used four replications. Table 7 identifies the treatment for each plot.

One of the treatment variables was vegetation height. We used a push mower to obtain a cut vegetation height of 3 inches. Mowing was performed approximately two days prior to the rainfall event. For the vegetated buffer strip treatment, 24 feet of the up slope portion of the plot was cut to 3 inches, and the lower 8 feet remained in its natural uncut state. A summary of the vegetation heights for the high vegetation treatment and vegetated buffer stip treatment is given in Table 8.

The baseline or standard poultry litter application rate was 3 ton/acre (1.08 Mg/ha). The high litter application rate was 6 ton/acre. For the buffer plots, 4 tons/acre was applied to the short grass (3 inch height) non-buffer area and no litter was applied to the vegetated buffers. This resulted in the same mass of litter being applied as the 3 ton/acre plots. For the commercial fertilizer treated plots we applied 280 lbs N/acre (34:0:0 ammonium nitrate) and 80 lbs P_2O_5/acre or 35 lbs P/acre (0:46:0 triple super phosphate). For the dairy manure treatment plot, we applied 60 gallons of manure at an approximate rate of 180 lbs P_2O_5/acre.

For each of the two Kerr demonstrations, an aerator was used on four of the standard 3 inch vegetation height plots with 3 tons/acre poultry litter. Aeration was conducted prior to applying the poultry litter. For the June demonstration a “home made” aerator was used. The aerator was 4 foot diameter drum filled with water, and had a series of 5 inch long 0.5 inch diameter spikes on a 6 inch spacing. For the August demonstration, an Aer Way aerator was used. Both pieces of equipment were donated by J&W Farm Equipment Sales of Poteau, Oklahoma.

The last treatment used was the application of water treatment residuals (WTRs) to 3 inch vegetation height plots with 3 ton/acre poultry litter application. To determine what WTRs to use and at what rates, a laboratory incubation study and a small-scale greenhouse study was conducted. The details of this results from these two studies are given in Appendix A and B. Based on these results, different WTRs were used for the Kerr and Hudson Farm demonstrations. WTRs from the AB Jewell reservoir (ABJ) was used at Hudson Farms and Lake Wister WTR (WISTER) was used at Kerr. Three WTR treatments were applied over the litter treated plots: 1) high broadcast 44.8 Mg ha -1 or 72.6 kg plot -1, 2) low broadcast 18.5 Mg ha -1 or 18.2 kg plot -1, and 3) as a buffer strip of 44.8 Mg ha -1 or 18.2 kg plot -1 to the bottom 8 feet (2.44 m) of the plot.

Chemical Characterization of Residuals, Litter, and Soil

Chemical properties and metal content of the water treatment residuals (WTRs) were determined (Table 9). The pH of each WTR was determined using a 1:2 WTR:0.01 M CaCl2. Salinity (EC) was measured in 1:2 WTR:deionized water. Calcium carbonate equivalent (CCE) was measured by back titration of HCl (Peters and Basta, 1996). Cation exchange capacity of WTR was determined by sodium saturation (Rhoades, 1982). Organic carbon content and total N of the WTR was determined by dry combustion (Schepers et al., 1989). The Al & 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 water for 1 h and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP) analysis. Plant available N (NO_3 and NH_4) in KCl extracts of WTR were determined by automated and colorimetric methods (Mulvaney, 1996). Plant available P was determined using Mehlich-III extraction (Mehlich, 1984) and ICP analysis. Sulfate content of WTR was determined by monocalcium phosphate extraction (Johnson, 1992).

For each setup, approximately 15 0-6 inch soil cores from just outside the plots were composited prior to rainfall. Plant available N was determined by automated and colorimetric methods (Mulvaney, 1996). Plant available P was determined using Mehlich-III extraction (Mehlich, 1984) and ICP analysis. The results are summarized in Table 10.

A composite poultry litter sample for each rainfall simulator setup was 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 results are given in Table 11.

Surface Runoff Collection and Chemical Analysis

Experimental plots received simulated rainfall for 75 minutes at a rate of 2.5 inches per hour (6.35 cm/hr). Runoff samples were collected from the plots at intervals of 2.5 or 5 minutes. 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 using a 0.45-µm membrane filter.

Total N and P was determined by wet digestion of the unfiltered runoff water samples (APHA, 1992), with measurement of NH_4-N performed using the Indophenol blue method (Keeney and Nelson, 1982) and total P using the Modified Murphy-Riley ascorbic acid method (Kuo, 1996). Dissolved NH_4-N was determined using the filtered runoff water samples and the Indophenol blue method. Soluble P was determined using the filtered water samples and the Modified Murphy-Riley ascorbic acid method.

Dissolved Al present in the filtered runoff water samples was determined by ICP analysis.

BMP RESULTS AND DISCUSSION

Time to surface runoff is given in Table 12, and Table 13 presents runoff volume, average surface runoff concentrations for percent solids, total P, soluble P, total N, ammonium, and organic N. As shown in Table 14, the actual mass of N and P applied for treatments D, E and F (3 tons/acre poultry litter) did not match the commercial fertilizer applied N and P. Therefore, additional response variables were defined to attempt to normalize these differences. Average concentrations response variables were divided by the amount of either N or P applied to the plot. Total P and soluble P were divided by 90, 100, and 95 lbs P/acre for treatments D, E, and F for Kerr-June, Kerr-August, and Hudson Farms, respectively. Total N, ammonium, and organic N were divided by 210, 210, and 180 lbs N/acre for treatments D, E, and F for Kerr-June, Kerr-August, and Hudson Farms, respectively. Response variables for treatment H was divided by twice these values. Finally, treatment G response variables were divided by either 280 lbs N/acre or 35 lbs P/acre.

A two-factor factorial (site and treatment) ANOVA in a completely randomized design was performed. Most response variables were identified as being significantly affected by slope: runoff volume (α=0.0001), total P (α=0.0032), soluble P (α=0.0124), total N (α=0.0616), and ammonium (α=0.0001). Therefore, the ANOVA was performed using plot slope as a covariant. Next, we checked interactions and if the interactions were significant, we analyzed simple effects of treatment, i.e. the effect of treatment at a given site. The only non-significant main effects variable was runoff volume. At an α=0.05, runoff volumes at Hudson and Kerr-June were the same and Hudson and Kerr-August were the same, but runoff volume at Kerr-June and Kerr-August were different.

Comparison of the response variables (total P, soluble P, total N, ammonium, organic N, solids) and the normalized response variables by treatment and site are given in Table 15. Both means and least square means are provided. The analysis was performed at an α=0.05. The Kerr-June data set had high variance and very inconsistent results (Tables 13 and 15). At this time, we do not know the physical and chemical processes and/or the methodologies that are the source of this high variance. Therefore, we recommend that the inferences drawn from this analysis be based on the Kerr-August and Hudson Farms data only.

Percent solids concentrations were the same across all treatments at the Kerr demonstrations. At the Hudson Farms demonstration, however, the high litter application treatment H had significantly higher concentrations than all other treatments. In addition, at Hudson Farms the control (treatment J), high vegetation with low litter application rate (treatment F), and low vegetation with low litter application rate (treatment D) were not significantly different.

We had the same response for the soluble P and total P variables, which was expected since most of the P was in the soluble form. Treatments D and F (low vs high vegetation height) were not significantly different. Average P concentrations from Treatment J (control) always had significantly lower concentrations compared to all other treatments. Treatment H (high litter application rate) had significantly higher average P concentrations than treatment D (low litter application rate). Treatment G (commercial fertilizer) had significantly higher average P concentrations compared to treatment D and was significantly larger (Hudson Farms) or not significantly different (Kerr-August) from treatment H (high litter application rate). When comparing the normalized P mean concentrations for the commercial fertilizer treatments, they were always significantly higher than the litter application treatments. This indicates that on a per unit application basis commercial fertilizer has higher losses to surface runoff compared to poultry litter.

For total N and ammonium, the more poultry litter applied the higher the average concentration, i.e. treatments D, H, and J. This was true for organic N as well, except for the Hudson Farms demonstration. Treatments D and F were not significantly different for all N response variables. The commercial fertilizer treatment had mixed results for the N concentrations. For the Hudson Farms demonstration, the normalized total N, ammonium, and organic N average concentrations were significantly higher for the commercial fertilizer treatment compared to the poultry litter treatments. However, these normalized N response variables were not significantly different for the Kerr-August demonstration and the normalized mean concentrations were lower for the commercial fertilizer treatment.

To judge the effect of treatment E (aeration, 3 ton/ac poultry litter, 3 inch vegetation), contrasts were computed to compare treatment E to treatment D (3 ton/ac poultry litter, 3 inch vegetation) without the Hudson Farm site included. The Hudson Farms demonstration was excluded from the analysis since it did not have an aeration treatment. At an $\alpha=0.05$, there was not a significant difference between treatments D and E for all response variables, i.e. aeration did not have a significant effect.

WATER TREATMENT RESIDUALS RESULTS AND DISCUSSION

Increased freshwater eutrophication in many regions of the USA has generated much concern. Introduction of soluble P in surface water can result in eutrophication when P is the limiting nutrient (Galarneau and Gehr, 1996). Sources of soluble P include agricultural non-point source pollution associated with commercial fertilizers or manures. Poultry litter is a cheap N fertilizer and often applied to pastures without incorporation at 10 Mg ha -1 in Oklahoma (Robinson and Sharpley, 1996). Surface application of poultry litter increases NH_4^+ and P concentrations in runoff water (Liu et al., 1997 and Sharpley, 1997).

Several best management practices have potential to reduce nutrient in runoff water. One BMP involves decreasing soluble P in poultry litter by adding chemical amendments. Moore and Miller (1994) found large reductions with Ca, Al and Fe amendments. Soluble P in poultry litter was reduced from >2000 to <1 mg P kg -1 by adding the equivalent of 43 g Ca as Calcium oxide to one kg of litter. Poultry litter treated with $CaCO_3$ and alum (17 g Al kg -1) decreased soluble P from >2000 to <1 mg P kg -1. Similar reductions of soluble P were obtained with ferrous sulfate (36 g Fe kg -1). Land application of chemical treated litter (1:5 amendment/litter) had lower soluble P in runoff than untreated litter (Shreve et al., 1995). Alum treatment of poultry litter reduced soluble P from 90 to 10 mg L-1 while $FeSO_4$ treatment reduced P runoff from 90 to 20 mg L-1 in runoff water. Another approach to reduce P runoff involves addition of chemical amendments to soil. Addition of 80 g kg -1 fluidized bed combustion fly ash (FBC) to soil reduced Mehlich-III P from >200 to <100 mg kg -1 (Stout et al., 1998).

Water treatment residuals (WTRs), are primarily insoluble aluminum oxides, carbon, polymers, as well as sand, silt and clay particles removed from the raw water (Elliot and Dempsey, 1991). Residual by-products from the drinking water treatment process contain Al oxides and Ca capable of adsorbing or precipitating soluble P. Incorporation of WTRs with soil reduced soluble P and extractable P in soil (Peters and Basta, 1996). Lake Wister WTR (WISTER) at 100 g WTR kg -1 reduced Mehlich-III from 296 to <200 mg kg -1 in soil that had excessive levels of available P (Peters and Basta, 1996). Residual from the AB Jewell reservoir (ABJ), at 100 g WTR kg -1 reduced Mehlich-III P from 553 to 250 mg kg -1.

Treatment of soil with WTR may reduce soluble P and consequently runoff P but incorporation of WTR into permanent pasture land should be discouraged. For WTRs to be incorporated into pasture the sod must be broken using conventional tillage, which temporarily leaves the soil susceptible to significant erosion. If a surface runoff producing rainfall event occurs during this period, significant amounts of sediment and P may be transported to receiving water bodies. Surface application of WTR to land treated with poultry litter may reduce soluble P and nutrient in runoff water. The objectives of this work was (i) to determine the ability of WTRs to reduce N and P runoff from land treated with poultry litter under field conditions, and (ii) to evaluate potential environmental impacts associated with land application of WTR.

Effect of WTR on Phosphorus in Surface Runoff

The high broadcast and buffer strip treatments of WTR applied reduced soluble P ($p < 0.05$) in the runoff water compared to the control plots in the Adair County experiment (Figure 6). Mean soluble P was 88% of the mean total P in the runoff water for the Adair County site. Therefore, total P and soluble P results were similar for all treatments. Mean concentration of total P was 8.60 mg L -1 (43% reduction compared to control) in the high broadcast treatment and 8.12 mg L-1 (46% reduction compared to control) for the buffer strip treatment (Figure 6). Small reductions in soluble P were found for the low broadcast treatment, but these reductions were not significant ($p < 0.05$). A summary of the statistical analysis is given in Table 16.

Buffer strips were found to be more effective than the broadcast treatments in reducing P in the surface runoff (Figure 6). The buffer strip treatment required 18.2 kg plot-1 of WTR, which was the same amount that was applied in the low broadcast treatment. However, soluble P in runoff water for buffer strips was lower than results from the low broadcast plots. The buffer strip may have provided greater contact between the rainfall water and the WTR than the broadcast treatments resulting in more P removed from solution. The high broadcast treatments showed similar reductions in soluble P as the buffer strip treatment, but the high broadcast treatment required four times the amount of WTR (72.6 kg plot-1).

Reductions in soluble P in the runoff water due to WTR application in LeFlore County (Figure 7) was smaller than the results from Adair County (Figure 6). In general, WTR treatments showed small but significant reductions in soluble P ($p < 0.05$) in the LeFlore County experiment. Further reductions in soluble P in the runoff water were not seen when higher amounts of WTR were applied to the plots (Figure 7). Mean soluble P is 94% of the mean total P in the runoff water from LeFlore County. Therefore reductions between total P and soluble P were similar. Differences in soluble P in runoff between locations can result from different sources of poultry litter, different WTR, or a combination of litter and WTR. The poultry litters used at the two locations were from different sources. Laboratory analysis showed P content of the two litters were similar (Appendix A). Furthermore, total P concentrations in runoff from the control plots from Adair County (15.0 mg L-1) and control plots from LeFlore County (18.8 mg L-1) were similar. Different WTR was used for each experiment; WISTER was used in LeFlore County, while ABJ was used in Adair County. Laboratory P adsorption studies have shown WISTER removes less P from solution than ABJ WTR (Peters and Basta, 1996).

Effect of WTR on Nitrogen in Surface Runoff

Nitrogen measured in runoff water included NH_4-N, NO_3 and total N. The relative amounts of the three forms of soluble N in runoff water were total N>NH_4>>NO_3. Therefore only NH_4-N and total N values are shown. Significant reductions of soluble NH_4-N for the high broadcast treatments and the buffer strip treatments compared to control plots were observed at the Adair County site (Table 17). Total N was not reduced ($p < 0.05$) for any of the treatments as compared to the control plots (Figure 8). Mean soluble NH_4-N was 50% of the mean total N indicating that almost half of soluble N was in organic forms in runoff water. The ABJ WTR had a CEC of 54.7 cmol kg -1 capable of adsorbing significant amounts of NH_4. Soluble NH_4-N can be absorbed by the CEC of the WTR, but NO_3 and organic forms of N have less affinity for the WTR. A summary of the statistical analysis is given in Table 16.

WTR treatments did not reduce soluble NH_4-N or total N at the LeFlore County location (Figure 9, Table 17). Both locations had similar amounts of soluble NH_4-N in the runoff water from the control plots. However, only 37% for total N in runoff water was NH_4-N indicating most of the soluble N was in organic forms. The WISTER WTR of 16.4 cmol kg -1 is smaller than ABJ 54.7 cmol kg -1. Perhaps, adsorption of NH_4 on CEC sites was limited by WISTER.

Potential Environmental Impacts

Increased solids in surface runoff into nearby water bodies from areas treated with WTR may be a concern. Mean total suspended solids in Adair County for the high broadcast, low broadcast and the buffer strip treatments of 0.750, 0.375 and 0.588 g kg -1, respectively, were not different ($p < 0.05$) than the 0.438 g kg -1 from control plots. Mean total suspended solids in the LeFlore County experiment for the high broadcast, low broadcast and the buffer treatments of 0.563, 0.625 and 0.463 g kg -1, respectively, were not different than the 0.500 g kg -1 from control plots. Land application of WTR did not increase solids present in the surface runoff water.

Because alum-based WTR contains amorphous Al, there is concern that land application of WTR will increase Al solubility in soil and may cause Al toxicity to plants. However, most alum residuals are alkaline (pH>7) and most Al occurs as insoluble oxides not as highly soluble aluminum sulfate. Application of 100 g ABJ kg -1 to an acidic Dickson soil (pH 5.3) increased the pH to 7.0 (Peters and Basta, 1996). Similarly, application of WISTER WTR at 100 g kg -1 to the same acidic soil raised the pH to 5.6.. Mean soluble Al (in mg L-1) 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 ($P<0.05$) for the Adair County experiment (Figure 10). Mean soluble Al in runoff water in the LeFlore County experiment (in mg L-1) from the control plots (0.060), the high broadcast plots (0.048), the low broadcast plots (0.055), and the buffer strip plots (0.049) were not different ($p < 0.05$). Land application of WTR did not increase soluble Al in the surface runoff water.

Discussion

The ABJ WTR reduced P and NH_4 in the runoff water more than WISTER WTR. 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 -1 while WISTER was 2.1 g kg -1. Furthermore, soluble Ca in ABJ is greater than WISTER WTR (Table 9). Other studies have shown amorphous Al was correlated with the P adsorption capacity of WTR (Elliot, 1990). Amorphous Al content of ABJ was 50.5 g kg -1, which was much greater than the WISTER amorphous Al content of 11.7 g kg -1. Our results suggest that adsorption of soluble P by amorphous Al and/or precipitation of soluble P with Ca in WTR were important mechanisms to reduce soluble P in runoff water. Soluble NH_4-N can be absorbed by the CEC of the WTR. Larger decreases of soluble NH_4 in runoff water from plots treated with ABJ than plots treated with WISTER suggest adsorption of soluble NH_4 by CEC sites in WTR was an important mechanism to reduce soluble NH_4 in runoff water (Table 16).

Reductions in N and P were found for the high broadcast and buffer treatments in this field study. However, broadcast treatments required four times the amount of WTR to be as effective as buffer strips. Application of WTR as buffer strips was more effective than broadcast in reducing nutrients in runoff water in this study, but larger scale operations may produce different results. Our field study used 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 runoff water 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 absorbing nutrients while some of the buffer strip may be saturated with nutrients by the surface runoff water. In this case, a broadcast application may provide more interaction with nutrients in runoff water and reduce nutrient runoff more effectively than the buffer strip.

Land application of alum based WTR does not increase dissolved Al in surface runoff (Peters and Basta, 1996; Elliot et al., 1988) or extractable Al in soil (Peters and Basta, 1996). Aluminum in WTR exists as insoluble form of aluminum oxide, in soil environments that are not strongly acidic (pH>5). In this study, soil acidity was not increased by the application of alkaline WTR. Soils typically contain 5 to 10% Al and WTRs contain similar amounts of Al. However, WTRs contain a higher percentage of amorphous Al, which is more soluble under highly acid conditions (pH<5). If the pH remains greater that 5, both Al in the soil and WTR are insoluble and thus would not be expected to be associated with Al toxicity. At pH less than 5, differences in Al solubility between WTR and soil have not been determined.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the demonstrated BMPs that had replicated plots, i.e. manure application rate, pasture aeration, water treatment residuals (alum sludge), vegetation height, commercial fertilizer and poultry litter comparison.

Traditional BMPs

For the conditions studied, plot slope had a significant effect for all response variables except solids and organic N. In previous Oklahoma State University rainfall simulator studies, slope was found to be insignificant or occasionally marginally significant. In the current and previous studies the effect of slope was found to be very complex. Thus we do not recommend adjusting BMP recommendations for slope without further studies. We also found that, for the conditions studied, the aeration and vegetation height treatments does not have a significant effect.

Based on the Kerr-August and Hudson Farms data, as well as previous studies, we found that increasing litter application rate increases nutrient loss (N and P) in surface runoff. When the P and N response variables were normalized by the N or P application rate, the high and low litter application rates were not significantly different. This indicates there was a linear response to litter application rate for P and N.

The commercial fertilizer treatment response was different from the litter application treatments. The normalized surface runoff P concentrations for the commercial fertilizer treatments were always significantly higher than the litter application treatments. This indicates that on a per unit application basis commercial fertilizer has significantly higher losses to surface runoff than poultry litter. Therefore, poultry litter is the preferred P fertilizer source for permanent pasture.

Nitrogen showed mixed results. For the Hudson Farms demonstration, the normalized surface runoff total N, ammonium, and organic N concentrations were significantly higher from commercial fertilizer than poultry litter. However, these normalized N response variables were not significantly different for the Kerr-August demonstration, and the normalized mean concentrations were lower for the commercial fertilizer treatment. Therefore we have no recommendation at this time on use of poultry litter vs commercial fertilizer (ammonium nitrate) for N losses to surface runoff.

Based on these demonstrations the following conclusions can be made:

1. Slope should be considered when developing BMP recommendations. However, additional studies are needed to make specific recommendations.
2. Aeration has no significant effect and should not be considered a BMP.
3. For the conditions studied, i.e. good vegetation stand with 1.5 to 20 inch height, vegetation height has no significant effect.
4. Increasing litter application rate increases nutrient losses. Therefore, litter application rates should be minimized to reduce potential off-site water quality impacts.
5. P from triple super phosphate fertilizer is more mobile that poultry litter, and thus has higher losses in surface runoff. Therefore, from a water quality perspective, poultry litter is the preferred P fertilizer for permanent pasture.
6. Based on current information, no recommendation can be made at this time between commercial N fertilizer (ammonium nitrate) and poultry litter.

Water Treatment Residuals

Two WTRs were used in three treatments: an edge of plot buffer strip and two broadcast rates. One WTR reduced P and NH_4 in surface runoff significantly, whereas the other WTR did not. No significant difference was found between broadcast and buffer strip treatments. In addition, soluble Al in surface runoff ranged from 0.02 to 0.09 mg/Lm, and WTR treated plots were not significantly different from the control. Therefore, land application of alum-based WTR does not increase dissolved Al in surface runoff. Related studies showed that these WTRs did not increase soil extractable Al.

The ability of WTRs to reduce P and NH_4 in runoff depends on the Ca content, amorphous Al content and cation exchange capacity of the WTR. Drinking water treatment plants use different source waters and different treatment chemicals and produce WTRs with different chemical compositions and properties. Therefore, further studies on specific WTRs are needed to evaluate their potential to reduce nutrients in surface runoff.

The following can be concluded for WTRs from these demonstrations:

1. Some WTRs can reduce P and NH_4 in surface runoff, and thus have potential as a BMP.
2. Land application of alum-based WTR does not increase dissolved Al in surface runoff or extractable Al in soil.

EDUCATION ACTIVITIES

Three rainfall simulator demonstrations were conducted. Two demonstrations were conducted in LeFlore County at the Kerr Center for Sustainable Agriculture, Poteau, Oklahoma, one on June 18-19 and the second on August 6-7. The third demonstration was conducted in Adair County, at the Hudson Farms Chance Complex Number 8, just outside Chance, Oklahoma, on July 9-10. For the June19, 1996 demonstration approximately 80 people attended, for the July 10, 1996 demonstration approximately 40 people attended, and for the August 7, 1996 demonstration approximately 40 people attended. The agenda for the demonstration programs is given below.

Rainfall Simulator Field Demonstration Program

8:30	Begin Rainfall
9:00	Welcome (Local County Agricultural Extension Agent)
9:10	Experimental Design and Setup (Dan Storm)
9:20	Use of Hydrosolids to Reduce Phosphorus Runoff (Nick Basta)
9:30	How Results of Study Relate to Application of Broiler Litter and Swine Lagoon Effluent (Doug Hamilton, Extension Waste Management Specialist)
9:50	Move Audience to Litter Calibration Area
10:00	Calculating Application Rates, Spreader Truck Calibration (Doug Hamilton, and Joe Bullard or Mitch Fram)
10:30	Demonstration of Pasture Renovator to Roughen Surface and Distribute Litter (Joe Bullard and Jim Ennis) - Poteau Only.
10:55	Move Audience back to Main Area for Refreshments
11:00	Pond Fencing Demonstration at Pond Site (Baker, and Mitch Fram or Joe Bullard)
11:30	Free time to visit equipment displays.

Three facts sheets on animal waste were developed and are given in Appendix C. Also included in Appendix C are handouts given at the demonstrations, an example newspaper clipping, and the demonstration announcements.

As one measure of success, a follow up survey to non-governmental attendees was conducted, i.e. agricultural producers. Joe Bullard and Mitch Fram conducted the surveys in March of 1997 by telephone or by a site visit. The surveys are given in Appendix D. A summary of the survey results is given in Table 18. Results from the Hudson Farms demonstration were lost in the mail. No backup copies were available, and thus these data are not included.

The results of the survey were very encouraging. The producers thought the presented BMPs were very practical and could be easily implemented. Although we did not completely convince everyone that there can be problems with excessive land application of nutrients, all were convinced that they could effectively use a combination of poultry litter and commercial fertilizer. Quite a few practices were implemented as a result of information obtained at the demonstrations. One example is the use of buffer strips, which went from 20% to 60% implementation from before to after the demonstrations. In addition, each producer implemented at least one additional BMP following the demonstration.

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Table 1. Kerr plot slopes for the June rainfall simulator demonstration.

Setup Number	Plot Number (LUH)[1]	Plot Number	Average Slope (%)
1	1	1	7.3
1	2	2	7.3
1	3	3	7.8
1	4	4	7.5
2	1	5	6.3
2	2	6	5.7
2	3	7	5.7
2	4	8	5.5
3	1	9	6.4
3	2	10	6.6
3	3	11	6.4
3	4	12	6.4
4	1	13	6.6
4	2	14	6.3
4	3	15	6.8
4	4	16	7.6
5	1	17	8.6
5	2	18	9.3
5	3	19	9.1
5	4	20	9.0
6	1	21	8.5
6	2	22	8.6
6	3	23	8.5
6	4	24	8.6
7	1	25	6.2
7	2	26	6.3
7	3	27	6.6
7	4	28	6.7
8	1	29	7.8
8	2	30	8.1
8	3	31	4.1
8	4	32	6.9

[1] Left to right looking uphill.

Table 2. Kerr plot slopes for the August rainfall simulator demonstration.

Setup Number	Plot Number (LUH)[1]	Plot Number	Average Slope (%)
9	1	1	4.6
9	2	2	4.4
9	3	3	3.8
9	4	4	3.7
10	1	5	9.6
10	2	6	9.4
10	3	7	7.9
10	4	8	7.4
11	1	9	7.4
11	2	10	7.3
11	3	11	6.5
11	4	12	6.5
12	1	13	9.6
12	2	14	9.6
12	3	15	4.8
12	4	16	9.2
13	1	17	8.3
13	2	18	8.5
13	3	19	9.0
13	4	20	9.8
14	1	21	9.1
14	2	22	9.6
14	3	23	9.9
14	4	24	9.9
15	1	25	5.2
15	2	26	5.3
15	3	27	5.6
15	4	28	6.0
15	1	29	5.7
16	2	30	5.6
16	3	31	5.0
16	4	32	4.9

[1] Left to right looking uphill.

Table 3. Hudson Farms plot slopes for the June rainfall simulator demonstration.

Setup Number	Plot Number (LUH)[1]	Plot Number	Average Slope (%)
17	1	1	2.9
17	2	2	2.9
17	3	3	3.1
17	4	4	3.0
18	1	5	3.5
18	2	6	3.2
18	3	7	2.9
18	4	8	3.1
19	1	9	3.6
19	2	10	3.5
19	3	11	3.3
19	4	12	3.0
20	1	13	3.0
20	2	14	3.5
20	3	15	4.0
20	4	16	3.9
21	1	17	4.4
21	2	18	4.2
21	3	19	3.8
21	4	20	3.8
22	1	21	3.2
22	2	22	3.1
22	3	23	3.9
22	4	24	3.8
23	1	25	4.5
23	2	26	3.9
23	3	27	4.3
23	4	28	4.5
24	1	29	4.8
24	2	30	4.7
24	3	31	4.2
24	4	32	3.7

[1] Left to right looking uphill.

Table 4. Average plot slope by setup for the Kerr and Hudson Farms rainfall simulator demonstrations.

Location	Month	Setup Number	Average Slope (%)
Kerr	June	1	7.5
		2	5.8
		3	6.5
		4	6.8
		5	9.0
		6	8.6
		7	6.5
		8	6.7
		Average	7.2
	August	9	4.1
		10	8.6
		11	6.9
		12	8.3
		13	8.9
		14	9.6
		15	5.5
		16	5.3
		Average	7.2
Hudson Farms	July	17	3.0
		18	3.2
		19	3.4
		20	3.6
		21	4.1
		22	3.5
		23	4.3
		24	4.4
		Average	3.7

Table 5. Rainfall simulator demonstration treatment summary.

Site	Month	I.D.	Plots	Average Slope	Treatment
Kerr	June	A	4	6.9	High Application Rate Alum - Broadcast
		B	4	7.3	Low Application Rate Alum - Broadcast
		C	4	6.5	Low Equivalent Application Rate Alum - Buffer
		D	4	7.4	Standard Poultry Litter Application Rate - Low Vegetation
		E	4	7.8	Treatment D with Aeration
		F	4	7.2	Standard Poultry Litter Application Rate - High Vegetation
		G	4	7.3	Commercial Fertilizer - Low Vegetation
		H	2	6.8	High Poultry Litter Application Rate - Low Vegetation
		I	1	6.7	Eq. Standard Poultry Litter Application Rate - Buffer Stip
		J	1	7.6	Control - No Nutrient Additions - Low Vegetation
Kerr	August	A	4	6.5	High Application Rate Alum - Broadcast
		B	4	6.2	Low Application Rate Alum - Broadcast
		C	4	7.0	Low Equivalent Application Rate Alum - Buffer
		D	4	7.6	Standard Poultry Litter Application Rate - Low Vegetation
		E	4	7.4	Treatment D with Aeration
		F	4	6.4	Standard Poultry Litter Application Rate - High Vegetation
		G	2	6.1	Commercial Fertilizer - Low Vegetation
		H	1	9.6	High Poultry Litter Application Rate - Low Vegetation
		I	1	9.9	Eq. Standard Poultry Litter Application Rate - Buffer Stip
		J	3	8.7	Control - No Nutrient Additions - Low Vegetation
		K	1	7.3	Swine Manure - Low Vegetation
Hudson	July	A	4	3.9	High Application Rate Alum - Broadcast
		B	4	3.5	Low Application Rate Alum - Broadcast
		C	4	3.4	Low Equivalent Application Rate Alum - Buffer
		D	4	3.3	Standard Poultry Litter Application Rate - Low Vegetation
		F	4	3.5	Standard Poultry Litter Application Rate - High Vegetation
		G	4	4.0	Commercial Fertilizer - Low Vegetation
		H	3	3.6	High Poultry Litter Application Rate - Low Vegetation
		I	1	4.8	Eq. Standard Poultry Litter Application Rate - Buffer Stip
		J	3	3.8	Control - No Nutrient Additions - Low Vegetation
		K	1	4.4	Dairy Manure - Low Vegetation

Table 6. Rainfall simulator demonstration treatments.

Location (Month)	I.D.	Plots	Amend-ment	Amend-ment Area (ft)	Amend-ment Rate (Mg/ha)	Nutrient Source	Nutrient Rate (tons/ac)	Veget-ation Height (in)	Buffer Length (ft)	Aera-tion
Kerr (June)	A	4	Alum	32	10	Poultry	3	3	0	None
	B	4	Alum	32	5	Poultry	3	3	0	None
	C	4	Alum	8	20	Poultry	3	3	0	None
	D	4	None	0	0	Poultry	3	3	0	None
	E	4	None	0	0	Poultry	3	3	0	Yes
	F	4	None	0	0	Poultry	3 eq.	6+	0	None
	G	4	None	0	0	Com. Fert.	3 eq.	3	0	None
	H	2	None	0	0	Poultry	6	3	0	None
	I	1	None	0	0	Poultry	4	3	8	None
	J	1	None	0	0	None	0	3	0	None
Kerr (August)	A	4	Alum	32	45	Poultry	3	3	0	None
	B	4	Alum	32	11	Poultry	3	3	0	None
	C	4	Alum	8	90	Poultry	3	3	0	None
	D	4	None	0	0	Poultry	3	3	0	None
	E	4	None	0	0	Poultry	3	3	0	Yes
	F	4	None	0	0	Poultry	3 eq.	6+	0	None
	G	2	None	0	0	Com. Fert.	3 eq.	3	0	None
	H	1	None	0	0	Poultry	6	3	0	None
	I	1	None	0	0	Poultry	4	3	8	None
	J	3	None	0	0	None	0	3	0	None
	K	1	None	0	0	Swine	?	3	0	None
Hudson (July)	A	4	Alum	32	45	Poultry	3	3	0	None
	B	4	Alum	32	11	Poultry	3	3	0	None
	C	4	Alum	8	90	Poultry	3	3	0	None
	D	4	None	0	0	Poultry	3	3	0	None
	F	4	None	0	0	Poultry	3 eq.	6+	0	None
	G	4	None	0	0	Com. Fert.	3 eq.	3	0	None
	H	3	None	0	0	Poultry	6	3	0	None
	I	1	None	0	0	Poultry	4	3	8	None
	J	3	None	0	0	None	0	3	0	None
	K	1	None	0	0	Dairy	?	3	0	None

Table 7. Plot number and treatment identification.

Site	Month	Setup #	Plot #	Treatment I.D.
Kerr	June	1	1	B
		1	2	C
		1	3	H
		1	4	E
		2	5	G
		2	6	H
		2	7	A
		2	8	C
		3	9	E
		3	10	C
		3	11	D
		3	12	F
		4	13	C
		4	14	F
		4	15	A
		4	16	J
		5	17	E
		5	18	F
		5	19	D
		5	20	B
		6	21	G
		6	22	E
		6	23	A
		6	24	B
		7	25	D
		7	26	G
		7	27	A
		7	28	I
		8	29	D
		8	30	G
		8	31	B
		8	32	F

Table 7 (cont.). Plot number and treatment identification.

Site	Month	Setup #	Plot #	Treatment I.D.
Kerr	August	9	1	B
		9	2	C
		9	3	A
		9	4	G
		10	5	H
		10	6	E
		10	7	D
		10	8	J
		11	9	D
		11	10	K
		11	11	B
		11	12	A
		12	13	C
		12	14	J
		12	15	F
		12	16	J
		13	17	B
		13	18	G
		13	19	F
		13	20	E
		14	21	C
		14	22	D
		14	23	A
		14	24	I
		15	25	B
		15	26	D
		15	27	E
		15	28	F
		16	29	F
		16	30	A
		16	31	C
		16	32	E

Table 7 (cont.). Plot number and treatment identification.

Site	Month	Setup #	Plot #	Treatment I.D.
Hudson	July	17	1	D
		17	2	F
		17	3	B
		17	4	J
		18	5	A
		18	6	B
		18	7	H
		18	8	G
		19	9	D
		19	10	C
		19	11	A
		19	12	C
		20	13	F
		20	14	D
		20	15	J
		20	16	G
		21	17	K
		21	18	G
		21	19	C
		21	20	B
		22	21	C
		22	22	D
		22	23	H
		22	24	B
		23	25	J
		23	26	H
		23	27	F
		23	28	A
		24	29	I
		24	30	G
		24	31	A
		24	32	F

Table 8. Uncut vegetation heights for 1996 rainfall simulator demonstrations.

Location	Month	Treatment	Plot #	Setup #	Vegetation Height (in)
Kerr	June	F	4	3	6-8
		F	2	4	5
		F	2	5	6-8
		F	4	8	6
		I	4	7	5
Kerr	August	F	3	12	12-20
		F	3	13	12-16
		F	4	15	12-18
		F	1	16	10-16
		I	4	14	8-14
Hudson	July	F	2	17	7
		F	1	20	6
		F	3	23	6
		F	4	24	6
		I	1	24	6

Table 9. Properties, chemical components and nutrient content of water treatment residuals.

Properties	Water Treatment Residual AB Jewell	Wister
pH	7.6	7.0
EC, dS m^{-1}	0.58	0.31
CCE, g kg^{-1}	148	18.7
CEC, cmol kg^{-1}	54.7	16.4
OC, g kg^{-1}	66.8	39.3
Chemical Components		
Al oxide, g kg^{-1}	50.5	11.7
Fe oxide, g kg^{-1}	4.2	5.0
Total N, g kg^{-1}	8.98	4.53
Aqueous Components, mg L^{-1}		
Al	0.08	0.10
Ca	375	60.0
Mg	4.70	7.65
P	0.27	0.10
Nutrients, mg kg^{-1}		
NH_4-N	58.4	31.2
NO_3-N	240	34.2
P	11.9	16.8
SO_4-S	143	165

Table 10. Soil moisture and chemical properties for 0-6 inch composite soil cores.

Site	Month	Setup	Soil Moisture Dry Basis (%)	Soil pH	Available N (lbs/ac)	Mehlich P (lbs/ac)	Mehlich K (lbs/ac)
Kerr	June	1	21	5.1	6	11	233
		2	13	4.9	6	19	347
		3	.	5.0	9	39	393
		4	.	5.0	25	25	252
		5	23	4.6	8	21	232
		6	14	5.0	12	17	217
		7	30	5.2	28	31	205
		8	29	5.3	22	36	235
Kerr	August	9	32	5.3	20	24	266
		10	36	5.1	10	19	161
		11	35	5.0	18	36	419
		12	.	4.8	15	22	268
		13	37	4.7	12	21	169
		14	22	4.6	9	29	277
		15	29	5.4	8	13	217
		16	24	5.3	7	12	314
Hudson	July	17	14	5.6	17	38	158
		18	12	5.4	8	42	182
		19	15	5.2	5	35	267
		20	15	5.6	19	38	328
		21	14	5.1	6	34	154
		22	17	5.3	18	51	297
		23	17	5.3	5	31	149
		24	14	5.2	5	33	133

Table 11. Poultry litter analysis results.

Site	Month	Moisture Dry Basis (%)	N (%)	P (%)	K (%)
Kerr	June	18	3.5	1.5	2.6
Kerr	August	19	3.5	1.7	3.1
Hudson	July	14	3.0	1.6	2.8

Table 12. Time to surface runoff by plot number and treatment identification.

Site	Month	Setup #	Plot #	Treatment I.D.	Time to Runoff (min)
Kerr	June	1	1	B	30.5
		1	2	C	28.5
		1	3	H	22.5
		1	4	E	24.0
		2	5	G	28.5
		2	6	H	44.5
		2	7	A	46.0
		2	8	C	52.0
		3	9	E	42.5
		3	10	C	45.0
		3	11	D	44.5
		3	12	F	48.0
		4	13	C	30.0
		4	14	F	32.0
		4	15	A	5.5
		4	16	J	9.5
		5	17	E	8.0
		5	18	F	4.0
		5	19	D	6.5
		5	20	B	8.5
		6	21	G	12.0
		6	22	E	4.0
		6	23	A	22.5
		6	24	B	25.0
		7	25	D	23.0
		7	26	G	28.5
		7	27	A	27.5
		7	28	I	39.0
		8	29	D	41.5
		8	30	G	41.5
		8	31	B	46.0
		8	32	F	51.5

Table 12 (cont.). Time to surface runoff by plot number and treatment identification.

Site	Month	Setup #	Plot #	Treatment I.D.	Time to Runoff (min)
Kerr	August	9	1	B	21.0
		9	2	C	22.5
		9	3	A	22.5
		9	4	G	23.5
		10	5	H	12.0
		10	6	E	12.0
		10	7	D	11.0
		10	8	J	11.5
		11	9	D	25.5
		11	10	K	32.0
		11	11	B	26.0
		11	12	A	25.0
		12	13	C	14.0
		12	14	J	12.0
		12	15	F	21.0
		12	16	J	13.5
		13	17	B	13.5
		13	18	G	10.5
		13	19	F	14.5
		13	20	E	10.5
		14	21	C	21.0
		14	22	D	23.0
		14	23	A	6.5
		14	24	I	14.5
		15	25	B	16.0
		15	26	D	12.0
		15	27	E	15.0
		15	28	F	13.5
		16	29	F	21.5
		16	30	A	24.5
		16	31	C	22.5
		16	32	E	19.5

Table 12 (cont.). Time to surface runoff by plot number and treatment identification.

Site	Month	Setup #	Plot #	Treatment I.D.	Time to Runoff (min)
Hudson	July	17	1	D	25.5
		17	2	F	69.5
		17	3	B	46.5
		17	4	J	46.0
		18	5	A	48.0
		18	6	B	46.0
		18	7	H	42.5
		18	8	G	55.0
		19	9	D	5.5
		19	10	C	6.0
		19	11	A	6.0
		19	12	C	6.0
		20	13	F	3.0
		20	14	D	3.5
		20	15	J	28.0
		20	16	G	3.5
		21	17	K	37.5
		21	18	G	35.5
		21	19	C	25.0
		21	20	B	34.5
		22	21	C	51.5
		22	22	D	47.0
		22	23	H	37.0
		22	24	B	50.5
		23	25	J	3.5
		23	26	H	5.0
		23	27	F	5.0
		23	28	A	5.5
		24	29	I	5.5
		24	30	G	3.5
		24	31	A	5.5
		24	32	F	4.5

Table 13. Surface runoff results.

Site	Month	Plot #	Treat-ment	Setup #	Rep. #	Solids (%)	Volume (L)	Total P (mg/L)	Sol P (mg/L)	Total N (mg/L)	Amm (mg/L)	Sol. Al (mg/L)
Kerr	June	7	A	2	1	0.035	233	8.4	9.3	45	8.7	0.072
Kerr	June	15	A	4	2	0.040	791	10.2	12.3	68	16.9	0.061
Kerr	June	23	A	6	3	0.070	846	5.8	6.9	42	13.4	0.037
Kerr	June	27	A	7	4	0.065	578	8.1	8.9	52	17.8	0.051
Kerr	June	1	B	1	1	0.030	644	6.2	7.0	31	3.6	0.050
Kerr	June	20	B	5	2	0.045	647	6.0	6.3	24	7.0	0.044
Kerr	June	24	B	6	3	0.060	709	5.8	6.7	48	13.3	0.037
Kerr	June	31	B	8	4	0.075	156	6.0	6.7	48	13.7	0.060
Kerr	June	2	C	1	1	0.075	1026	4.7	5.6	24	3.1	0.039
Kerr	June	8	C	2	2	0.025	60	5.6	6.7	31	9.0	0.062
Kerr	June	10	C	3	3	0.020	818	4.8	6.3	12	8.9	0.038
Kerr	June	13	C	4	4	0.060	373	8.1	10.4	51	18.9	0.051
Kerr	June	11	D	3	1	0.010	202	5.6	5.0	14	6.8	0.041
Kerr	June	19	D	5	2	0.050	709	4.5	5.8	27	6.5	0.035
Kerr	June	25	D	7	3	0.055	819	6.7	6.9	56	15.8	0.044
Kerr	June	29	D	8	4	0.055	276	6.9	8.7	49	13.7	0.040
Kerr	June	4	E	1	1	0.055	1228	3.8	4.3	19	15.3	.
Kerr	June	9	E	3	2	0.025	283	4.0	5.1	14	5.0	.
Kerr	June	17	E	5	3	0.025	677	4.6	5.7	23	5.8	.
Kerr	June	22	E	6	4	0.045	834	8.2	9.2	55	14.6	.
Kerr	June	12	F	3	1	0.045	94	4.4	4.4	27	5.2	.
Kerr	June	14	F	4	2	0.035	441	11.1	12.7	56	17.8	.
Kerr	June	18	F	5	3	0.025	987	3.4	3.9	17	5.5	.
Kerr	June	32	F	8	4	0.055	113	9.1	11.1	59	17.1	.
Kerr	June	5	G	2	1	0.020	356	15.3	20.0	34	18.5	.
Kerr	June	21	G	6	2	0.065	865	14.1	13.4	50	14.1	.
Kerr	June	26	G	7	3	0.055	928	23.5	27.4	67	23.5	.
Kerr	June	30	G	8	4	0.050	357	20.8	24.7	53	20.8	.
Kerr	June	3	H	1	1	0.080	938	14.5	16.3	72	19.5	.
Kerr	June	6	H	2	2	0.075	308	18.5	22.7	77	26.2	.
Kerr	June	28	I	7	1	0.065	383	6.3	6.9	52	13.6	.
Kerr	June	16	J	4	1	0.020	468	0.5	0.7	6	0.3	.
Hudson	July	5	A	18	1	0.045	16	4.6	4.4	26	10.6	0.024
Hudson	July	11	A	19	2	0.045	114	2.9	2.4	29	5.9	0.025
Hudson	July	28	A	23	3	0.045	544	11.7	7.3	56	17.8	.
Hudson	July	31	A	24	4	0.165	588	15.2	11.4	29	11.1	0.026
Hudson	July	3	B	17	1	0.025	80	12.6	12.5	75	30.4	0.027
Hudson	July	6	B	18	2	0.040	59	12.4	11.2	47	27.4	0.028
Hudson	July	20	B	21	3	0.050	304	13.2	11.4	55	27.7	0.022
Hudson	July	24	B	22	4	0.035	108	12.3	11.1	38	27.1	0.030
Hudson	July	10	C	19	1	0.060	237	6.4	6.1	51	14.8	0.035
Hudson	July	12	C	19	2	0.070	163	7.0	6.0	22	14.7	0.022
Hudson	July	19	C	21	3	0.055	530	10.0	9.2	55	22.5	0.028
Hudson	July	21	C	22	4	0.050	848	9.2	8.1	45	19.7	0.029
Hudson	July	1	D	17	1	0.045	292	11.9	11.1	47	27.1	0.022
Hudson	July	9	D	19	2	0.050	163	14.1	13.9	43	33.9	0.021
Hudson	July	14	D	20	3	0.035	156	15.0	13.9	64	33.8	0.021
Hudson	July	22	D	22	4	0.045	228	19.0	16.5	48	40.1	0.028
Hudson	July	2	F	17	1	0.050	2	8.7	8.3	32	20.3	.
Hudson	July	13	F	20	2	0.035	320	10.9	10.4	85	25.4	.
Hudson	July	27	F	23	3	0.045	637	11.6	11.0	53	26.7	.
Hudson	July	32	F	24	4	0.040	665	15.7	15.2	68	37.1	.
Hudson	July	8	G	18	1	0.050	21	36.0	34.6	164	84.4	.
Hudson	July	16	G	20	2	0.065	118	19.8	19.5	52	47.6	.
Hudson	July	18	G	21	3	0.045	103	46.7	42.1	207	102.5	.
Hudson	July	30	G	24	4	0.060	681	44.9	43.0	229	104.7	.
Hudson	July	7	H	18	1	0.110	104	28.9	27.7	101	67.6	.
Hudson	July	23	H	22	3	0.060	215	25.0	23.0	82	56.0	.
Hudson	July	26	H	23	4	0.080	746	25.8	23.6	105	57.5	.
Hudson	July	29	I	24	1	0.055	701	12.1	11.4	61	27.8	.
Hudson	July	4	J	17	1	0.010	254	2.1	1.8	8	4.4	.
Hudson	July	25	J	23	2	0.015	677	0.5	0.5	7	1.2	.

Table 13 (cont.). Surface runoff results.

Site	Month	Plot #	Treat-ment	Setup #	Rep. #	Solids (%)	Volume (L)	Total P (mg/L)	Sol P (mg/L)	Total N (mg/L)	Ammonium (mg/L)	Soluble Al (mg/L)
Hudson	July	15	J	20	3	0.030	331	2.1	2.1	12	5.2	.
Hudson	July	17	K	21	1	0.065	155	15.4	10.8	36	26.5	.
Kerr	August	3	A	9	1	0.05	1102	17.5	17.0	53	19.8	0.031
Kerr	August	12	A	11	2	0.065	742	15.7	16.0	53	28.2	0.045
Kerr	August	23	A	14	3	0.055	966	15.0	15.2	55	27.5	0.063
Kerr	August	30	A	16	4	0.055	819	13.4	13.1	55	25.0	0.054
Kerr	August	1	B	9	1	0.07	760	15.0	13.8	74	19.6	0.056
Kerr	August	11	B	11	2	0.045	674	17.2	15.3	78	27.9	0.062
Kerr	August	17	B	13	3	0.095	895	15.7	13.1	74	22.9	0.049
Kerr	August	25	B	15	4	0.04	1056	13.6	12.6	59	22.4	0.053
Kerr	August	2	C	9	1	0.035	935	16.7	17.3	59	19.8	0.033
Kerr	August	13	C	12	2	0.025	872	15.4	14.1	69	24.6	0.061
Kerr	August	21	C	14	3	0.075	693	13.1	13.7	47	19.3	0.065
Kerr	August	31	C	16	4	0.05	920	12.4	11.8	54	19.7	0.035
Kerr	August	7	D	10	1	0.07	1305	20.6	18.7	106	26.1	0.057
Kerr	August	9	D	11	2	0.06	454	17.8	16.5	70	24.8	0.050
Kerr	August	22	D	14	3	0.03	564	16.8	13.5	42	18.7	0.088
Kerr	August	26	D	15	4	0.04	1166	19.8	19.6	69	31.2	0.043
Kerr	August	6	E	10	1	0.08	1587	17.0	17.0	78	23.1	.
Kerr	August	20	E	13	2	0.035	1001	19.8	17.7	65	25.7	.
Kerr	August	27	E	15	3	0.00	1064	20.2	18.9	77	29.8	.
Kerr	August	32	E	16	4	0.04	879	13.9	13.6	44	23.1	.
Kerr	August	15	F	12	1	0.065	807	15.2	14.9	72	27.1	.
Kerr	August	19	F	13	2	0.065	1061	18.9	17.4	85	22.3	.
Kerr	August	28	F	15	3	0.065	1157	17.6	15.4	66	26.7	.
Kerr	August	29	F	16	4	0.05	866	14.6	12.6	54	24.3	.
Kerr	August	4	G	9	1	0.055	430	59.4	53.5	33	14.7	.
Kerr	August	18	G	13	4	0.04	1415	52.6	49.8	54	41.3	.
Kerr	August	5	H	10	1	0.04	819	45.0	43.0	181	62.5	.
Kerr	August	24	I	14	1	0.04	795	12.8	11.3	30	14.7	.
Kerr	August	16	J	12	1	0.055	1009	0.8	0.4	8	0.9	.
Kerr	August	8	J	10	2	0.07	765	1.9	1.4	10	2.3	.
Kerr	August	14	J	12	3	0.135	1077	0.5	0.3	7	0.4	.
Kerr	August	10	K	11	1	0.06	420	5.0	4.6	21	6.1	.

Table 14. Poultry litter and commercial fertilizer application rates.

Location	Month	Poultry Litter tons/ac	Poultry Litter lbs N/ac	Poultry Litter lbs P/ac	Commercial Fertilizer lbs N/ac	Commercial Fertilizer lbs P/ac
Kerr	June	3	210	90	280	35
		6	420	180		
Kerr	August	3	210	100	280	35
		6	410	200		
Hudson	July	3	180	95	280	35
		6	360	190		

Table 15. ANOVA statistical analysis results.

Variable[1] Treatment	Kerr-June Mean	Kerr-June Least Square Mean	Kerr-June Comparison[2]	Kerr-August Mean	Kerr-August Least Square Mean	Kerr-August Comparison[2]	Hudson Farms Mean	Hudson Farms Least Square Mean	Hudson Farms Comparison[2]
Total P									
D	5.9	6.6	a	19.	20.	b	15.	14.	b
F	7.0	7.6	a	17.	17.	b	12.	11.	b
G	18.	19.	b	56.	56.	c	37.	36.	d
H	17.	17.	b	45.	47.	c	27.	26.	c
J	0.5	1.3	a	1.1	2.4	a	1.6	0.6	a
Norm. Total P									
D	0.066	0.079	a	0.19	0.20	a	0.16	0.14	a
F	0.078	0.089	a	0.17	0.17	a	0.12	0.10	a
G	0.53	0.54	b	1.60	1.60	b	1.05	1.03	b
H	0.092	0.099	a	0.23	0.26	a	0.14	0.12	a
Soluble P									
D	6.6	7.5	a	17.	18.	b	14.	12.	b
F	8.1	8.9	a	15.	15.	b	11.	9.7	b
G	21.	22.	b	52.	52.	c	35.	34.	d
H	20.	20.	b	43.	45.	c	25.	23.	c
J	0.7	1.7	a	0.7	2.4	a	1.5	0.2	a
Norm. Sol. P									
D	0.073	0.089	a	0.17	0.19	a	0.15	0.12	a
F	0.089	0.10	a	0.15	0.16	a	0.12	0.096	a
G	0.61	0.63	b	1.47	1.48	b	1.00	0.98	b
H	0.11	0.12	a	0.22	0.25	a	0.13	0.11	a
Total N									
D	36.	35.	a	72.	70.	b	51.	53.	ab
F	40.	39.	a	69.	69.	b	60.	61.	b
G	51.	50.	a	44.	44.	ab	163.	165.	c
H	75.	74.	a	181.	178.	c	96.	98.	b
J	6.1	4.9	a	8.4	6.3	a	9.0	11.	a
Norm.Total N									
D	0.17	0.17	a	0.34	0.34	a	0.28	0.29	a
F	0.19	0.19	a	0.33	0.33	a	0.33	0.34	a
G	0.18	0.18	a	0.16	0.16	a	0.58	0.59	b
H	0.18	0.18	a	0.43	0.42	a	0.27	0.27	a
Amm.									
D	11.	11.	a	25.	25.	b	34.	34.	b
F	11.	11.	a	25.	25.	b	27.	28.	b
G	19.	19.	a	28.	28.	b	85.	85.	d
H	23.	23.	a	63.	62.	c	60.	61.	c
J	0.3	0.1	a	1.2	0.9	a	3.6	3.8	a

[1]Total P and soluble P are in units of mg/L and normalized P variables are in units of mg/L/lbs P/acre.
[2]Equal letters are not significantly different at an α=0.05.

Table 15 (cont.). ANOVA statistical analysis results.

Variable[1] Treatment	Kerr-June Mean	Kerr-June Least Square Mean	Kerr-June Comparison[2]	Kerr-August Mean	Kerr-August Least Square Mean	Kerr-August Comparison[2]	Hudson Farms Mean	Hudson Farms Least Square Mean	Hudson Farms Comparison[2]
Norm. Amm.									
D	0.05	0.05	a	0.12	0.12	a	0.19	0.19	a
F	0.05	0.05	a	0.12	0.12	a	0.15	0.15	a
G	0.07	0.07	a	0.10	0.10	a	0.30	0.30	b
H	0.05	0.05	a	0.15	0.15	a	0.17	0.17	a
Organic N									
D	25.	25.	a	46.	45.	b	17.	19.	a
F	28.	27.	a	44.	44.	b	32.	34.	a
G	32.	31.	a	16.	16.	ab	78.	80.	b
H	52.	51.	a	119.	116.	c	36.	37.	a
J	5.8	4.8	a	7.2	5.4	a	5.4	6.7	a
Norm.Organ. N									
D	0.12	0.12	a	0.22	0.22	a	0.10	0.10	a
F	0.13	0.13	a	0.21	0.21	a	0.18	0.18	ab
G	0.11	0.11	a	0.06	0.06	a	0.28	0.28	b
H	0.12	0.12	a	0.28	0.28	a	0.10	0.10	a
Solids (%)									
D	0.043	0.041	a	0.050	0.049	a	0.044	0.046	ab
F	0.040	0.039	a	0.061	0.061	a	0.043	0.044	ab
G	0.048	0.046	a	0.048	0.047	a	0.055	0.057	b
H	0.078	0.077	a	0.040	0.037	a	0.083	0.085	c
J	0.020	0.019	a	0.087	0.084	a	0.018	0.020	a

[1]Organic N is in units of mg/L and normalized Organic N is in units of mg/L/lbs N/acre.
[2]Equal letters are not significantly different at an α=0.05.
[3]Total N and ammonium are in units of mg/L and normalized N variables are in units of mg/L/lbs N/acre.
[4]Equal letters are not significantly different at an α=0.05.

Table 16. ANOVA statistical analysis results for WTRs.

Site/ Treatment		NH_4 Mean (mg/L)	Comparison[1]	Total N Mean (mg/L)	Comparison[1]	Dissolved P Mean (mg/L)	Comparison[1]	Total P Mean (mg/L)	Comparison[1]
Hudson - July									
Broadcast - High	A	11	b	35	a	6.4	b	8.6	b
Broadcast - Low	B	28	a	54	a	12	a	13	a
Buffer	C	18	b	43	a	7.4	b	8.1	b
Control	D	34	a	51	a	14	a	15	a
Kerr - August									
Broadcast - High	A	25	a	54	a	15.3	a	15	b
Broadcast - Low	B	23	a	71	a	13.7	b	15	b
Buffer	C	21	a	57	a	14.2	a	14	b
Control	D	25	a	72	a	17.1	a	19	a

[1]Equal letters are not significantly different at an α=0.05.

Table 17. Reduction in NH_4 from application of water treatment residuals.

Site	Month	Treatment	NH_4 (mg/L)	NH_4 Average (mg/L)	NH_4 Reduction (%)
Hudson	July	A	11		
		A	6		
		A	18		
		A	11	11	-66
		B	30		
		B	27		
		B	28		
		B	27	28	-17
		C	15		
		C	15		
		C	23		
		C	20	18	-47
		D	27		
		D	34		
		D	34		
		D	40	34	0
Kerr	August	A	20		
		A	28		
		A	27		
		A	25	25	-0.4
		B	20		
		B	28		
		B	23		
		B	22	23	-8
		C	20		
		C	25		
		C	19		
		C	20	21	-17
		D	26		
		D	25		
		D	19		
		D	31	25	0

Table 18. Rainfall simulator demonstration survey results summary.

Question	Number of Responses	Response
1) How practical do you rate the following practices:		
a) Manure Spreader Calibration	4	Very Practical
	1	Very Practical to Practical
b) Floating Fence for Limiting Pond Access	2	Very Practical to Practical
	3	Practical
c)Vegetative Buffer Strips	4	Very Practical
	1	Very Practical to Practical
d) Soil Testing for Nutrient Management	5	Very Practical
2) Do you think high rates of fertilizer or manure application can cause off-site water quality problems?	4	Yes
	1	No (not with proper management)
3) Do you think balancing nutrient application of poultry litter with commercial fertilizer is a viable option?	5	Yes
4) Since the rainfall simulator demonstration during the summer of 1996, what changes in management have you considered?	1	Soil Testing
	1	Buffer Strips
	1	More Frequent Soil Testing
	1	Soil Testing
	1	Use Commercial N to Balance Nutrients
	1	Pond Exclusion
	1	Floating Fence
5) Which have you implemented on your farm?	2	Buffer Strips
	1	Soil Testing
	1	Freeze Proof Water System for Livestock Exclusion
	1	Buffer Strips (Already in Use)
6) What do you recall learning from the summer of 1996 field day?	1	Excess rates of litter or fertilizer increase runoff losses
	1	Buffer strips have value
	1	soil testing to determine litter application
	1	rainfall simulator results
	1	aeration was not valuable (for water quality)
7) Do you have any suggestions or comments?	1	Need more producers at demonstrations
	1	Good
	1	More demonstrations like this

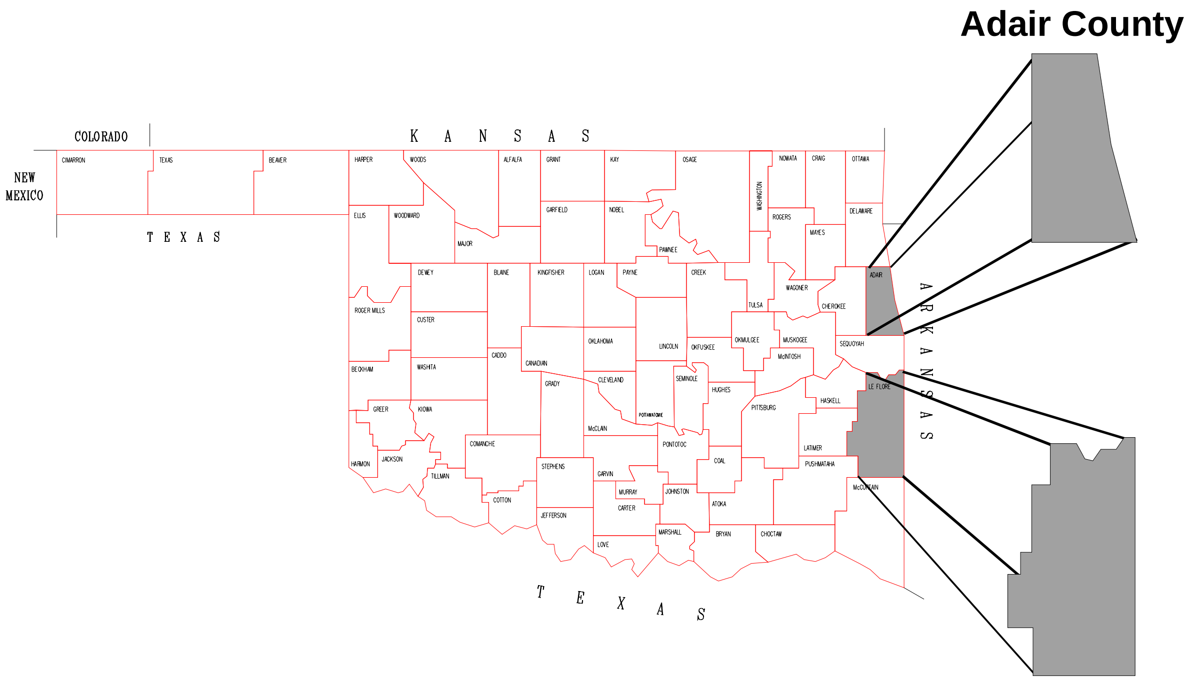

Figure 1. Location of Adair and LeFlore Counties.

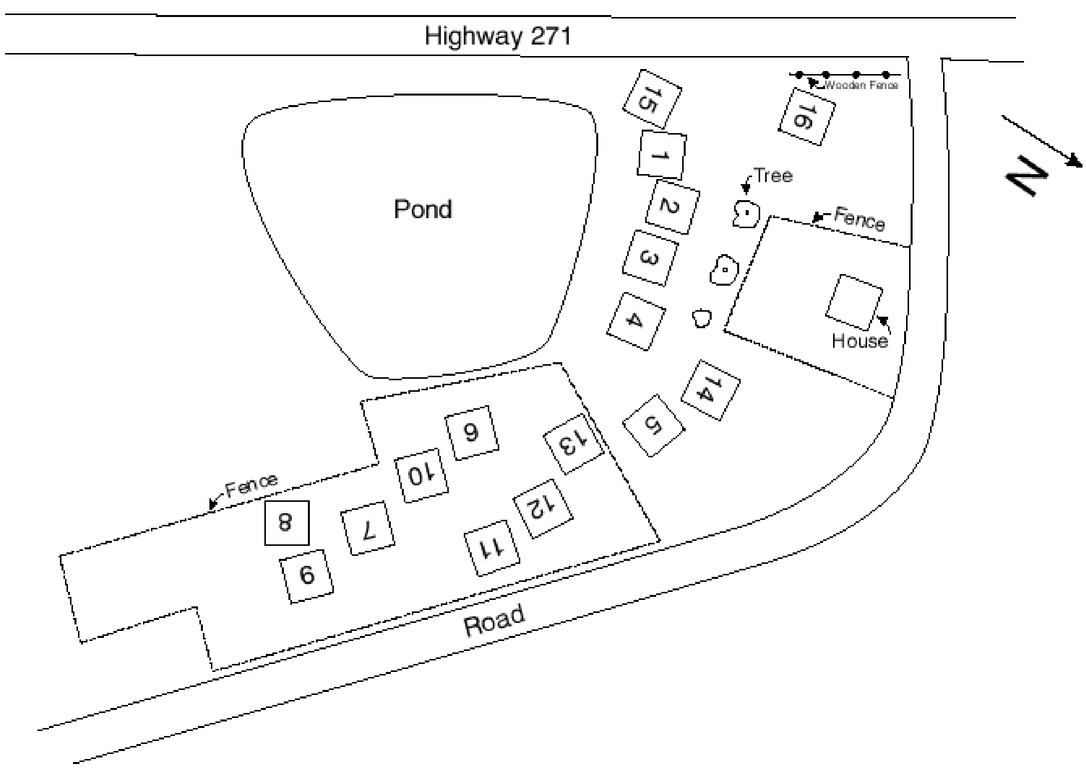

Figure 2. Setup locations for the Kerr Center for Sustainable Agriculture site.

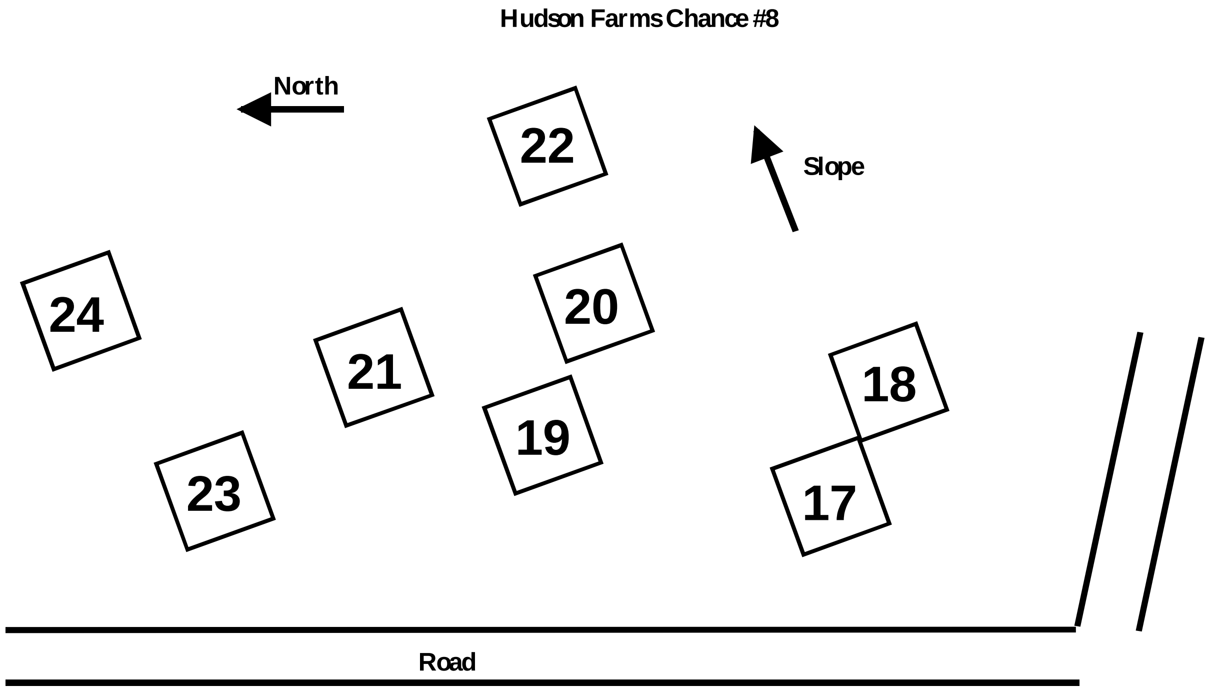

Figure 3. Setup locations for the Hudson Farms Chance Complex Number 8 site.

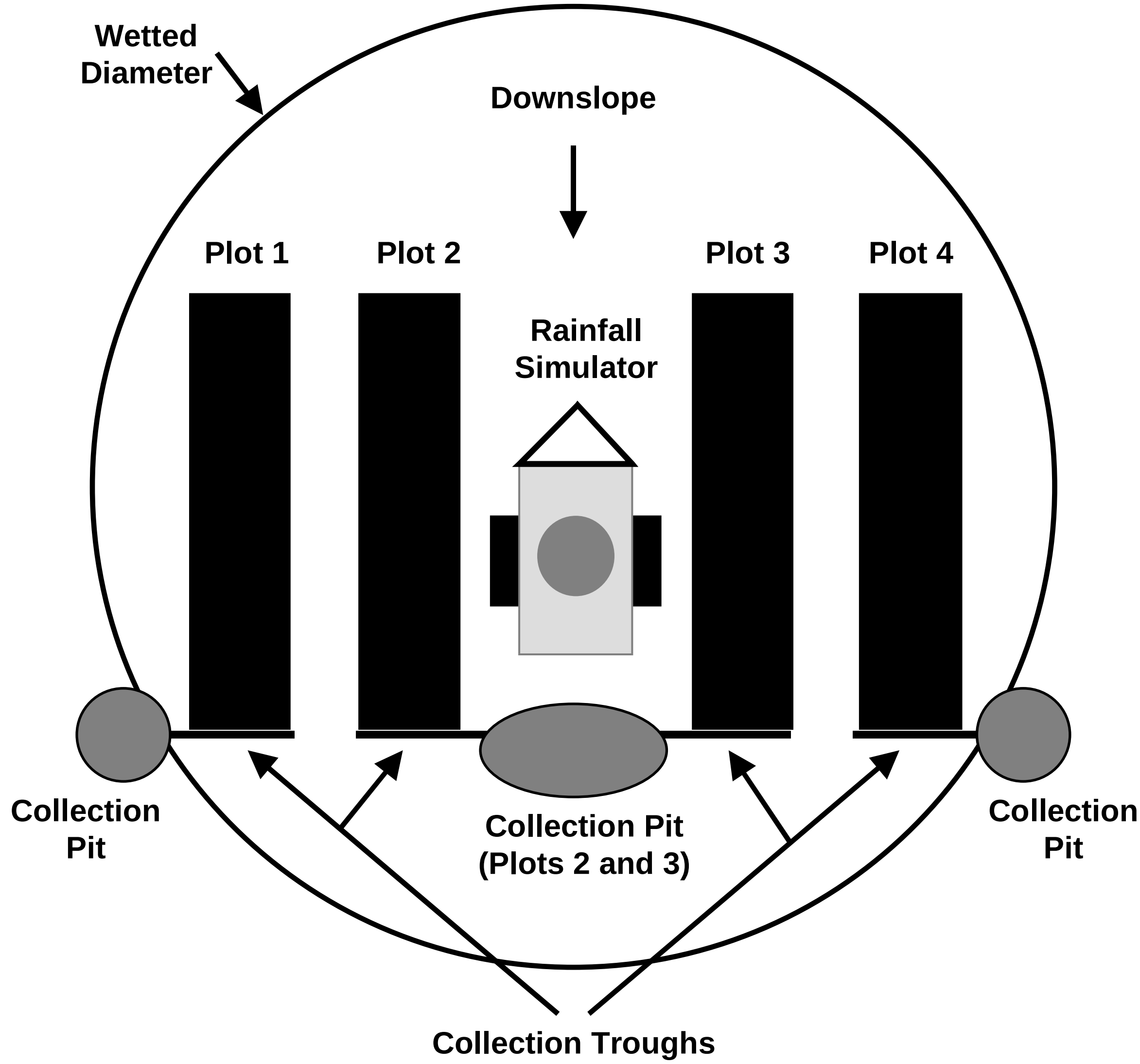

Figure 4. Rainfall simulator with plot layout. Ten booms with staggered nozzles not shown .

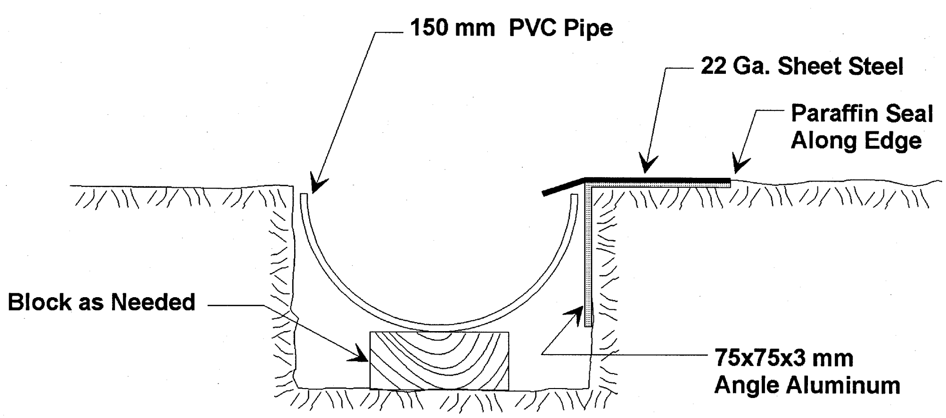

Figure 5. Cross-section view of plot area showing position of end plate and collection trough.

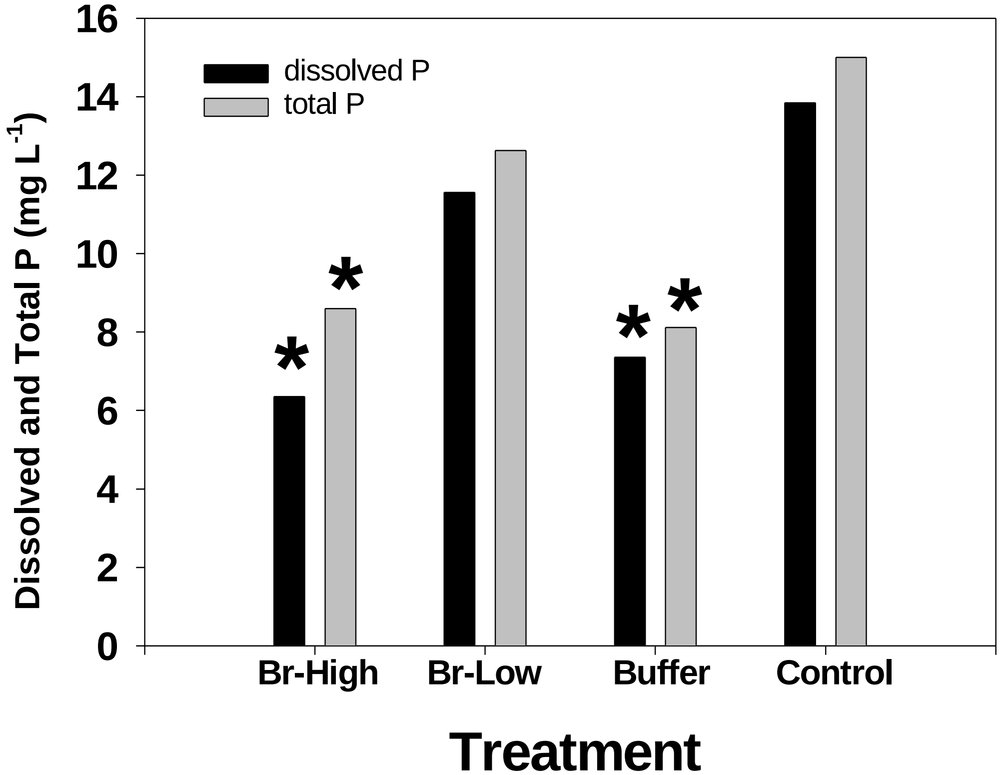

Figure 6. Soluble and total P in runoff water from plots treated with poultry litter in the Adair county experiment. Treatments are broadcast high application (Br-High, 44.8 Mg ha -1 or 72.6 kg plot -1), broadcast low application (Br-Low, 18.5 Mg ha -1 or 18.2 kg plot -1, buffer strip (Buffer, 44.8 Mg ha -1 or 18.2 kg plot -1), and control.

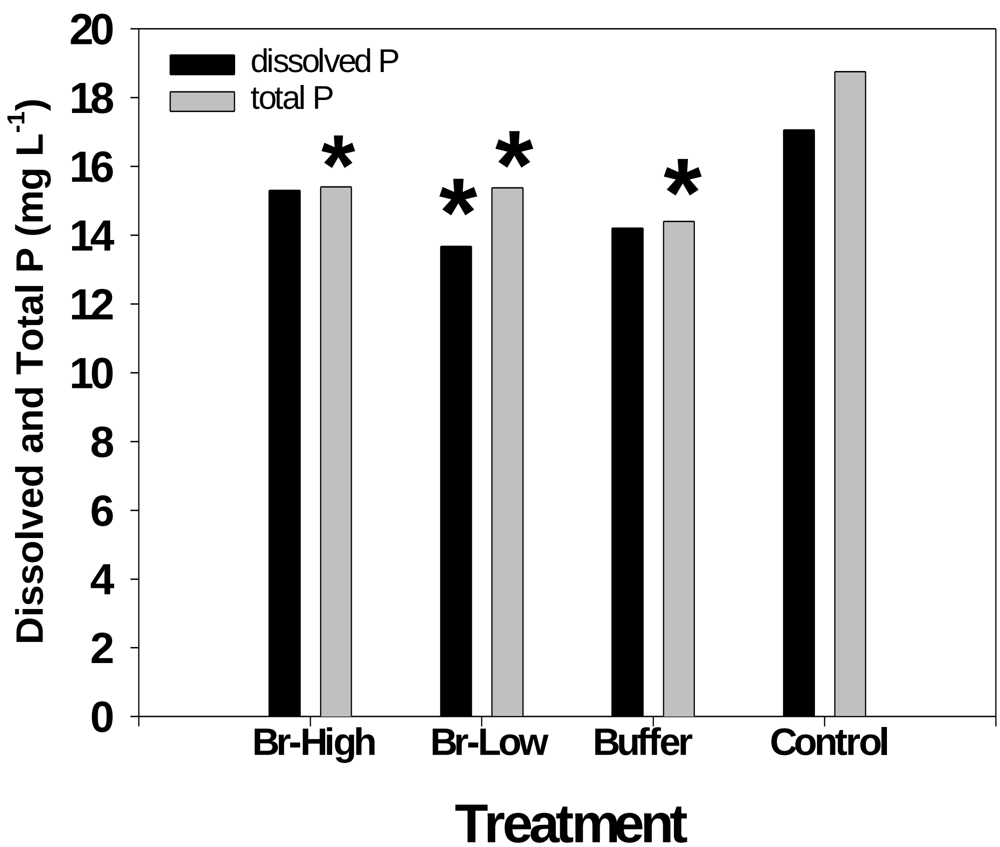

Figure 7. Soluble and total P in runoff water from plots treated with poultry litter in the LeFlore county experiment. Treatments are broadcast high application (Br-High, 44.8 Mg ha -1 or 72.6 kg plot -1), broadcast low application (Br-Low, 18.5 Mg ha -1 or 18.2 kg plot -1, buffer strip (Buffer, 44.8 Mg ha -1 or 18.2 kg plot -1), and control.

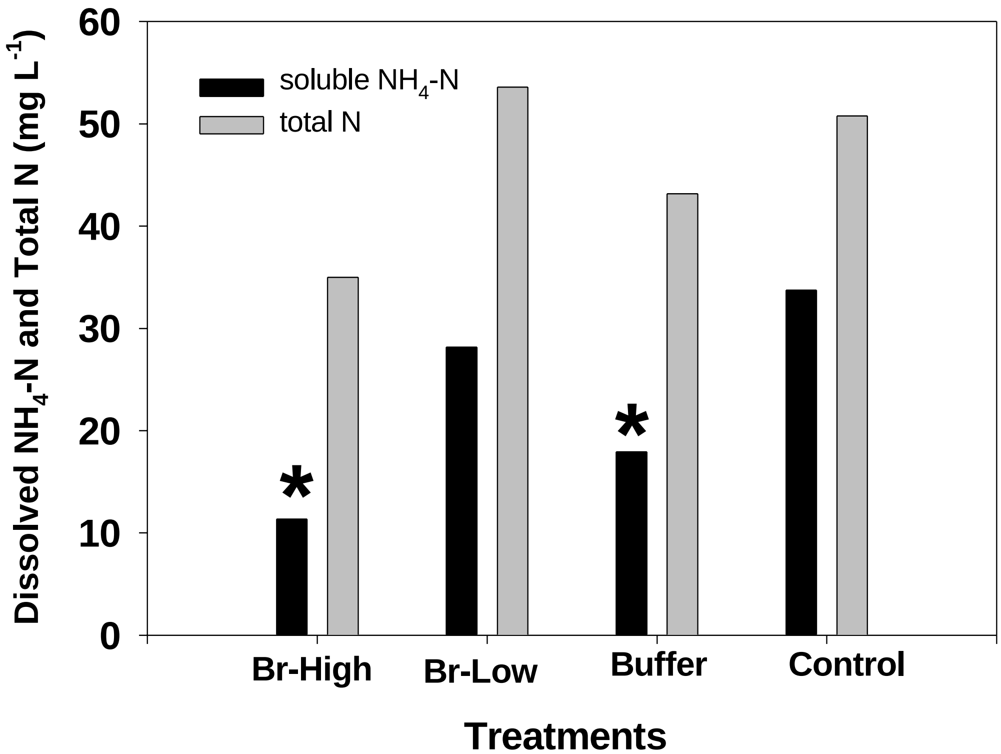

Figure 8. Total N and soluble NH_4 in runoff water from plots treated with poultry litter in the Adair county experiment. Treatments are broadcast high application (Br-High, 44.8 Mg ha -1 or 72.6 kg plot -1), broadcast low application (Br-Low, 18.5 Mg ha -1 or 18.2 kg plot -1, buffer strip (Buffer, 44.8 Mg ha -1 or 18.2 kg plot -1), and control.

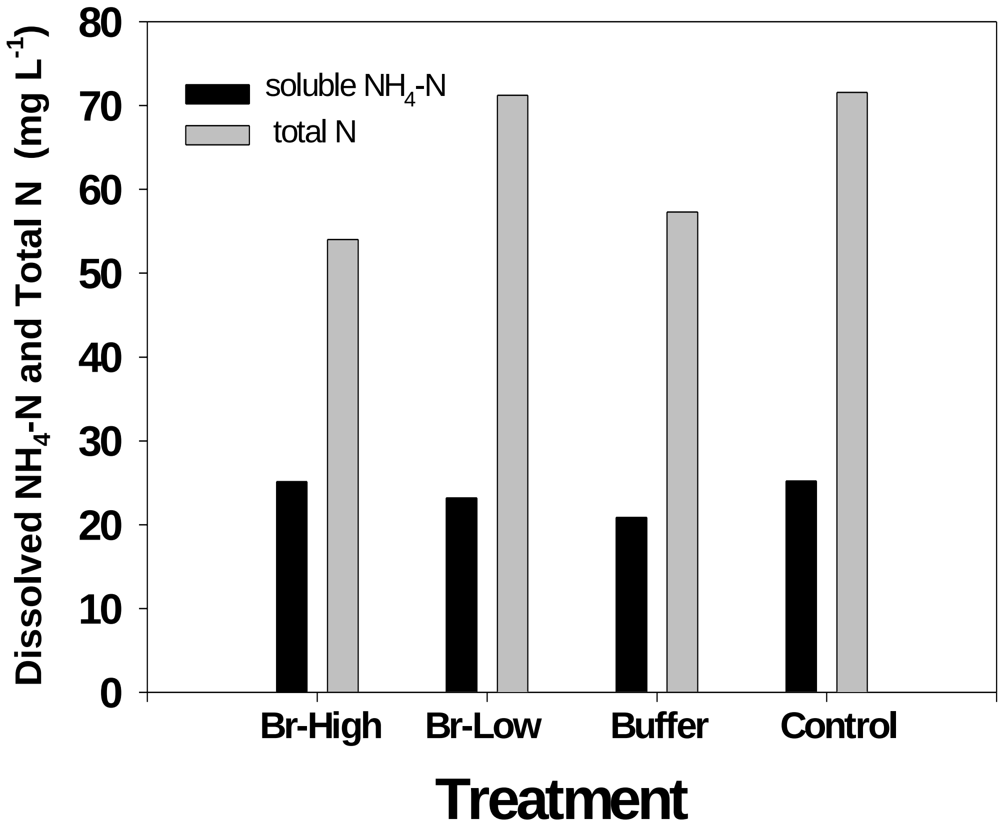

Figure 9. Total N and soluble NH_4 in runoff water from plots treated with poultry litter in the LeFlore county experiment. Treatments are broadcast high application (Br-High, 44.8 Mg ha -1 or 72.6 kg plot -1), broadcast low application (Br-Low, 18.5 Mg ha -1 or 18.2 kg plot -1, buffer strip (Buffer, 44.8 Mg ha -1 or 18.2 kg plot -1), and control.

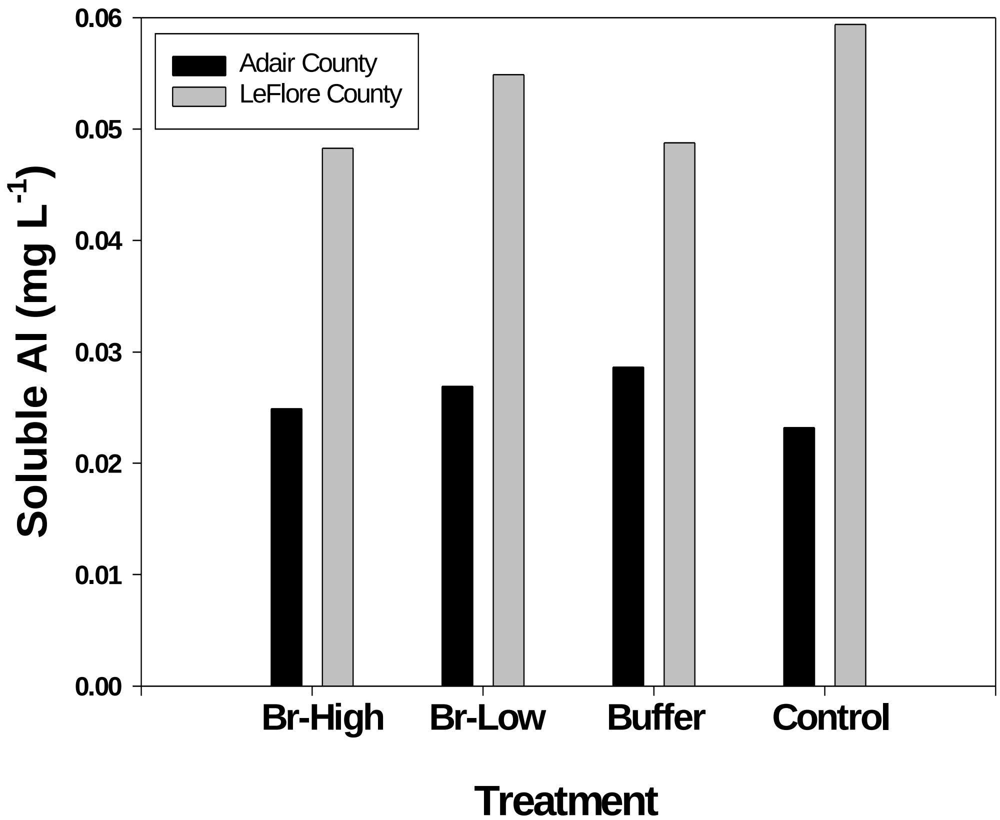

Figure 10. Soluble Al in runoff water from plots in the Adair and LeFlore county experiments. Treatments are broadcast high application (Br-High, 44.8 Mg ha -1 or 72.6 kg plot -1), broadcast low application (Br-Low, 18.5 Mg ha -1 or 18.2 kg plot -1, buffer strip (Buffer, 44.8 Mg ha -1 or 18.2 kg plot -1), and control.

APPENDIX A
Laboratory Results: Evaluating the Properties of Biosolids

SUMMARY

Poultry and swine production has created both economic growth in Oklahoma and concern over the effect of excessive land application of animal manure on water quality. The objectives of this study were to evaluate the ability of municipal and industrial wastes to reduce excessive amounts of bioavailable P in soil and to determine potential environmental impacts from these waste treatments. The ability of two drinking water treatment alum hydrosolids (HS1, HS2), cement kiln dust (CKD), and treated bauxite red mud (RM) to reduce bioavailable P in soil was evaluated in a laboratory incubation study. Two soils that contained 553 and 296 mg kg-1 Mehlich III extractable P, as a result of prior treatment with poultry litter or dairy manure, were mixed with amendments at the rate of 30 and 100 g kg-1 soil and incubated at 25°C for 9 weeks. Reductions in Mehlich III extractable P from 553 mg kg-1 to 250 mg kg-1 followed the trend HS2, CKD ³ HS1 ³ RM in the slightly acidic Dickson soil. Reductions in Mehlich III extractable P from 296 mg kg-1 to 110 mg kg-1 followed the trend HS2 > HS1 > RM > CKD in the calcareous Keokuk soil. Reduction of soluble P followed similar trends. In general, increasing amendment rates from 30 to 100 g kg-1 decreased Mehlich III P and soluble P. Most treatments did not result in excessive soil pH or increases in soil salinity, in extractable Al, or in heavy metals in soils. Alum hydrosolid is currently being landfilled at great expense to municipalities. Application of alum hydrosolids to soils with excessive amounts of bioavailable P in sensitive watersheds may improve drinking water quality and provide financial savings for municipalities.

INTRODUCTION

Growing poultry and swine production has contributed to an increase in economic growth for Oklahoma agriculture (Sharpley et al., 1991). Along with economic benefits, producers are faced with disposal of large amounts of animal manure generated from poultry and swine production. Land application of animal manure increases soil available P and has raised concerns about P runoff from agricultural land (Field et al., 1985; Reddy et al., 1980; Sharpley et al., 1991; Singh and Jones, 1976).

Recent benchmark Conservation Practice Standard and Waste Utilization guidelines set by the Oklahoma Natural Resource Conservation Service (NRCS) limit animal manure applications to soils with excessive amounts of Mehlich III (M3) P (NRCS, 1994). These guidelines were designed to determine the application rate of animal manure beneficial to soils in sensitive watersheds. Application rate is based on soil test P determination by M3 extraction, field slope, soil depth, soil erodibility, flood plain, and other factors that minimize non point source (NPS) P pollution.

Recently, U.S. EPA Region VI promulgated Concentrated Animal Feeding Operation (CAFO) regulations and the Oklahoma Feed Yard Act have utilized Oklahoma NRCS guidelines that limit application of animal manures to P-sensitive watersheds. These guidelines limit animal manure applications to land with excessive amounts of available

P. Reduction of bioavailable P in soils that exceed CAFO levels would reduce the NPS threat to sensitive watersheds. Land application of nonhazardous waste materials that reduce P solubility may be a feasible approach to reduce bioavailable P in soils.

Soluble forms of phosphorus are readily adsorbed and precipitated by soil or sediment components that contain aluminum, iron, and calcium (Hsu, 1964; Hsu, 1976). Iron and aluminum oxides (hydrous oxides) strongly adsorb and precipitate P from solution in natural water and soil systems (Stumm and Morgan, 1981; Tisdale et al., 1985). Calcium reacts with soluble P to form insoluble phosphorus compounds (Lindsay, 1979).

Alum sludge, or alum hydrosolid, is a waste by-product generated from drinking water pretreatment. Alum hydrosolids contain aluminum oxides capable of adsorbing and precipitating soluble phosphorus. Alum hydrosolids were investigated as a soil amendment to improve the physical properties of potting media and plant growth by Bugbee and Frink (1985). Alum hydrosolids improved water-holding capacity and served as a liming material, but higher application rates of alum hydrosolids caused severe P deficiency and decreased lettuce yield (Bugbee and Frink, 1985). Alum hydrosolid additions to soil improved soil structure and plant growth, but high application rates (>2 MT ha-1) induced P deficiencies and reduced corn yields (Rengasamy et al., 1980). Land application of alum hydrosolids have induced similar P deficiencies in other studies (Heil and Barbarick, 1989). The ability of commercial alum to reduce P solubility in poultry litter (Moore and Miller, 1994) and reduce soluble P in field runoff water (Shreve at al., 1995) has recently been reported. Acidity derived from alum is neutralized by ammonia from poultry litter resulting in production of amorphous aluminum oxides in alum-treated poultry litter (Moore et al., 1995). Similarly, Al in alum hydrosolids from water treatment plants exists as insoluble aluminum oxides. Untreated alum (aluminum sulfate) is a very soluble salt that releases toxic aluminum and produces acidity when dissolved in water. Land application of alum may result in undesirable soil acidification and phytotoxic levels of Al3+. However, alum-treated litter or alum hydrosolids have neutral or alkaline pH and Al exists as insoluble aluminum oxides which should not release toxic aluminum or produce acidity in soil or aqueous systems.

Bauxite red mud, which contains large amounts of aluminum and iron oxides and calcium, is a waste product of the aluminum industry (Shiao and Akashi, 1977). Shannon and Verghese (1976) suggested that bauxite red mud could be economically used as a phosphorus removal amendment by precipitation. After treatment with acids, bauxite red mud is an effective adsorbent for the removal of P (Barrow, 1982; Shiao and Akashi, 1977; and Weaver and Ritchie, 1987). However, bauxite red mud has undesirable properties. Bauxite red mud contains lye and has a high pH (9-12), large electrical conductivity (60-350 dS m-1), and large amounts of soluble sodium (9 meq 100g-1) and aluminate. Bauxite red mud is corrosive and is classified as a hazardous waste (Thompson, 1987). Land application of bauxite red mud results in saline and alkaline conditions and poor soil physical structure (Wong and Ho, 1991). These undesirable properties have prevented use of bauxite red mud in natural water and soil systems (Vachon et al., 1994). Most studies have focused on reclamation of soils rendered infertile by bauxite red mud (Thompson, 1987). In a study by Vlahos et al. (1989) on the effects of P reduction on sandy soils, bauxite red mud was found to be an extremely effective material in removal of total P in leachate after application of superphosphate fertilizer. Water retention, pH, calcium, and total soluble salt increased after application of the bauxite red mud amendment to soil.

The ability of calcium to "fix" phosphorus into relatively insoluble forms is well known (Ford, 1933). Calcium reacts with soluble P to form insoluble calcium phosphates in soils at moderate to high pH (pH >6). Reagent-grade CaO and $Ca(OH)2$ were the best amendments in reducing soluble P in chicken litter (Moore and Miller, 1994). Cement kiln dust (CKD) is a waste product generated during production of cement. Cement kiln dust is rich in calcium and potassium oxides.

Land application of nonhazardous waste materials has the potential to reduce excessive amounts of bioavailable P in soil but more information is needed. Waste materials that contain hydrous oxides (e.g., alum sludge, bauxite red mud) or calcium (cement kiln dust) are readily available. Additional information is needed to assess the ability of waste amendments to reduce bioavailable P and not cause any potential adverse environmental impacts. The objectives of this study were (1) to evaluate the ability of two drinking water treatment alum hydrosolids, cement kiln dust, and treated bauxite red mud to reduce bioavailable P in soils, and (2) to determine potential environmental impacts including excessive pH, salinity, available Al, and heavy metal availability associated with application of these waste materials to soil.

MATERIALS AND METHODS

Amendments

The effect of soil amendments to reduce bioavailable P was evaluated in a laboratory incubation study. Four amendments used in this study were two alum hydrosolids (HS1, HS2) collected from two water treatment facilities, cement kiln dust, and treated bauxite red mud. Both alum hydrosolid materials were alum sludges. Untreated bauxite red mud (21 kg) was treated with gypsum (4.1 kg) and leached with deionized water to remove excess lye and sodium before analysis and use in this incubation study.

All amendments were analyzed for pH, salinity, calcium carbonate equivalent (CCE), total metal content, and extractable heavy metals by U.S. Environmental Protection Agency Toxicity Characteristic Leaching Procedure (TCLP; U.S. EPA, 1990).

Amendment pH was analyzed in 1:2 amendment:0.01 M $CaCl2$ solution using a glass electrode (McLean, 1982). Electrical conductivity (EC) of each amendment was analyzed in 1:2 amendment:deionized water solution (Rhoades, 1982). Calcium carbonate equivalent (CCE) was determined by reaction with HCl and backtitration as described by Rund (1984).

Total metal content of amendments was determined by wet digestion with HNO3 and HClO4 (Burau, 1982) and subsequent determination of Al, Ca, Cd, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, and Zn by inductively coupled plasma atomic emission spectroscopy (ICP). Metals were extracted from amendments according to the U.S. EPA TCLP method (U.S. EPA, 1990). The samples were filtered using 0.45 mm membrane filters and analyzed by ICP instrumentation for Ba, Cd, Cu, Mo, Ni, Pb, and Zn.

Soils

Two soils with a history of animal manure application and contained large amounts of M3 P were selected for the incubation study. Surface (<10 cm) soil samples were collected, air dried, and sieved (<2 mm). Mehlich III extractable P levels were 553 and 296 mg P kg-1 soil and soil pH were 5.3 and 8.2 for Dickson silt loam (fine-silty, siliceous, Thermic Glossic Fragiudult) and Keokuk very fine sandy loam (coarse-silty, mixed, Thermic Fluventic Haplustoll), respectively. The Dickson soil received >10 years of poultry litter and the Keokuk soil received >10 years of dairy manure.

Cation exchange capacity of the soils was determined by using BaCl2 as described by Rhoades (1982). The citrate-bicarbonate-dithionite procedure described by Olsen and Ellis (1982) was used to measure free iron oxides. A modified Mebius method was used to determine the soil organic carbon content of each soil (Yeomans and Bremner, 1988).

Soils were incubated with amendments in a growth chamber for a nine week period. Incubation temperature was 26°C during the day (16 h) and 24°C during the night (8 h). The incubator was maintained at approximately 60% humidity. Soil (250 g) was mixed with amendment rates of 30 g kg-1 and 100 g kg-1 in plastic pots. The experimental design was a completely randomized block with three replications and controls (no amendment) for each soil. Soils were maintained at field capacity (-0.3 bar) moisture content. Triumph 64 wheat (Triticum spp.) was planted on the amended soils as a qualitative indicator of potential impact of amendments on crop growth.

The ability of amendments to reduce plant available P was determined by measuring phosphorus extracted by the Mehlich III procedure from amended soils at 3, 5, and 9 weeks of incubation (Mehlich, 1984). Soils were sampled by thoroughly mixing the entire volume of treated soil and removing a subsample (10 g). Twenty milliliters of M3 extractant was added to 2 g of soil from each sample and placed on a rotary shaker for 5 min. The samples were then filtered using Whatman #2 filter paper. Phosphorus extracted by the M3 P procedure was measured by the Modified Murphy-Riley method (Murphy and Riley, 1962). Soluble P in amended soils was determined after 9 weeks of incubation. Ten milliliters of 0.01 M CaCl2 was added to soil (5 g) and placed on a shaker for 15 h. The Modified Murphy-Riley method was used to analyze soluble P in filtered soil solution. Extractable aluminum was determined using potassium chloride (KCl) extraction (Barnhisel and Bertsch, 1982). Aluminum in KCl extracts was measured by ICP.

Treatment effects on measured parameters were evaluated by using multiple comparison of means by Duncan's Multiple Range Test (Steele and Torrie, 1980). Statistical analysis of data was performed using appropriate procedures given by the SAS Institute (SAS, 1988).

RESULTS AND DISCUSSION

Reduction of Bioavailable P

The greatest changes in Mehlich III (M3) P and pH occurred in the first three weeks of incubation for the Dickson (Fig. 1) and Keokuk soils (data not shown). Chemical reactions between the soils and amendments were assumed to be essentially complete after nine weeks of incubation. Therefore, only results after nine weeks of incubation will be presented.

Both soils showed significant ($P < 0.05$) decreases in M3 P for all amendment treatments after nine weeks of incubation (Fig. 2). Reduction of M3 P followed the trend HS2, CKD ^{3} HS1 ^{3} RM for the slightly acidic Dickson soil. A different trend for the calcareous Keokuk soil was found: HS2 > HS1 > RM > CKD. The alum hydrosolids followed the same general trend in both the slightly acidic and the calcareous soils: HS2 ^{3} HS1. Greater reduction of M3 P by alum hydrosolids than CKD or RM is likely due to highly reactive amorphous Al oxides (Elliott et al., 1988; Young et al., 1988). Because drinking water treatment may involve adjustment of water pH with liming materials, some alum hydrosolids may contain significant amounts of calcium. The larger total calcium in HS2 compared to HS1 (Table 2) suggests larger reductions in M3 P may be partly due to formation of calcium precipitates. The ability of CKD to reduce P in the calcareous soil is significantly less than P reductions in slightly acidic soil. Although CKD does not contain large amounts of aluminum oxides it does contain significant amounts of calcium (Table 2). Large amounts of calcium in CKD may reduce P bioavailability in soil by forming Ca-P precipitates. The ability of CKD to reduce bioavailable P in the calcareous soil was significantly less than in the slightly acidic soil. These differences may be related to relative contribution of CKD to changes in soil pH of the treated soils (Table 2). Treatment of soil with CKD may have resulted in formation of greater amounts of Ca-P precipitates in the Dickson soil than in the Keokuk soil. In general, increasing rates of all amendments from 30 to 100 g kg-1 decreased soil M3 P.

None of the amendments reduced the M3 P to <200 mg kg-1, the severe non point source (NPS) P pollution level guideline of the Oklahoma Natural Resource Conservation Service (NRCS, 1994), in the Dickson soil. However, the HS2 100 g kg-1 rate lowered the M3 P from 553 to 250 mg kg-1 in the Dickson soil. In the Keokuk soil, the HS1, HS2, and RM 100 g kg-1 rate lowered the M3 P from 296 to <200 mg kg-1. The addition of these amendments should decrease the NPS runoff threat of bioavailable phosphorus in soil to sensitive surface waters.

The M3 P procedure extracts both readily soluble and insoluble P minerals that may not be immediately bioavailable in aquatic environments (Fixen and Grove, 1990).

Although M3 P is related to potential P availability and Oklahoma NRCS guidelines are based on M3 P, soluble P may be a better environmental indicator of bioavailability and impact on aquatic life. All amendments reduced soluble P in soils (Fig. 2). Reduction of soluble P in Dickson and Keokuk soils followed the trend HS2 ^{3} HS1 > CKD, RM. Soluble P reduction was similar to M3 P reduction results. A greater reduction in soluble P was found in the slightly acidic Dickson soil than in the calcareous Keokuk soil. Similar to M3 P reduction, increasing the amendment rates from 30 to 100 g kg-1 reduced soluble P in all treatments except for HS2 in the Keokuk soil.

Potential Environmental Impact

Soil pH, salinity (EC), extractable aluminum, and heavy metal content and extractability were determined in amendments and soils to ensure the addition of amendments to soil did not result in undesirable potential environmental impacts.

The Triumph 64 wheat (Triticum spp.) that was planted in the treated soils as a qualitative indicator showed no indications of nutrient problems unlike other studies which found P deficiencies in sorghum-sudangrass (Heil and Barbarick, 1989), in lettuce (Bugbee and Frink, 1985), and in tomatoes (Elliott and Singer, 1988; Elliott et al., 1990; Young et al., 1988) induced by alum sludge. Plant available P in the Dickson and Keokuk soils treated with alum hydrosolids were well above P requirements for wheat production (Allen and Johnson, 1993).

The slightly acidic Dickson soil showed significant increases in pH from 5.7 to 8.0 after the addition of CKD at the 100 g kg-1 rate (Fig. 3). Cement kiln dust, a known liming material, can easily increase soil pH >7.0 (Gelderman et al., 1992). In general, increasing the amendment rate from 30 to 100 g kg-1 significantly increased pH for all amendments in the Dickson soil. Amendments had little effect on soil pH in the Keokuk soil. Final pH <8.3 of all treated soils is not considered excessive and is not typically associated with potential environmental hazards.

Several amendments (CKD, RM) have significant amounts of soluble salts (Table 1) and might increase soil salinity. The alum hydrosolids did not increase soil salinity (Fig. 3). However, 100 g kg-1 rates of CKD and RM resulted in small but significant ($P < 0.05$) changes in EC that may affect salt-sensitive plants (Rhoades and Miyamito, 1990).

The effect of alum hydrosolids and other amendments on extractable aluminum in soil is shown in Fig. 3. None of the amendments significantly increased extractable Al in the Dickson soil. Only the 100 g kg-1 rate of HS1 showed a significant increase in extractable Al in the Keokuk soil. Amendments did not increase extractable aluminum in incubated soils >5 mg Al kg-1. Adverse affects are associated with much higher levels of extractable Al (>60 mg Al kg-1) for wheat (Sloan et al., 1995). Therefore, slight increases in available aluminum from application of amendments should not have adverse effects on soils or plants.

Total metal and TCLP extractable metal of the amendments are presented in Table 3. With the exception of total Cd in CKD and total Cd and Pb in RM, all amendment total metal contents were within the range of typical soil total metal contents. Alum hydrosolid heavy metal contents were similar to those reported in other water treatment sludges (Elliott et al., 1990). Alum hydrosolids used in this study do not contain elevated levels of Ni which have been reported for ferric coagulant water-treatment sludges from steel pickling or bauxite extraction wastes (Elliott et al., 1990; Heil and Barbarick, 1989). Therefore, land application of alum hydrosolids should not increase heavy metal concentration in soil. Heavy metals extracted by TCLP were below U.S. EPA regulatory levels and showed the amendments are not hazardous wastes. Comparison of TCLP and total metal values show most heavy metal is not in bioavailable forms (Table 3). Amendment TCLP levels were similar to heavy metals determined by TCLP in typical baseline soils (Scott, 1994). Therefore, land application of alum hydrosolids should not increase heavy metal availability in soil. Similarly, Elliott et al. (1990) found most heavy metals in alum hydrosolids were strongly bound by aluminum and iron oxides in forms that do not have potential adverse environmental impacts.

CONCLUSIONS

The addition of alum hydrosolids, cement kiln dust, and treated bauxite red mud reduce excessive amounts of bioavailable P in soil. Increasing the rate of amendment will, in most cases, decrease the amount of bioavailable P. Adverse potential environmental impacts from salinity, pH, aluminum, and total and extractable metals on application of these municipal and industrial amendments should be insignificant. Most soil treatments did not result in excessive soil pH or increased soil salinity. However, high rates of cement kiln dust and bauxite red mud may increase soil salinity in the amended soil, which may affect salt-sensitive crops. Alum hydrosolid applications had little or no effect on extractable Al in soil. Land application of alum hydrosolids used in this study should not increase content or availability of heavy metals in soils. Alum hydrosolid wastes are currently being landfilled at great expense to municipalities. Also, several municipal water- treatment plants producing alum hydrosolids in Oklahoma may have source water degraded by non point source P pollution. Alum hydrosolid application to soils in sensitive watersheds that have soils with excessive amounts of bioavailable P has the potential to improve drinking water quality and provide financial savings for municipalities.

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Table 1. Soil chemical properties and characteristics

Parameter	Soil: Dickson	Soil: Keokuk
Soil texture	silt loam	sandy loam
Mehlich III P (mg kg^{-1})	553.	296.
Soluble P (mg kg^{-1})	13.5	4.1
pH	5.3	8.0
Electrical conductivity (dS m^{-1})	0.18	0.37
Cation exchange capacity ($cmol_c$ kg^{-1})	9.3	13.7
Free iron oxides (g Fe kg^{-1})	0.15	0.10
Soil organic C (g kg^{-1})	17.2	13.1

Table 2. Chemical properties and total metal content of amendments.

Property	HS1	HS2	CKD	RM	
	Amendments †				
pH	7.0	7.6	12.6	8.1	
EC‡	0.31	0.58	17.8	2.63	
CCE§	1.87	14.8	87.5	24.2	

Total Metal	HS1	HS2	CKD	RM	Normal metal content in soil¶
	g kg^{-1}				
Al	141	147	17.6	111	11-79
Ca	2.1	21.9	205	65.0	1-18
Fe	35.8	29.6	-	209	0.7-56
K	0.79	1.2	-	-	0.8-33
Mg	3.26	7.2	7.2	0.79	0.6-12
Mn	11.0	0.82	0.13	0.03	0-4
Na	0.09	0.38	1.65	9.25	0.7-22

† HS1 = hydrosolids 1; HS2 = hydrosolid 2;
CKD = cement kiln dust; RM = bauxite red mud.

‡ Electrical conductivity (dS m^{-1})

§ Calcium carbonate equivalent expressed in percent

¶ From Isaac and Kerber, 1971

Table 3. Toxicity characteristic leaching procedure (TCLP) extractable and total heavy metal content of amendments.

Total Metal	Amendments† HS1	HS2	CKD	RM	Normal metal content in soil‡
	---- mg kg^{-1} ----				
Cd	0.57	0.93	2.98	6.61	0.01-1.3
Cu	24.8	37.9	7.48	27.3	1.4-216
Mo	0.12	0.25	0.70	0.53	0-40
Ni	26.6	28.5	14.4	10.0	2.2-154
Pb	14.0	15.9	29.7	56.4	3.0-36
Zn	86.1	80.7	36.8	56.1	3.2-170
TCLP					**EPA Regulatory Limit§**
	---- mg L^{-1} ----				
Ba	1.17	0.83	0.20	0.02	100
Cd	0.03	0.03	0.03	0.03	1.0
Cu	0.03	0.02	0.03	0.03	-
Mo	0.06	0.05	0.08	0.03	-
Ni	0.06	0.03	0.08	0.40	-
Pb	0.08	0.08	0.16	0.16	5.0
Zn	0.07	0.08	0.13	0.40	-

† HS1 = hydrosolids 1; HS2 = hydrosolid 2; CKD = cement kiln dust; RM = bauxite red mud.

‡ Cd, Cu, Ni, Pb, Zn from Holgrem et al., 1993 (1st to 99th percentile); Mo from Alloway, 1990.

§ Regulatory limit specified by U.S. EPA SW-846 Method 1311.

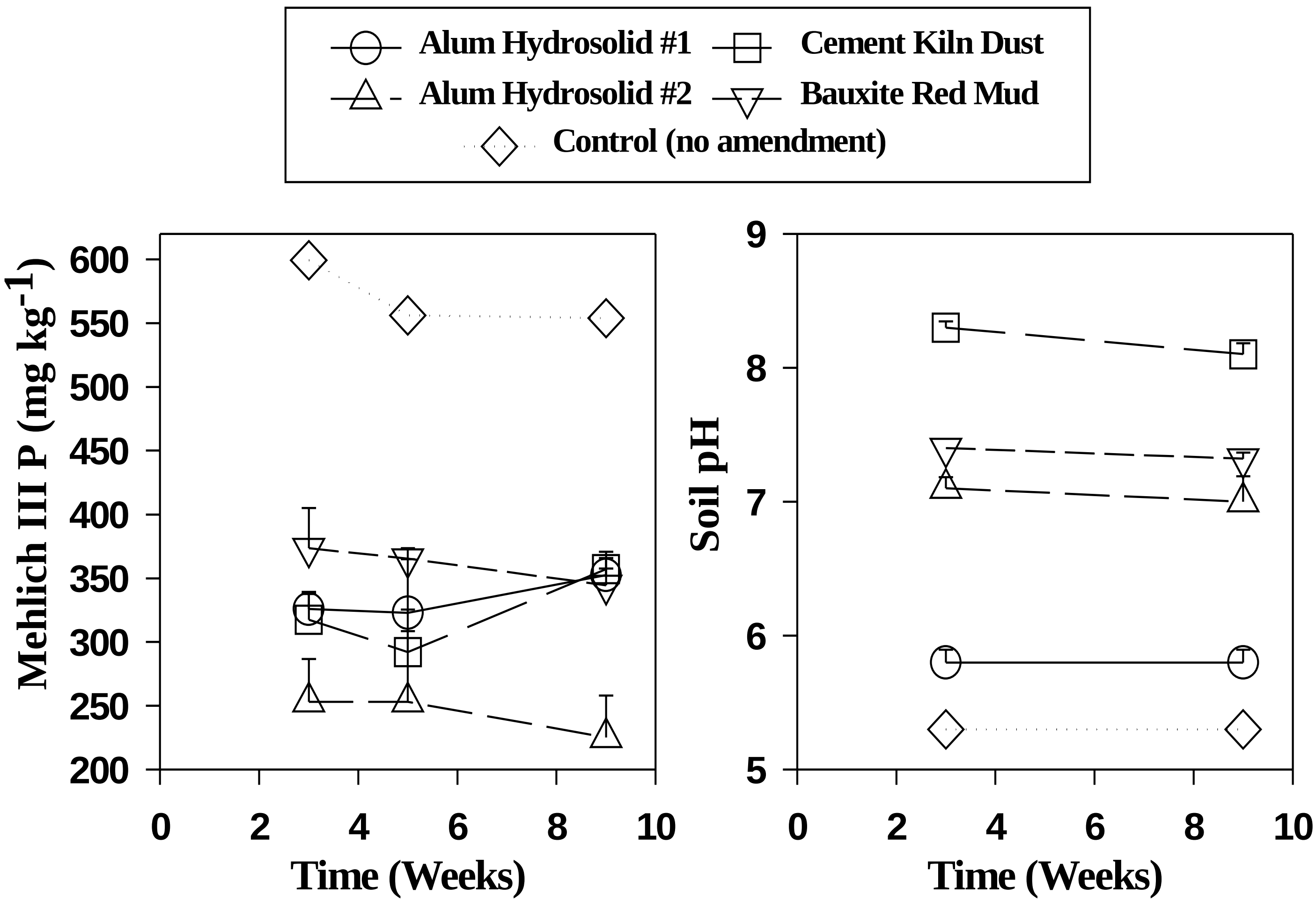

Figure 1. Effect of amendments on Mehlich III extractable P and soil pH treatment means with time in the Dickson soil.

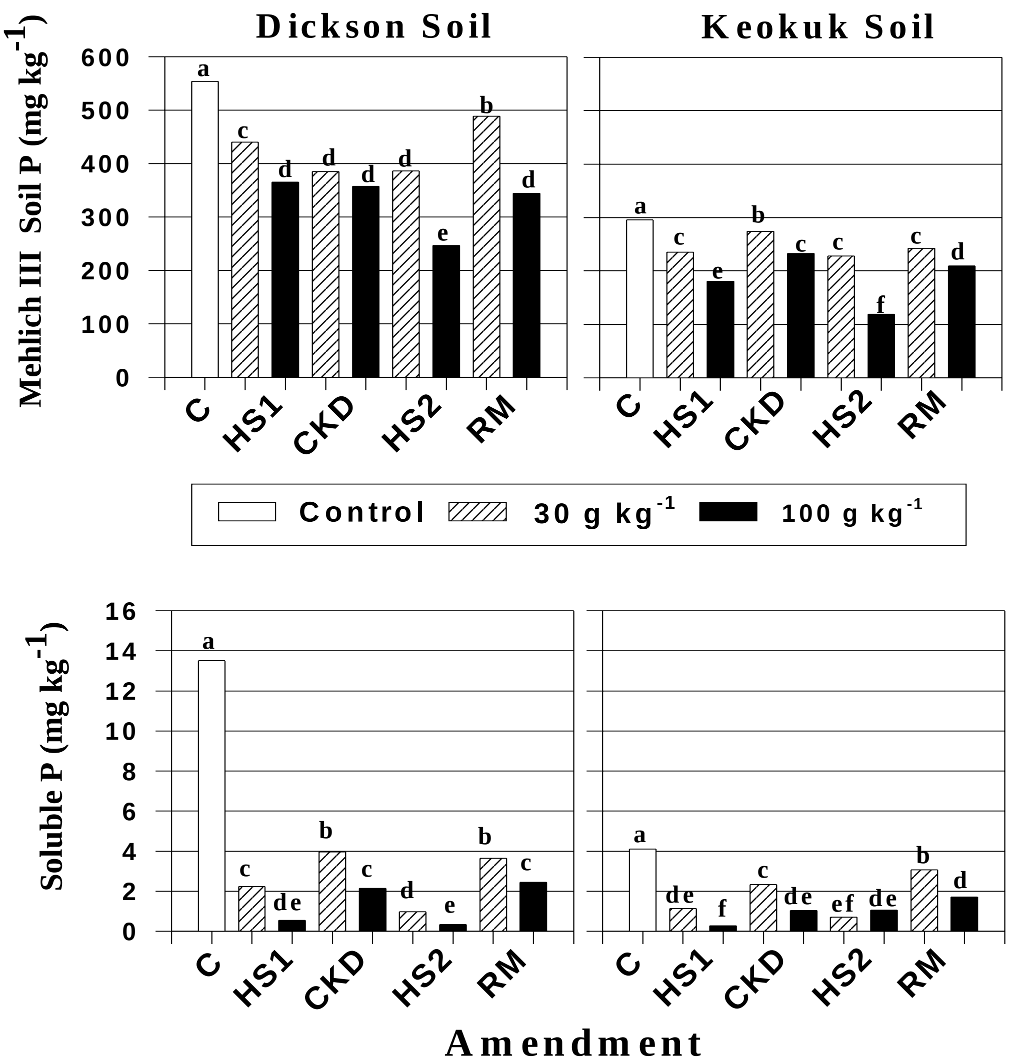

Figure 2. Mehlich III extractable P and 0.01 M CaCl2-soluble P in amended soils after 9 weeks of incubation. Columns with the same letter are not different at $P < 0.05$ within each soil. C = control; HS1 = alum hydrosolids #1; CKD = cement kiln dust; HS2 = alum hydrosolid #2; RM = bauxite red mud.

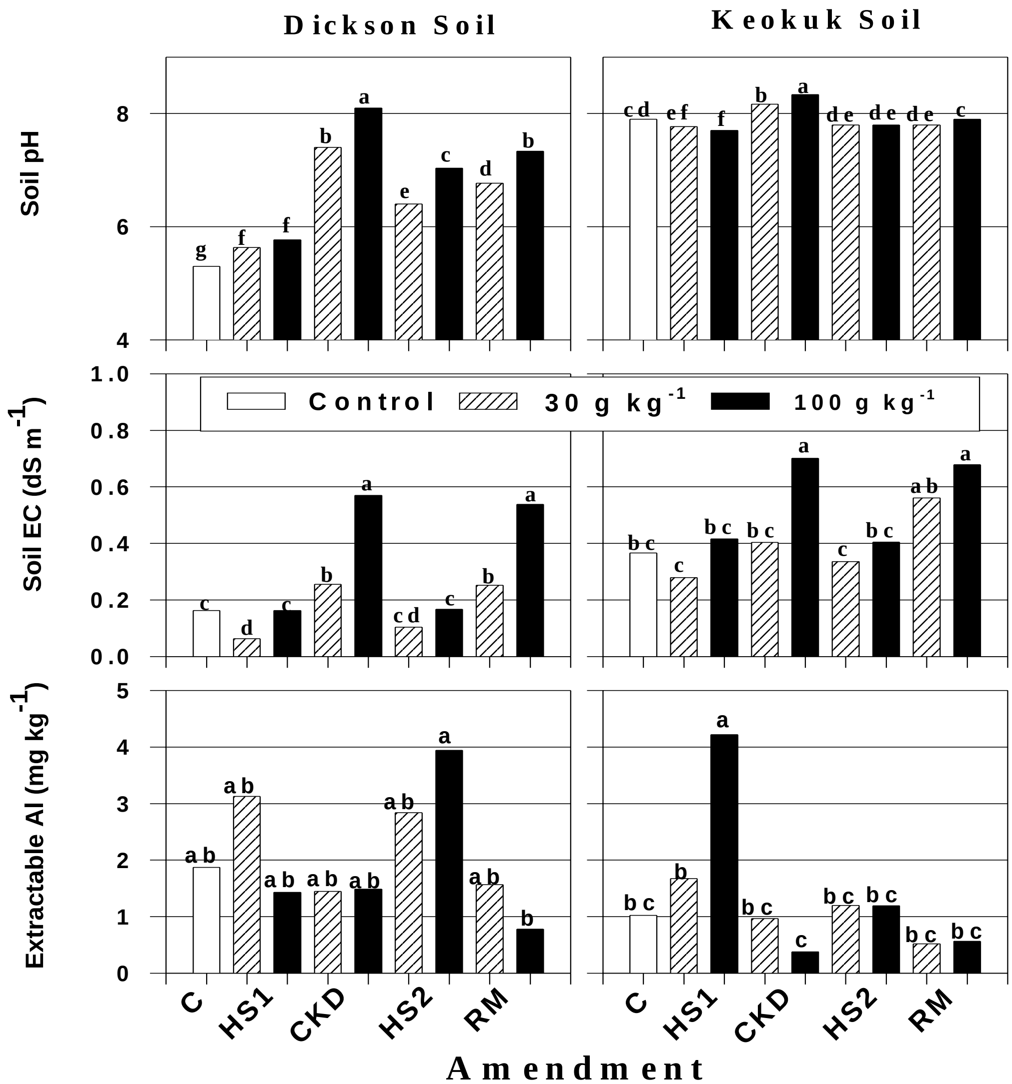

Figure 3. Effects of amendments on soil pH, soil EC, and KCl-extractable aluminum in amended soils after 9 weeks of incubation. Columns with the same letter are not different at P < 0.05 within each soil. C = control; HS1 = alum hydrosolids #1; CKD = cement kiln dust; HS2 = alum hydrosolid #2; RM = bauxite red mud.

APPENDIX B
Greenhouse Results: Application of Water Treatment Residuals

SUMMARY

Phosphorus losses in runoff water from land receiving surface application of poultry litter is becoming a non-point source (NPS) problem to sensitive watersheds and may result in eutrophication of surface waters. The beneficial use of two drinking water treatment alum sludges (hydrosolids) to reduce P in runoff water from land treated with poultry litter was evaluated. Poultry litter (6.5 Mg ha^{-1}) was applied to box plots containing fescue (*Festuca arundinacea*) to simulate permanent pasture typical of the Southeastern U.S. Hydrosolid treatments were a completely randomized design with three replications. Treatments included two types of hydrosolids (HS1, HS2) with broadcast and buffer strip application methods. Simulated rainfall from a single oscillating nozzle was applied to fescue boxes at a rate of 3.8 cm h^{-1} for 84 minutes. Concentration and total mass of soluble phosphorus (P), total P, and total aluminum (Al) in runoff samples were determined. Hydrosolid application significantly reduced the concentration and total mass of soluble P and total P in runoff water ($P < 0.05$). Only slight or no increases in total Al concentration and mass in runoff water was found. The buffer strip application appears to be more effective than the broadcast application in reducing the concentration (Table 2) and mass (Table 3) of cumulative soluble and total P in runoff water. Perhaps better contact between P in the runoff water and the hydrosolid particles occurred in the buffer strip than the broadcast application. Both hydrosolids reduced P similarly for the contact times of the runoff study. Crushing of hydrosolids to finer (<0.2 mm) particles will increase surface area and P adsorption capacity, thus increasing the ability of the hydrosolids to reduce P in runoff water. Land application of hydrosolids may provide a safe and inexpensive solution to control phosphorus runoff from agricultural land. Hydrosolid application to agricultural land treated with animal manure in sensitive watersheds may improve drinking water quality and provide financial savings for municipalities.

INTRODUCTION

The land application of poultry litter and swine manure to agricultural lands provides an economical means of supplying beneficial nutrients to crops. However, field applications of poultry litter and swine manure at rates to meet forage nitrogen requirements normally exceeds phosphorus (P) crop requirements and results in excessive levels of soil P (Shreve et al., 1995). Phosphorus losses in runoff water from land receiving surface application of poultry litter is becoming a non-point source (NPS) problem to sensitive watersheds (Edwards and Daniel, 1993; Sharpley and Menzel, 1987) and may result in eutrophication of surface waters.

Recent benchmark Conservation Practice Standard and Waste Utilization guidelines passed by the Oklahoma Natural Resource Conservation Service (NRCS) limit animal manure applications to soils with excessive amounts of bioavailable P (NRCS, 1994). These guidelines were designed to determine the application rate of animal manure beneficial to soils in sensitive watersheds. Application rate is based on preventing excessive accumulation of P in soil. The Concentrated Animal Feeding Operations (CAFO) regulations in U.S. EPA Region VI have adopted the use of NRCS guidelines that limit application of animal manures to P sensitive watersheds. Runoff P will increase with an increase in bioavailable P in soils (Sharpley, 1992). Reduction of bioavailable P in soils that exceed CAFO levels would reduce the NPS threat to sensitive watersheds.

Land application of alum (aluminum sulfate) has long since been used to reduce lake sediment P release (Kennedy and Cooke, 1982; Knauer and Garrison, 1981; Welch et al., 1982; and Young et al., 1988). Litter amended with alum to reduce P solubility in runoff water on agricultural lands with excessive P has also been investigated (Shreve et al., 1995). They found that soluble and total P were significantly reduced. Coale et al. (1994) mixed municipal drinking water purification facility waste material (alum sludge) with soil in a column and reduced P concentration in drainage water.

Surface application of nonhazardous alum sludges (hydrosolids) that reduce P solubility through precipitation and/or adsorption reactions to agricultural lands treated with poultry litter would effectively reduce the potential for P loss in runoff. The beneficial use of two drinking water treatment hydrosolids (HS1, HS2) to reduce P in runoff water were evaluated in this study.

MATERIALS AND METHODS

Small-scale plots (fescue boxes) in a controlled greenhouse environment were used in the runoff study. Eighteen boxes which measured 1.0 meter square by 0.33 meter deep were used with a perforated bottom to hold soil and grow fescue in an effort to simulate permanent pasture typical of much of the Southeastern U.S. Boxes were constructed to determine the effects of rainfall, slope, and vegetation height on runoff water quality from fescue plots treated with poultry litter (Olson, 1995). The description of the boxes used in this study as constructed by Olson is as follows.

The fescue (*Festuca arundinacea*) boxes were constructed from a supporting frame of heavy angle iron with treated plywood attached as the sides of the box. Four steel rods provided the support for the bottom of the box. The steel rods also supported a section of expanded metal (4.76 mm) on which a piece of fine mesh polyethylene screening was then attached. The boxes were filled to a depth of 5 cm with a gravel/sand mixture (Fig. 1). The gravel/sand layer was covered with 2.5 cm of coarse sand. The remaining volume was filled with a Baxter silt loam (clayey, mixed, mesic, Typic Paleudult) from Delaware County, Oklahoma. The plywood side on the front of the box was cut 2.5 cm lower than the other three sides so runoff could leave the plot. A flume made of galvanized metal was attached to the lower side to direct runoff. To make the fescue boxes retrievable, four 10 cm X 10 cm wooden blocks were bolted on the bottom of each box at the corners to allow access by a floor dolly and forklift.

The fescue used in this study was maintained by watering with a soaker hose. One day prior to the rainfall event, the fescue was trimmed to 7.6 cm to simulate typical field conditions for poultry litter application. Poultry litter was applied by hand to the box surface with special attention devoted to the uniformity of application. One application rate of 6.5 Mg ha^{-1} was used in this experiment.

The experimental design was a completely randomized design with three replications. Two types of hydrosolids (HS1 and HS2) were investigated. Both hydrosolids were alum sludges from municipal drinking water treatment plants and are described in Chapter 1 of this thesis. Due to lack of uniformity in hydrosolid size, both hydrosolids were crushed to <6 mm size. Hydrosolids were applied to box plots by broadcasting or as a buffer strip (Fig. 2). The buffer strip was approximately 7.6 cm from the runoff flume and 10.2 cm wide. Broadcast amendments were applied generously across the box starting 7.6 cm from the runoff flume being careful to give equal application over the fescue.

Surface residue and fescue cover measurements were conducted to show uniformity of boxes. Percent of blade, debris, and ground cover on the box surface were evaluated by using a simple point measurement system where a pointed rod was placed downward toward the soil surface. The rod was guided by a ridge frame that had 10 sets of holes. The frame was set on the box surface and rods were slowly pushed through the guides toward the soil surface. The first material that the tip of the rod touched was the measured recording for that sampling point. The three possible types of material to characterize the cover of the plots are defined as follows:

BLADE - any living green material such as a leaf or stem
DEBRIS - any nonliving material such as leaf litter
GROUND - bare uncovered soil

Once the first ten measurements were taken, the frame was rotated on the vertical axis 90° and another ten measurements were taken in the same manner. The 20 sampling points were used to determine the percentage of blade, debris, and ground.

The quantity of forage on each box before the treatments were applied was also determined by clipping all the forage from a small area of each box. The area clipped was defined by a square frame with inside dimensions measuring 10 cm X 10 cm. The square was tossed on the box surface and all of the forage that was rooted inside the frame was harvested, bagged, and oven dried at 95°C for 24 h.

Four boxes were used in a preliminary study to determine the hydrosolid amendment rate. Hydrosolid #2 (HS2) was used for the preliminary study at 5.0 Mg ha^{-1} and 10 Mg ha^{-1} rates with 6.5 Mg ha^{-1} poultry litter. Poultry litter samples were collected and analyzed for total Kjedahl nitrogen (TKN), total P (TP), and percent moisture. TKN, on a dry basis, was 55.0 g kg^{-1}, TP dry was 15.7 g kg^{-1}, and percent moisture was 215 g kg^{-1}. The hydrosolid was tested as a buffer strip and as a broadcast application. Runoff was collected and analyzed for soluble P reduction.

Hydrosolid #1 (HS1) was applied at a 15 Mg ha^{-1} rate and HS2 was applied at a 10 Mg ha^{-1} rate. It was noted after the selection of amendment rates that HS2 caused significant damming of runoff water. A 10 Mg ha^{-1} rate was later selected to allow the runoff to pass through the buffer strip. Amendment rates were determined from the preliminary study.

The rainfall simulator was constructed and described by Olson (1995). The rainfall simulator used is a modified design of the Kentucky Rainfall Simulator described by Moore et al. (1983). The rainfall simulator was designed to allow fescue boxes to tilt and accommodate different slope settings. The simulator used in this study consists of a single oscillating nozzle which travels back and forth across the fescue boxes and between two return pans. The simulator utilizes a Veejet 80100 nozzle with an operating pressure at the nozzle of 41 kPa to achieve the drop size and kinetic energy typical of natural rainfall (Meyer and Harmon, 1979).

Runoff collection was similar to that described by Olson (1995). Runoff was collected in a tank that rested on a balance with two strain gauges, one on either side. The strain gauges are electronic sensors that measure weight (in kg) of runoff in the collection tank. A data-logger recorded the strain gauge readings every 15 seconds for the duration of the storm event. This information was then downloaded to a personal computer and later summarized as a mass flow rate runoff hydrograph.

The rain simulator was electronically programmed to deliver 3.8 cm h^{-1} over an 84 minute rainfall duration (Olson, 1995). The experiment was conducted in a greenhouse where temperatures ranged from 27 to 35°C. Boxes were saturated with water and allowed to drain for 72 hours prior to simulated rainfall. Poultry litter and amendments were applied to the fescue boxes and placed in the rainfall simulator by a forklift. Boxes were tilted at a 5% slope. A plastic tarp was attached to the front of the fescue box and extended over the runoff weighing system to shield it from stray rainfall. Simulated rainfall rate was calibrated daily.

Runoff from fescue boxes was collected in a galvanized metal container. After 84 minutes of rainfall, the runoff was stirred vigorously for 2 to 3 minutes followed by collection of a 0.5 liter composite sample. Runoff samples were stored at -10°C. All chemical analysis were conducted within one week after sampling.

Soluble phosphorus (P), total P, and total aluminum (Al) in runoff samples were determined. Soluble P was measured on filtered (0.45 μm) runoff samples (Greenburg et al., 1992). Soluble P was measured by Murphy-Riley colorimetric method based on formation of phospho-molybdenum blue complex (Murphy and Riley, 1962).

Total P and total Al in unfiltered runoff samples were determined by wet digestion with HNO_3. Runoff samples (25 mL) were digested with 5 mL of HNO_3 for 1.5 h and 150°C and diluted to volume (25 mL) with distilled water. Total P was measured by the Murphy-Riley Method (1962) and total Al by inductively coupled plasma atomic emission spectroscopy (ICP) instrumentation.

RESULTS AND DISCUSSION

Uniformity of vegetation and debris distribution was determined by measuring surface coverage of blade, debris, ground, and forage density in randomly selected fescue boxes (Table 1). In general, the green living fescue (blade), the non-living fescue (debris), the uncovered soil (ground), and the forage density were similar ($P < 0.05$) and indicated vegetation was uniform among boxes.

Treatment means of cumulative runoff flow volumes were determined from hydrographs (Fig. 3). Total runoff volumes appeared larger for broadcast vs. buffer applications for HS2, but not HS1. These trends suggest that the HS2 buffer strip application may have slowed water runoff from the box plots compared to the broadcast application. However, large amounts of variation were found in runoff volumes between box plots ($LSD_{0.10} = 17.5$) making interpretation of the HS2 trend difficult.

The effects of hydrosolid application on concentration of soluble phosphorus (P), total P, and total aluminum (Al) in runoff water were determined (Table 2). Hydrosolid application significantly reduced the concentration of soluble P and total P ($P < 0.05$). In general, buffer strip applications reduced the concentration of soluble P and total P more than broadcast application ($P < 0.10$). Total Al, determined by wet digestion with HNO_3, was determined in runoff to ensure precipitated Al in the hydrosolid did not dissolve and result in undesirable potential environmental impacts. In general, only slight or no increase in total Al concentration in runoff water was found (Table 3). The largest observed Al concentration of 1.71 mg L^{-1} was well below levels of >50 mg L^{-1} associated with adverse effects of dissolved Al on plant growth (Sloan et al., 1995). Therefore, slight increases in total Al in runoff water should not result in adverse potential environmental impacts.

The effect of hydrosolid application on cumulative runoff losses of soluble P, total P, and total Al were determined (Table 3). Hydrosolid applications significantly reduced cumulative losses of soluble and total P compared to untreated plots ($P < 0.05$). Similarly, Shreve et al. (1995) found that alum amended litter, with chemical properties similar to a hydrosolid, decreased soluble and total P load in runoff from fields treated with poultry litter. However, no information is available on alum sludge (hydrosolid) and P reduction in runoff. Buffer strip application of hydrosolids significantly decreased runoff loss of soluble P and total P compared to broadcast application for HS2 ($P < 0.10$) and HS1 ($P \cong 0.10$). Cumulative runoff of total Al was not increased ($P < 0.10$) by hydrosolid application suggesting potentially adverse environmental impact from dissolved Al in runoff water is unlikely.

The buffer strip application appears to be more effective than the broadcast application in reduction of concentration (Table 2) and mass (Table 3) of cumulative soluble and total P in runoff water. Less runoff water was associated with the buffer strip compared to the broadcast application for HS2 (Fig. 3) suggesting buffer strip application may have resulted in greater infiltration of water in the plots. However, little difference in runoff water volumes between buffer strip and broadcast applications were found for HS1 (Fig. 3). Most of the runoff water passed through the buffer strips on the box plots (Fig. 2). Perhaps better contact between P in the runoff water and the hydrosolid particles occurred in the buffer strip than the broadcast application.

In Chapter 1, results from soil incubated with hydrosolids for nine weeks showed HS2 reduced greater amounts of soluble P than HS1. Evidently the HS2 contained more calcium than HS1 and may have resulted in greater amounts of calcium phosphate precipitation. A batch equilibration study where 150 mg L^{-1} of soluble P was shaken with 1 g of hydrosolid was conducted to study the kinetics of the phosphate adsorption and/or precipitation. Although HS2 reduced more soluble P than HS1 at equilibration times exceeding 10 minutes, HS1 and HS2 reduced the same amount of soluble P for equilibration times less than 5 minutes (Fig. 4). Soluble P in runoff water was in contact for less than 2 minutes in the box plot study. These results suggest little difference in soluble P reduction was due to reaction kinetics. However, cumulative rainfall events may result in cumulative times that exceed 10 minutes. Therefore, with time, HS2 would more likely adsorb more P than HS1.

The particle size distribution affects surface area and should influence the adsorption properties of the hydrosolids. Adsorption of soluble P by both coarse (87% greater than 0.2 mm) and fine (100% less than 0.2 mm) forms of HS2 was studied to determine the importance of hydrosolid particle size (Fig. 5). The fine HS2 adsorbed more soluble P faster than coarse HS2. Crushing of hydrosolids to finer (<0.2 mm) particles will increase surface area and P adsorption capacity, thus increasing the ability of the hydrosolids to reduce P in runoff water.

CONCLUSIONS

Non-point source phosphorus pollution from agricultural land treated with animal manures may be reduced by using municipal alum sludge (hydrosolids). Land application of hydrosolids may provide a safe and inexpensive solution to control phosphorus runoff from agricultural land. Hydrosolids should be surface applied when poultry litter is not incorporated into the soil. Hydrosolids can be broadcasted or applied as a buffer strip at the edge of the field. Buffer strips should be more effective than broadcasting in reduction of phosphorus in runoff water. Potential adverse environmental impacts from land application of hydrosolids are unlikely. However, potential environmental impacts from repeated application of hydrosolids are not addressed by this work.

Results from this study were completed on a small scale and may not be transferable to a large scale production. Other variables under field conditions (i.e. circulated flow) are scale dependent and may effect the ability of hydrosolids to reduce NPS. Further research is needed to evaluate the use of hydrosolids to reduce NPS phosphorus under field conditions.

Hydrosolid wastes are currently being landfilled at great expense to municipalities. Also, several municipal water treatment plants producing hydrosolids may have source water degraded by non-point source P pollution. Hydrosolid application to agricultural land treated with animal manure in sensitive watersheds may improve drinking water quality and provide financial savings for municipalities.

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Table 1. Mean Percent Cover and Forage Density of the Fescue Boxes.

Hydrosolid	Application	Blade	Debris	Ground	Forage
		---------------	%	----------------	kg ha^{-1}
HS1	Buffer	35.0	30.0	35.0	3352
HS1	Broadcast	17.5	45.0	37.5	3430
HS2	Buffer	25.0	55.0	20.0	4185
HS2	Broadcast	27.5	42.5	30.0	2659
LSD (α=0.05)		26.4	16.7	24.1	3804
LSD (α=0.10)		20.7	13.1	18.9	2982

Table 2. The Effect of Hydrosolid Application on Mean Concentration of Soluble P, Total P, and Total Al in Runoff Water.

Hydrosolid	Application	Soluble P	Total P	Total Al
		--------------------------	mg L^{-1}	-------------------------
HS1	Buffer Strip	bc 8.99 c	bc 8.77 c	ab 1.42 b
	Broadcast	b 13.0 b	b 12.9 b	bc 1.23 b
HS2	Buffer Strip	c 4.93 d	c 5.20 d	a 1.71 a
	Broadcast	bc 9.83 bc	b 9.87 bc	bc 1.22 bc
Control	6.5 Mg ha^{-1} poultry manure	a 22.3 a	a 20.8 a	c 0.96 c
LSD (α=0.05)		4.94	4.19	0.32
LSD (α=0.10)		4.02	3.41	0.26

Letters to the left of application means represent LSD α = 0.05.
Letters to the right of application means represent LSD α = 0.10.

Table 3. The Effect of Hydrosolid Application on Mean Cumulative Runoff Losses for Soluble P, Total P, and Total Al

Hydrosolid	Application	Soluble P	Total P	Total Al
		-------------------------	mg box^{-1}	-----------------------
HS1	Buffer Strip	b 142 bc	b 141 bc	a 25.3 a
	Broadcast	b 278 b	ab 279 b	a 30.7 a
HS2	Buffer Strip	b 8.2 c	b 103 c	a 27.7 a
	Broadcast	b 285 b	ab 284 b	a 35.0 a
Control	6.5 Mg ha^{-1} poultry litter	a 485 a	a 455 a	a 21.2 a
LSD (α=0.05)		197	193	28.7
LSD (α=0.10)		159	156	23.3

Letters to the left of application means represent LSD α = 0.05.
Letters to the right of application means represent LSD α = 0.10.

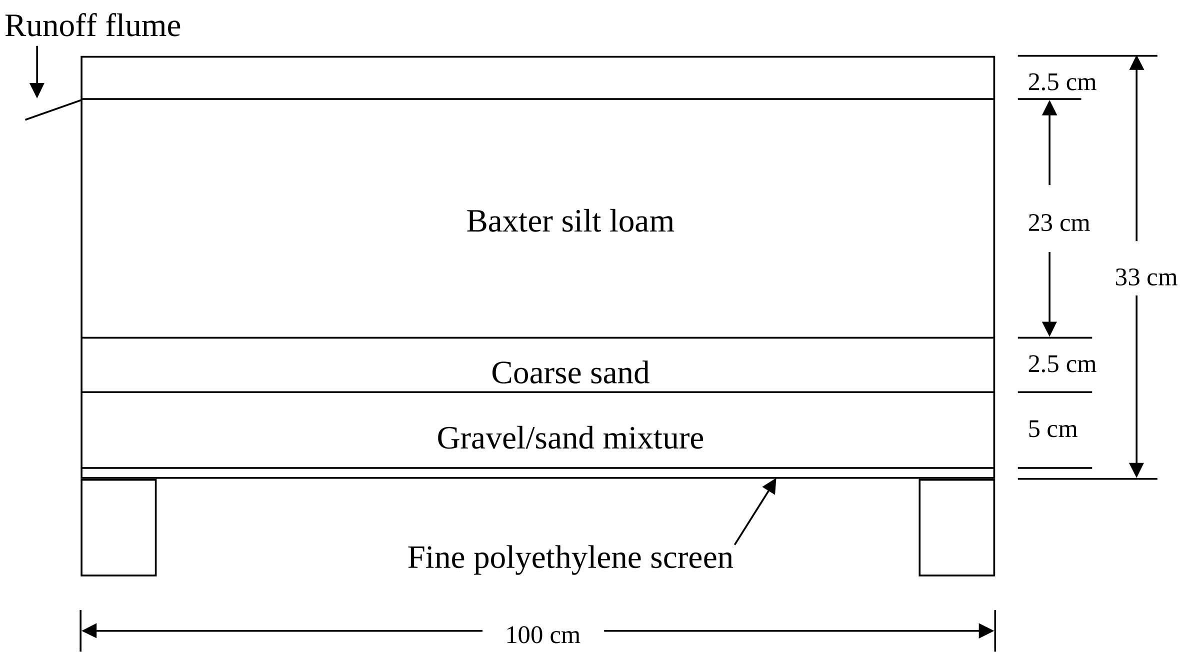

Figure 1. Box plot dimensions. (Not drawn to scale).

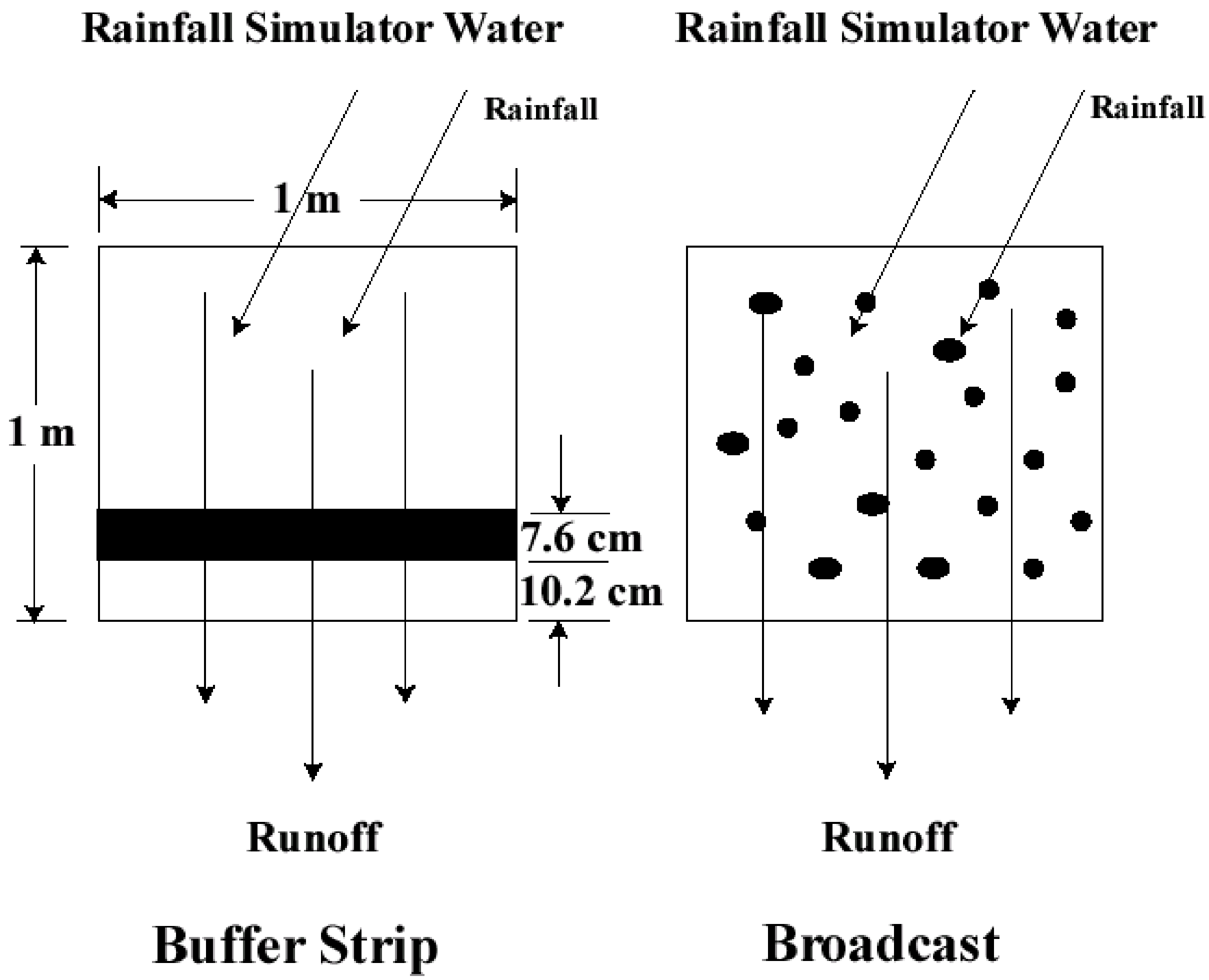

Figure 2. Buffer strip vs. broadcast application.

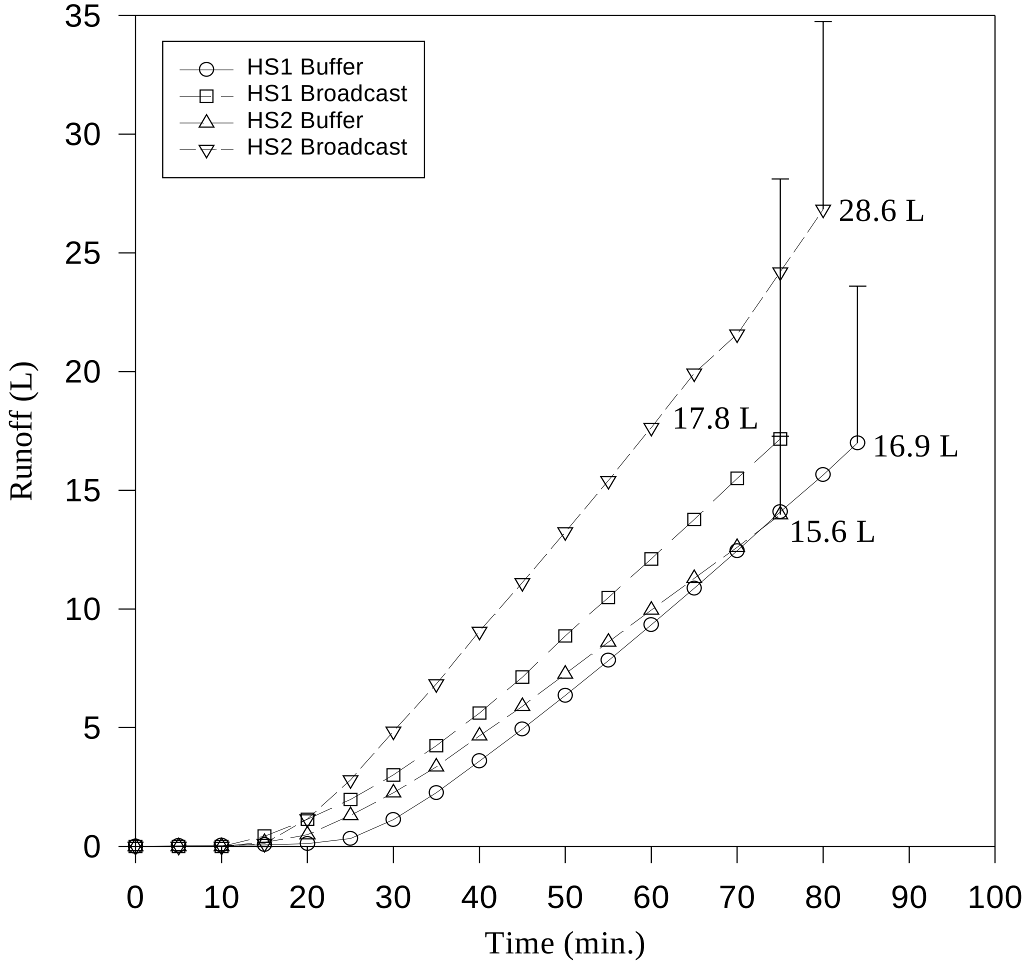

Figure 3. Mean cumulative runoff volume with time.

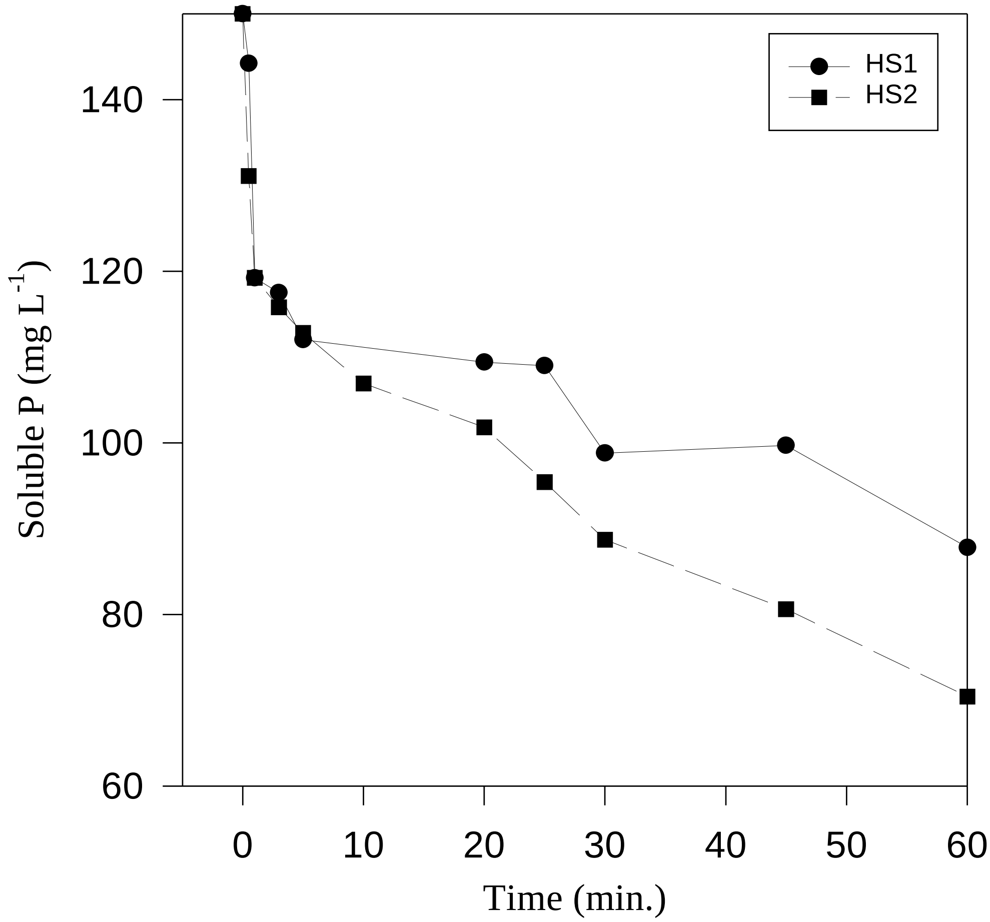

Figure 4. Soluble P reduction for HS1 and HS2 over time.

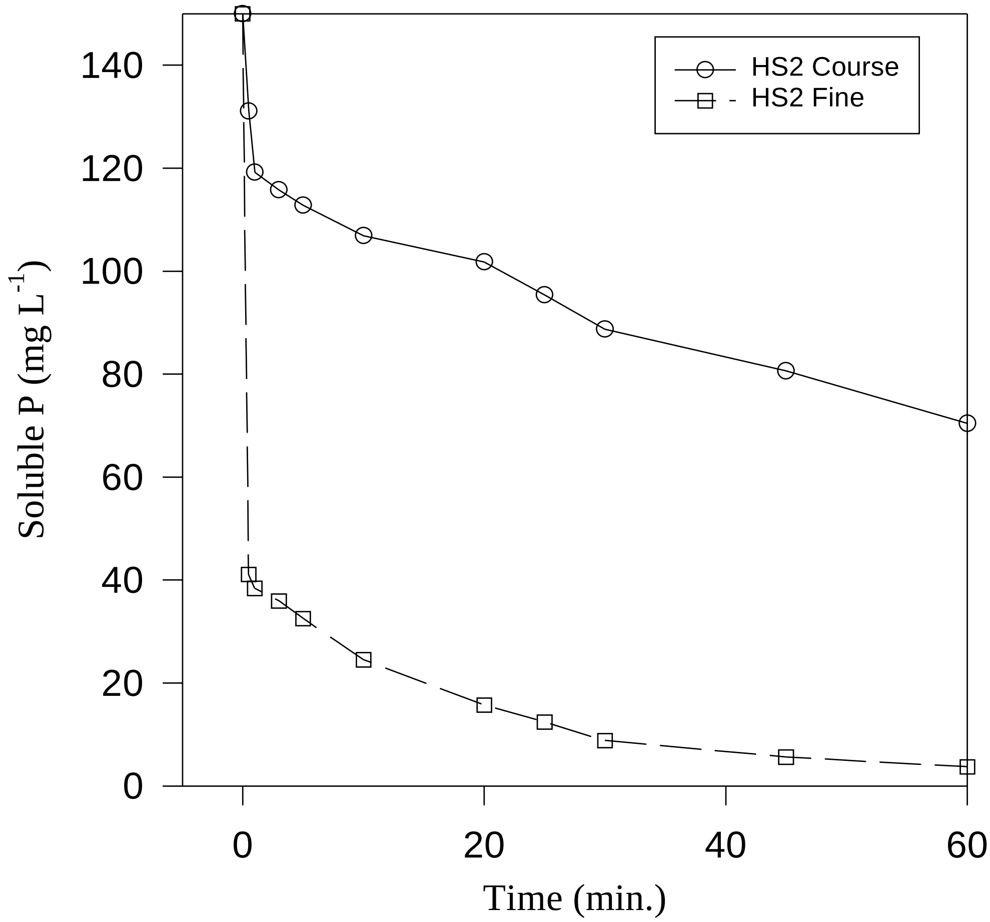

Figure 5. Amendment size effect on soluble P reduction of Hydrosolid #2 coarse and fine over time.

APPENDIX C
Education Materials

Fact Sheets

What Is A Waste Management System? Hamilton, D.W. OSU Extension Facts F-1734. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service, Stillwater, Oklahoma.

Using Lagoon Effluent as Fertilizer. Zhang, H. and D.W. Hamilton. OSU Extension Facts F-2245. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service, Stillwater, Oklahoma.

Using Poultry Litter as Fertilizer. Zhang, H., D.W. Hamilton, and J.G. Britton. OSU Extension Facts F-1734. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service, Stillwater, Oklahoma.

Additional Handouts

Selecting Forages for Nutrient Recycling. Redmon, L.A. OSU Production Technology - Forages, PT 96-36, June 1996, Vol 8, No. 36. Oklahoma State University, Plant and Soil Sciences, Division of Agricultural Sciences and Natural Resources, Stillwater, Oklahoma.

Calibration of Litter Spreading Trucks. Hamilton, D.W., G.L. Bullard, M.J. Fram. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service, Stillwater, Oklahoma.

Application Rates for Broiler Litter Applied to Pasture and Hay Crops. Hamilton, D.W. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service, Stillwater, Oklahoma.

Soil Fertility Demonstration, Jimmy Thomas Ranch, Pontotoc County. Results of First Clipping 7/13/95. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service, Stillwater, Oklahoma.

Example Newspaper Clipping

Experts Seek Pollution Solution. Ken Milam. Poteau Daily News & Sun, Poteau, Oklahoma. 895, Volume 100, Number 255, Thursday, June 20, 1996.

Rainfall Simulator Demonstration Announcements

What Is A Waste Management System?

OSU EXTENSION FACTS

Oklahoma Cooperative Extension Service • Division of Agricultural Sciences and Natural Resources

F-1734

Douglas W. Hamilton
Waste Management Specialist

A farm manure handling facility is a system for managing animal waste. In other words, it is a set of interdependent components working together to perform a task. The components are interdependent because you can't change one part of the system without affecting all the other parts. We deal with systems every day. Your automobile is a mechanical system. Its task is to get you where you need to go. The transmission is a component (or a subsystem) of the automobile system. The engine will still run without the transmission, but the car will not move. The manure handling facility, like the automobile, is also a set of interdependent components.

The Waste Management System's Task

The animal waste management system's task is to satisfy three "clients." The first client is the environment. The manure handling facility prevents your farm from contaminating air, soil, or water. The second client is the public. A well-managed system means your neighbor shouldn't have a reason to complain about odor, noise, or the appearance of your farm. The third client is the producer. The waste management system should make your job easier, not more difficult.

If all three clients are satisfied, you will increase economic return, which means more money in your pocketbook. Figure 1 shows the relationship among the three "clients."

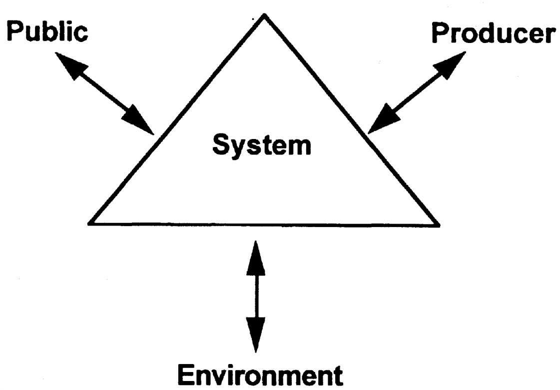

Figure 1. Three "clients" of a waste management system.

The double-headed arrows illustrate how the clients and the system influence each other. For example, the system can impact the environment and the environment can impact the system. Temperature, rainfall, and wind all affect how the system operates. Remember, you, the producer, have the largest responsibility and impact on the system.

How The Waste Management System Performs Its Task

Figure 2 is a general schematic diagram for manure handling facilities. The boxes represent components where various actions take place. The arrows represent components that transport material from one place to another.

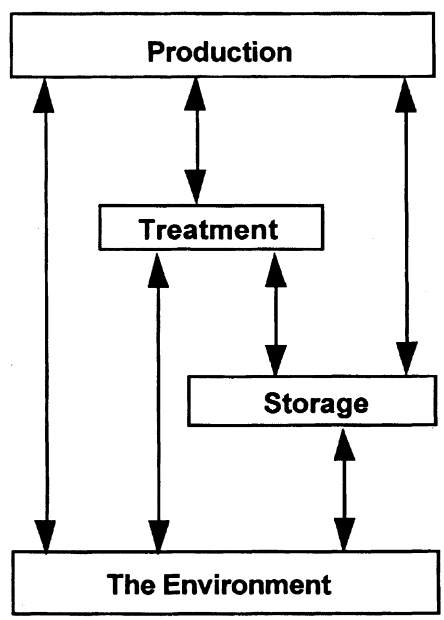

Figure 2. Components of an animal waste management system.

Oklahoma State University

Notice that, as in Figure 1, the arrows are double-headed. This means material can flow in both directions. Using well-designed action components with properly sized transport components makes a waste management system extremely flexible. Let's look at the five components in more detail.

Production

Animals convert feed to feces and urine. This isn't the only source of waste when animals are confined. Other sources of waste include: flush water, spilled feed, bedding, leaking waterers, and captured rainfall. The non-animal sources of waste can be controlled by careful management and regular equipment maintenance.

Storage

Storage is like a shock absorber. It makes the whole operation more flexible. For instance, storage allows you to temporarily hold material until weather and field conditions are acceptable for land application. The storage structure must also prevent waste from seeping into the soil and groundwater. Type of storage is determined by waste consistency and the intended use of the waste.

Treatment

Treatment components alter manure characteristics using physical, chemical or biological methods. The main function of waste treatment is to reduce pollution potential. Treatment components include lagoons, composters, oxidation ditches, solid separators and chemical additives.

The Environment

Animal manure is a resource that is too valuable to throw away. Instead, think of recycling manure nutrients and organic matter back to the environment. Land application is the primary method of recycling. Spreading manure may improve the soil's water holding capacity and may help control erosion. It also greatly reduces the amount of commercial fertilizer required to grow a crop.

Transportation

Material is transported from one system component to another. For example, a flushing system moves manure from under a slatted floor to a lagoon. An irrigation system applies the lagoon effluent to a field. Waste consistency determines what equipment you use to move material.

How Waste Consistency Affects The System

The consistency of the manure is described as liquid, slurry, semi-solid, or solid. Figure 3 illustrates these consistencies. Figure 4 shows how animal type and solids content determine manure consistency. Consistency of manure may change as it moves through the system. Feces are excreted from a pig as a slurry (10% TS). Adding water creates a thinner slurry (2% TS). A solid separator divides the flushed manure into a semi-solid (20% TS) and a liquid (0.1% TS).

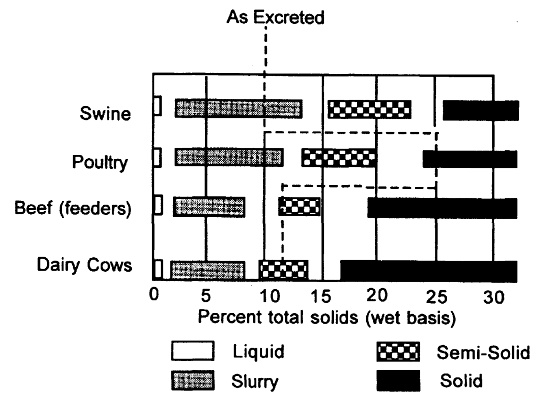

Figure 4. Manure consistency is dependent on animal type and solids content.

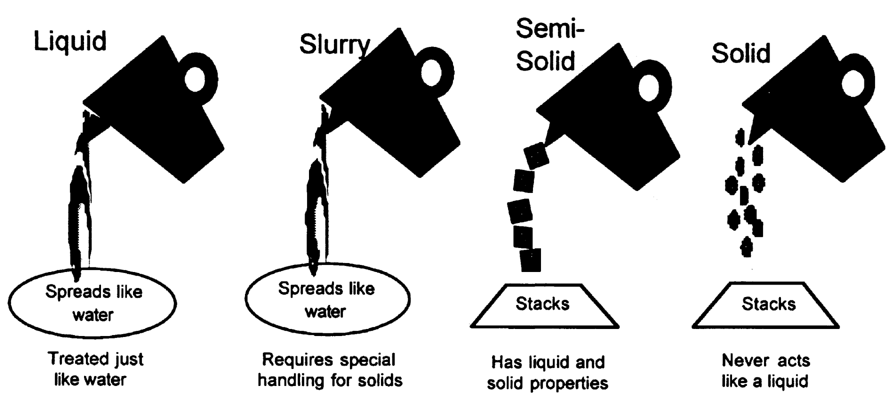

Figure 3. Manure consistency.

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Using Lagoon Effluent as Fertilizer

OSU EXTENSION FACTS

Oklahoma Cooperative Extension Service • Division of Agricultural Sciences and Natural Resources

F-2245

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Waste Nutrient Management Specialist

Douglas W. Hamilton
Waste Management Specialist

Lagoon effluent can be a good source of nutrients for crop production if it is managed properly. Effluent contains soluble elements required to grow plants. Although nutrient concentrations in lagoon effluent tend to be low, large volumes of effluent are often available to producers. Therefore, the total potential nutrient for crop production is quite high. The steps to proper effluent management are:

1. Determine the nutrient requirements of the crop based on a realistic yield goal.
2. Determine the nutrient content of the effluent.
3. Determine the fraction of effluent nutrients available to the crop in the first year of application.
4. Calculate the total depth of irrigation for the growing season.
5. Determine approximate number of applications to achieve total irrigation depth.
6. Determine supplemental nutrients needed for maximum crop growth.

These steps will assure the proper amount of effluent is applied. Avoiding excess effluent application protects soil and water quality.

Crop Nutrient Requirement

Lagoon effluent should not be applied to soil beyond the limits of the growing crop's nitrogen needs due to potential nitrate leaching. Applications of effluent at agronomic rates generally will not create salinity problems. Any soils scheduled for effluent application should first be tested to determine its fertility level. Periodic soil testing is recommended to monitor nutrient supplying capability of the soil. The soil test results and subsequent fertilizer recommendations for the crop to be grown are the only reliable way to obtain crop nutrient requirement.

Soil testing is available through OSU Soil, Water and Forage Analytical Laboratory in Stillwater, as well as a number of commercial laboratories. Crop nutrient needs are given in the interpretations and requirements section of the soil test report. You also can determine crop nutrient needs using Extension Facts #2225, OSU Soil Test Interpretations. Contact the local extension office for instructions and supplies for taking and submitting soil samples.

Effluent Nutrient Content

It is difficult to give an average nutrient content for lagoon effluent. A lagoon is a living system; therefore, nutrient concentrations in the effluent depend on how living organisms digest manure solids. The major factors influencing nutrient content include type of livestock supplying manure, time of year, and the balance of water into and out of the lagoon.

See Extension Facts F-2248, Sampling Animial Manure for Analyses, for details on sampling. Sample lagoon effluent at the same time of year you plan to irrigate effluent. After a number of years, you may see a predictable pattern of nutrient concentration emerge. Table 1 gives some typical analyses

Table 1. Nutrient Analyses of Swine Lagoon Effluent Sampled in Oklahoma.

Analysis	*LeFlore County*	*Pottawatomie County*	*Texas County*	*Texas County (nursery)*
Total-N (lbs/1000 gal)	4.5	5.6	2.1	4.4
NH_4-N (lbs/1000 gal)	4.5	4.9	1.8	3.7
Total P_2O_5 (lbs/1000 gal)	1.2	1.3	0.8	0.7
Total K_2O (lbs/1000 gal)	5.9	6.4	2.3	5.3
EC (mmho/cm)	5.9	7.3	3.0	5.6

of swine lagoon effluent at different locations in Oklahoma. We can make a number of general statements about the results in Table 1:

1. A large portion of the nutrients in lagoon effluent is dissolved and highly available to plants. Notice in all the samples, 80% or more of the total nitrogen appears as ammonium (NH_4-N). Plants can use ammonium directly from soil solution and soil exchange sites.
2. Nutrients fall into fairly predictable ratios. In this table, the ratio of Total-N to P_2O_5 to K_2O in units of lbs/1000 gallons is approximately 4:1:5. These ratios are a reflection of the living nature of a lagoon and the water balance. Bacteria release a fairly fixed proportion of the nutrients into the liquid. Nutrients are then concentrated or diluted according to lagoon operation. Since evaporation exceeds rainfall in most parts of Oklahoma, effluent tends to become more concentrated.
3. Nutrient concentration is roughly proportional to salt content or electrical conductivity (EC). The same operational factors concentrating nutrients also concentrate soluble salts. Lagoon effluent should be analyzed for EC and sodium content, as well as major nutrients. The detrimental effect of irrigating high salt effluent must be taken into account when planning a waste management system.

Availability of Effluent Nutrients to Crops

Nutrients in lagoon effluent cannot be substituted for those in commercial fertilizers on a pound-for-pound basis because not all the nutrients reported on a manure analysis report are readily available to a crop in the year of application. Some elements are released when organic matter is decomposed by microorganisms. Other elements can combine with soil constituents and become unavailable. Nitrogen may also be lost to the atmosphere through ammonia volatilization or denitrification depending on application methods, soil pH and soil moisture level.

Organic nitrogen in effluent must be converted (mineralized) into plant available inorganic forms (ammonium and nitrate) before it can be absorbed by roots. Although very little of the effluent N is organic, about 25% to 50% of the organic N may become available the year of application. Most effluent N is in ammonium form (NH_4-N). Potentially, all of the NH_4-N can be utilized by the plants in the first year of application. However, if manure is applied on the soil surface and not quickly incorporated, considerable NH_4-N can be lost to the air as ammonia (NH_3) gas. This decreases nitrogen available for plant growth. Ammonium worked into the soil is subject to nitrification (rapid conversion to NO_3-N). Nitrate-N is readily available to plants, but if excess water is present, it can be lost through leaching or denitrification (conversion of NO_3-N to N_2 gas). Combining inorganic N after ammonia volatilization losses, and N available from organic N, gives the total N available to crops. This is sometimes called plant available nitrogen, PAN. If ammonia volatilization was eliminated, almost all of the Total N in effluent is PAN. However, a rule of thumb is 50% of the Total N is available after volatilization losses. However, recent studies have shown that ammonia losses may be as high as 80% of total N.

Some studies have shown that the availability of effluent P is equal or superior to that of commercial phosphorus fertilizers; others have shown lower responses from manure than from fertilizer P. In general 90% availability has been commonly used for P calculation. Most manure K is soluble and readily available for plant use in the year of application. Ninety to 100% availability has been commonly used for K calculation.

Total Depth of Irrigation

Producers should develop a nutrient management plan that maximizes the use of manure nutrients available. In many cases the producer may need to supplement effluent with commercial fertilizers if total crop nutrient needs are not met. Land application rates should be based on the nutrient requirements of the crop being grown to ensure efficient use of manure nutrients and minimize the chances of nitrogen volatilization and leaching. Soil testing, effluent analysis, and proper estimation of yield goal are necessary to calculate proper agronomic application rates of lagoon effluent and additional fertilizers. Follow the first four steps in the attached worksheet to calculate the seasonal application rate.

When using many irrigation systems, it is more convenient to use application depth rather than application rate. There are approximately 27,000 gallons per acre-in of application. Divide application rate in 1000 gal/acre by 27 to determine irrigation depth in inches..

Irrigation Scheduling

You may not apply all the effluent at one time because of the limited water holding capacity and infiltration rate of your soil. A sandy loam soil, for example, can hold 0.8 to 1.4 inches of water per foot of soil when it is completely dry. It is reasonable to assume that the soil will be at half field capacity before irrigation. To bring one foot of soil up to field capacity, the most effluent you could apply would be between 0.4 to 0.7 inches. One half inch would be a reasonable irrigation depth under these conditions. So, if the total effluent irrigation needed to provide nitrogen through the growing season is three inches, you would apply six separate irrigations of 0.5 inch each.

Lagoon effluent has a high concentration of available nitrogen. Crops take up most nitrogen during the vegetative growth phase of plant development. Space irrigations throughout the vegetative growth period in order to get the most use out of the effluent nitrogen. Using the example in the last paragraph, if the vegetative growth period of the crop lasts six weeks, you will get the most use of nitrogen by irrigating 0.5 inch of effluent, once per week, for six weeks. Consult the agricultural extension educator or crop consultant in your area to find active growth periods for crops.

If applied pre-plant, effluent should be added as near to the planting dates as possible to provide starter nutrients. Effluent can also be applied post harvest to supply nutrients for winter cover crops. Lagoon effluent should not be applied to already stressed plants because the salt and ammonium in the liquid may further stress the crop. The water added with lagoon effluent will rarely be sufficient to provide the total moisture needs of a crop throughout the growing season. Use effluent to meet crop nutrient needs and irrigate with additional clean water to provide moisture needs.

Effluent Irrigation Work Sheet

		Example:	Your Number:
1.	**Nutrient needs of crop (lbs/acre)** Recommendations based on soil test results and a realistic yield goal.	N= 180 P_2O_5= *95* K_2O= *40*	N= ____ P_2O_5= ____ K_2O= ____
2.	**Total nutrient value of effluent (lbs/1000gal)** Based on manure analysis of a representative sample collected close to time of application.	N= *5.2* P_2O_5= *1.3* K_2O= *5.9*	N= ____ P_2O_5= ____ K_2O= ____
3.	**Determine available nutrients (lbs/1000gal)** Multiply the value from Step 2 by nutrient availability, 50% for N and 90% for P and K	N= *2.6* P_2O_5= *1.2* K_2O= *5.3*	N= ____ P_2O_5= ____ K_2O= ____
4a.	**Calculate application rates to supply N and, P_20_5 needs. (1000gal/acre)** Divide values from Step 1 by values from Step 3.	N= *69* P_2O_5= *79*	N= ____ P_2O_5= ____
4b.	**Choose between N or P_2O_5 application rate (1000gal/acre)** Select the highest rate calculated in Step 4a for using effluent as a complete fertilizer. Select the lowest rate for maximizing nutrient use.	Rate = *69* *(based on N for this example)*	Rate = ____
4c	**Determine total depth of irrigation (inch)** Divide application rate in 1000 gal/acre from Step 4b by 27 to get irrigation depth in inches.	Depth = *2.6*	Depth = ____
5.	**Determine numbers of application needed to apply total irrigation depth.** Most soils cannot accept the total irrigation depth in one application. Divide total irrigation depth in 4c by acceptable application depth for average soil conditions	*5* *(based on 1/2 inch per application)*	____
6a.	**Determine amount of nutrients applied at chosen rate (lbs/acre)** Multiply the rate chosen in Step 4b, by available nutrients, Step 3.	N= *180* P_2O_5= *83* K_2O= *366*	N= ____ P_2O_5= ____ K_2O= ____
6b.	**Determine supplemental nutrients (lbs/acre)** Subtract the nutrients applied, Step 4e, from nutrients needed, Step 1. If the difference is negative, enter 0.	N= 0 P_2O_5= 12 K_2O= *0*	N= ____ P_2O_5= ____ K_2O= ____

2245 / 3

Using Poultry Litter as Fertilizer

OSU EXTENSION FACTS

Oklahoma Cooperative Extension Service • Division of Agricultural Sciences and Natural Resources

F-2246

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Area Poultry Specialist

Poultry litter is an excellent, low cost fertilizer if used properly. Land application of litter returns nutrients and organic matter to the soil, building soil fertility and quality. In addition to the micronutrients, N, P and K, poultry manure contains calcium, magnesium, sulfur, and other micronutrients.

Land application of poultry manure should be managed to recycle plant nutrients rather than for disposal. Increasing environmental concerns about agricultural non-point source pollution make it imperative that poultry farmers use poultry litter in the manner most beneficial for the environment – both on and off the farm. Steps to proper litter management are:

1. Determine crop nutrient requirement based on a realistic yield goal.
2. Determine the nutrient content of litter.
3. Determine the fraction of litter nutrients available to the crop in the first year of application.
4. Determine litter application rate to supply crop nutrient needs.
5. Determine supplemental nutrients needed for maximum crop growth.

These steps will assure that the proper amount of litter is applied. Avoiding excess litter application protects water quality.

Crop Nutrient Requirement

Poultry litter should not be applied to soil beyond the limits of the growing crop's nutrient needs. This will ensure efficient use of manure nutrients and minimize nutrient leaching or runoff into the surface and ground water systems. Any soils scheduled to receive poultry litter should first be tested to determine fertility level. Periodic soil testing is recommended to monitor the nutrient supplying capability of the soil. Fertilizer recommendations based on soil test results are the only reliable way to determine the crop nutrient requirement.

Soil testing is available through OSU Soil, Water and Forage Analytical Laboratory in Stillwater, as well as, a number of commercial laboratories. Crop nutrient needs are given in the interpretations and requirements section of the soil test report. You can also determine crop nutrient needs using Extension Facts F-2225, OSU Soil Test Interpretations. Contact the local extension office for instructions and supplies for taking and submitting soil samples.

Fertilizer Value of Litter

The nutrient content of poultry litter varies quite a bit. Fertilizer value depends on the type of birds, age of the litter, and litter moisture content. It is always a good idea to take a sample and test the litter for nutrients prior to cleaning out a house. Use the test results to calculate how much litter to apply to fields.

Litter samples should be representative of the house or litter pile in the storage. See OSU Extension Facts F-2248, Sampling Animal Manure for Analyses for details of manure sampling. Results are reported as pounds of nutrient per ton on a "dry" and "as is" basis. "As is" means the amount of nutrients per ton at the moisture content when the sample was taken. Normally, "as is" numbers are used for rate calculation. Table 1 shows "as is" fertilizer values from a number of studies. As you can see, the values cover quite a range. Much of the variability is due to moisture content. You can overcome the moisture factor by using the "as is" values and calibrating spreading equipment based on weight of material actually spread.

Table 1. "As is" Broiler Litter Fertilizer Concentrations.

Source	*Total N*	*P_2O_5*	*K_2O*
	lbs/Ton		
Arkansas	56	48	36
Oklahoma	57	62	49
Missouri	54	26	32
Delaware	59	64	41
Alabama	78	74	50
Georgia	70	30	44
Tennessee	67	71	47
Texas	67	62	46
Average	**64**	**55**	**43**

Availability of Litter Nutrients to Crops

The values listed in Table 1 are total nutrients in litter. These are not equivalent to nutrients in commercial fertilizer because not all the nutrients listed on a manure analysis report are readily available to a crop in the year of application. Some elements are released when organic matter is decomposed by microorganisms. Nitrogen may be lost to the atmosphere by ammonia volatilization and denitrification, or lost below the root zone through leaching.

Nitrogen availability during the year of application varies greatly and ranges from about 30 to 80 percent. Nitrogen is present in both organic and inorganic forms. Organic Nitrogen must be converted (mineralized) into inorganic nitrogen to become available to plants. The amounts of organic N converted to plant-available forms during the first cropping year after application vary according to environmental conditions and manure handling systems. About 25% to 50% of the organic N becomes available during the year of application. All of the inorganic N, ammonium-N (NH_4-N) and nitrate-N (NO_3-N), is readily available to plants. However, if litter lays exposed on the soil surface, considerable NH_4-N may be released to the air as ammonia (NH_3) gas. Ammonium worked into the soil is subject to nitrification (rapid conversion to NO_3-N). Nitrate-N is readily available to plants, but if excess water is present, it can be lost through leaching or denitrification (conversion of NO_3-N to N_2 gas). Combining inorganic N, and N available from organic N, gives the total N available to crops. This is sometimes called plant available nitrogen, PAN.

Table 2 shows the approximate availability of nitrogen in the first three years after application. Notice that more nitrogen is available for plant use if the litter is incorporated into the soil soon after application. Incorporation reduces ammonia volatilization losses.

Few studies have been done on P and K availability in poultry litter; however, availability is considered to be about 80-100 % of P and K available in commercial fertilizer. In general, 90% availability is assumed when determining an application rate based on P.

Application Rate

Land application rates should be based on the nutrient requirement of the crop. Too little manure application will not provide sufficient nutrients for the desired crop production. Excess nutrients are a waste of resources, resulting in soil phosphorus buildup which may cause water contamination.

Soil testing, litter analysis, and proper estimation of yield goal are necessary to calculate proper agronomic application rates of litter. Develop a manure nutrient management plan that consumes manure nutrients, then supplement with commercial fertilizers to balance crop needs. Follow the steps in the attached worksheet to calculate application rate. Nitrogen credits should be given to previous years' applications in Step 1b if litter is applied to the same field continuously.

Table 2. Estimated Poultry Litter Nitrogen Availability Based on Application Method.

Year after Application	*Surface Application*	*Soil Incorporation*
First Year	50%	60%
Second Year	15%	15%
Third Year	6%	6%

Application Timing

Proper timing of litter application is essential for efficient use of nutrients and pollution prevention. Litter should be applied as near to field crop planting dates and as close to the forage crop growing season as possible. Applying manure outside of crop growth periods decreases nutrient availability, and may increase the risk to environmental quality.

Grasses or pasture offer some flexibility when crop fields are not available. Litter applied during spring provides starter nutrients and releases mineralized nitrogen throughout the growing season. Applying litter in the fall generally results in greater nutrient loss than does spring application, especially if the litter is not incorporated. Early fall application may be desirable to supply nutrients to cool season grasses. Winter application is the least desirable because litter must remain on the soil surface for 3 to 4 months ahead of the crop's active growing period.

Benefits of Application

Fifty pounds of nitrogen per acre is needed to produce one ton of grass forage. This is true whether the nitrogen comes from commercial fertilizer or poultry litter. Poultry litter has been shown to improve the quality of forage, as well as increase yields. Table 3 compares effects of poultry litter and commercial nitrogen fertilizer on the production of Bermuda grass in southeastern Oklahoma. Poultry litter not only increased forage yields but also increased protein content over control and commercial fertilizer plots. Higher yields and protein content at similar rates of litter and commercial fertilizer may result from the fact that litter provides a slow release nitrogen fertilizer, improves soil quality, and reduces soil acidity.

Table 3. Average Forage Yield and Crude Protein Content of Bermuda Grass in Southeastern Oklahoma at Four Nitrogen Treatments.

Treatment	*Forage Yield Tons/Acre*	*Crude Protein %*
No N	2.77	8.0
300 lbs/Acre Ammonium Nitrate (96 lbs Total N/Acre)	3.44	8.8
2 Tons/Acre Poultry Litter (approximately 130 lbs Total N/Acre)	3.54	11.4
4 Tons/Acre Poultry Litter (approximately 260 lbs Total N/Acre)	4.82	12.6

Poultry Litter Application Rate Calculation Work Sheet

		Example:	Your numbers:
1a	**Nutrient needs of crop (lbs/acre)** Recommendations based on soil test results and a realistic yield goal.	N = 200 P_2O_5 = 80 K_2O = 40	N = P_2O_5 = K_2O =
1b	**Nutrients carried over in last 2 years' applications (lbs/acre)** See Table 2.	N = 25 P_2O_5 = 0 K_2O = 0	N = P_2O_5 = K_2O =
1c	**Nutrient needs to meet with litter** Subtract line 1b from line 1a.	N = 175 P_2O_5 = 80 K_2O = 40	N = P_2O_5 = K_2O =
2	**Total nutrients available in litter (lb/ton)** Based on litter analysis of representative sample collected close to time of application.	N = 64 P_2O_5 = 55 K_2O = 43	N = P_2O_5 = K_2O =
3	**Determine available nutrients (lb/ton)** Multiply the value in step 2a by availability, 50% for N and 90% for P and K.	N = 32 P_2O_5 = 50 K_2O = 39	N = P_2O_5 = K_2O =
4a	**Calculate application rates to supply N, and P_2O_5 needs (tons/acre)** Divide values from Step 1c by values from Step 3.	N = 5.5 P_2O_5 = 1.6	N = P_2O_5 =
4b	**Choose between N or P_2O_5 application rate (tons/acre)** Select highest rate in Step 4a to use litter as complete fertilizer. Select lowest rate to maximize nutrient use.	Rate = 1.6 (based on P)	Rate =
5a	**Determine amount nutrients applied at chosen rate (lbs/acre)** Multiply the rate chosen in step 4b by available nutrients in step 3.	N = 51 P_2O_5 = 80 K_2O = 62	N = P_2O_5 = K_2O =
5b	**Determine supplemental nutrients (lbs/acre)** Subtract the nutrients applied, step 5a from nutrients needed, step 1c. If the difference is negative, enter 0.	N = 124 P_2O_5 = 0 K_2O = 0	N = P_2O_5 = K_2O =

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Bringing the University to You!

The Cooperative Extension Service is the largest, most successful informal educational organization in the world. It is a nationwide system funded and guided by a partnership of federal, state, and local governments that delivers information to help people help themselves through the land-grant university system.

Extension carries out programs in the broad categories of agriculture, natural resources and environment; home economics; 4-H and other youth; and community resource development. Extension staff members live and work among the people they serve to help stimulate and educate Americans to plan ahead and cope with their problems.

Some characteristics of the Cooperative Extension system are:

- The federal, state, and local governments cooperatively share in its financial support and program direction.
- It is administered by the land-grant university as designated by the state legislature through an Extension director.
- Extension programs are nonpolitical, objective, and based on factual information.
- It provides practical, problem-oriented education for people of all ages. It is designated to take the knowledge of the university to those persons who do not or cannot participate in the formal classroom instruction of the university.
- It utilizes research from university, government, and other sources to help people make their own decisions.
- More than a million volunteers help multiply the impact of the Extension professional staff.
- It dispenses no funds to the public.
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PRODUCTION TECHNOLOGY

Forages

Agronomy Department

Division of Agricultural Sciences & Natural Resources

Oklahoma State University

PT 96-36 June 1996 Vol. 8, No. 36

Selecting Forages for Nutrient Recycling

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Extension Forage Specialist

The production of animal waste products and their subsequent use as soil amendments will increase as poultry and swine producers expand their market share of the meat industry. Animal waste products contain valuable nutrients that are required in quantity by forage crops. These nutrients, primarily N, P, and K, can, however, accumulate on sites with continued application. Forages managed as hay crops can be utilized to remove these nutrients from sites that regularly receive poultry litter or swine lagoon effluent applications via plant uptake. This document discusses the use of forages for nutrient removal from areas subject to poultry litter and swine lagoon effluent applications.

Present Situation

Both the poultry and swine industries are presently experiencing dramatic growth in Oklahoma. At present, the poultry production areas in Oklahoma are located primarily in the eastern part of the state, while swine production areas are found in both the eastern and western regions. As these industries have grown, so have the quantities of poultry litter and swine lagoon effluent that is a by-product of these production systems.

Poultry litter is made up largely of poultry manure and substances with a high C:N ratio such as sawdust, wood chips, or rice hulls. Although poultry litter is highly variable with regard to nutrient composition (Table 1), a typical analysis for N-P-K per ton of litter is approximately 60-60-40 (Table 1). Routine disposal of poultry litter involves applying litter to pastures, generally on-farm or within a short distance of the poultry operation. Typical applications of litter on pasture may approach 5-7 tons of litter per acre per year. Nutrient accumulation or ***loading*** of elements such as P can occur in a very few years even on P-deficient soils under these application scenarios.

Table 1. Nutrient composition of litter from 147 broiler houses sampled in Alabama, 1977-1987.[1]

	Avg. analysis, dry wt. Basis (%)	Range (%)	Avg. nutrient content as is basis (lbs/ton)
Moisture	19.7	15-39	-
Nitrogen (N)	3.9	2.1-6.0	62
Phosphorus (P_2O_5)	3.7	1.4-8.9	59
Potassium (K_2O)	2.5	0.8-6.2	40
Calcium (Ca)	2.2	0.8-6.1	35
Magnesium (Mg)	0.5	0.2-2.1	8
Sulfur (S)	0.4	0.01-0.08	6

[1] Ball et al., 1996.

The use of swine lagoon effluent can cause nutrients to accumulate on a site in a similar manner. Analyses for lagoon effluent are usually given in the units pounds of nutrients per 1000 gallons. The ratio of plant available N to P_2O_5 to K_2O for swine lagoon effluent generally falls into the ratio of 1-1-2. Actual nutrient concentrations depend on the amount of flushwater added to the lagoon, the amount of precipitation falling on the lagoon, and the level of treatment achieved by the lagoon. Using a typical analysis -- 2.0 lbs N, 2.0 lbs P_2O_5, 4.0 lbs K_2O per 1000 gallons -- indicates that 1" of irrigation yields approximately 60 lbs N, 60 lbs P_2O_5, and 120 lbs K_2O per acre.

Management Strategies

To prevent excess nutrient loading of sites receiving routine applications of poultry litter or swine lagoon effluent, 2 management strategies should be closely observed. The first consideration is ***never*** apply more nutrient than can be effectively used by the forage system. Under most circumstances the critical nutrient to monitor will be P. Phosphorus is required in lower quantities by forage plants than either N or K; thus, P will be the macronutrient that is removed in the least quantity by the forage system. Poultry litter or swine lagoon effluent should only be applied to meet the P requirement of the forage system; additional N or K should be applied as inorganic fertilizer. If poultry litter or swine lagoon effluent is applied to meet the N requirement of the forage crop, excess P will accumulate at the site. An annual soil test of the application site will indicate the soil-P status and whether an accumulation is taking place. Routine analyses of the poultry litter or swine lagoon effluent will provide information regarding the level of nutrient inputs the system is receiving.

The other management strategy of critical importance is to use a forage crop or crops that will remove a maximum level of nutrients, especially the nutrients of concern. This may be accomplished by 1 or 2 strategies, or by using a combination of both strategies.

The first strategy involves using a forage crop that has a high dry matter yield potential. As dry matter yield increases, the level of nutrients taken up by plants increases and, thus, the potential for removal of more nutrients is enhanced. An example of a forage exhibiting high yield characteristics is bermudagrass. When grown in eastern Oklahoma with adequate precipitation, or under irrigation elsewhere in the state, bermudagrass is one of the most productive forage grasses that could be used in a forage system designed for nutrient removal.

Another forage-use strategy involves using forages that have higher rates of nutrient uptake for specific nutrients at reduced dry matter yield potentials. Table 2 indicates the differences between forage species in percentage concentrations of various nutrients contained in plant tissue. Orchardgrass, for example, does not yield as much dry matter as bermudagrass, but the orchardgrass uptake of P is almost twice that of bermudagrass.

Alfalfa has both a high yield potential, if given adequate moisture, and has a higher requirement for both P and K than does bermudagrass (Table 2). Although a legume and not dependent on applied N, alfalfa receiving N, P, and K as swine lagoon effluent has the potential to remove a large quantity of applied nutrients.

Table 2. Mineral nutrient composition of selected hays -- dry matter basis.[1]

Species	N	P	K	Ca	Mg
Alfalfa	-	0.35	2.20	1.80	0.26
Annual ryegrass	3.4	0.34	2.80	-	-
Bermudagrass	2.5	0.28	1.80	-	-
Orchardgrass	2.9	0.54	3.58	0.58	0.31
Pearlmillet	2.0	0.20	2.00	-	-
Red clover	2.6	0.25	1.62	1.53	0.43
Smooth bromegrass	3.4	0.45	3.20	0.55	0.32
Sorghum/sudangrass	1.6	0.18	1.80	-	-
Tall fescue	2.3	0.37	-	0.51	-
White clover	3.5	0.31	2.62	1.35	0.48

The most efficient nutrient removal forage system, however, will use a combination of both warm- and cool-season forage species to enhance nutrient removal on a year-round basis. One good combination of warm- and cool-season forage systems that uses a perennial forage as a base would be bermudagrass overseeded with a cereal grain such as wheat or rye in combination with annual ryegrass. Another system that would work well in the eastern part of Oklahoma would involve the use of the cool-season perennial tall fescue with an overseeded warm-season annual grass such as crabgrass for summer growth. Likewise, the use of orchardgrass, bromegrass, or wheatgrass (tall or intermediate) with crabgrass would be a good choice for use under irrigation in the western portion of the state.

Warm- and cool-season annuals could also be used for high levels of nutrient removal if producers currently have farming equipment. Possible species combinations could include double cropping cereal grains with sudangrass, forage sorghums, or pearlmillet under irrigation. Sudangrasses, forage sorghums, and pearlmillets have the ability to produce large quantities of dry matter, and thus, have the potential to remove high levels of nutrients from sites receiving swine lagoon effluent applications. The negative effects of nitrate accumulation associated with the use of these warm-season annual grasses during times of drought stress would be reduced or eliminated since adequate moisture should be present under irrigation to facilitate growth.

It should be noted that nutrients are not effectively removed from the forage system by grazing livestock. Table 3 compares the various levels of nutrient removal by grazing or by haying warm- or cool-season perennial grasses.

Table 3. Approximate quantities of nutrients removed under grazing and haying systems.

System	Nutrient Removal (lbs/ac)				
	N	P	K	Ca	Mg
Grazing[1]	12.5	3.4	0.75	6.5	0.75
Bermudagrass[2]	200	22	144	63	31
Orchardgrass[3]	174	32	215	35	19

[1] Assumes 1-500 lbs calf weaned off of 1 acre on a year-round basis. If more than 1 acre per year are required to produce the calf, the values would be reduced.
[2] Assumes 4-ton yield with all forage removed as hay crop.
[3] Assumes 3-ton yield with all forage removed as hay crop.

Nutrient removal is enhanced only by removing forage as a ***hay crop*** and transporting the nutrients elsewhere, away from the application site. Grazing, for the most part, recycles most of the nutrients back into the forage system. Continued use of poultry litter or swine lagoon effluent under grazed-only systems will lead to increased nutrient accumulation of that site.

Conclusion

Animal waste products contain valuable macronutrients that can and should be used as soil amendments in forage production systems. Continued application, however, of critical nutrients, such as P, in excess of the level that can be effectively removed as a hay crop by the forage system can lead to an accumulation of nutrients. Additionally, on sandy sites, relatively mobile nutrients, such as N, can be leached through the soil profile into groundwater aquifers, thus posing a potential environmental hazard.

Forages with a high yield potential can be used effectively to remove nutrients from application sites, if application rates are kept within reason. Bermudagrass and certain warm-season annual grasses have the potential to produce large dry matter yields, and thus, remove large quantities of applied nutrients. Cool-season grasses and certain legumes have higher uptake rates of certain nutrients (such as P) and may remove more specific nutrients than higher yielding forage species, such as bermudagrass, although the yield potential is not as high. Producers should seek to use a combination of both warm- and cool-season forages in a production system that attempts to remove a maximum level of nutrients from sites that regularly receive poultry litter or swine lagoon effluent applications. Grazed-only systems will not effectively remove nutrients from an application site since most of the applied nutrients are recycled to the land during the grazing process.

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Calibration Of Litter Spreading Trucks

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Waste Management Specialist
Biosystems & Agricultural Engineering

Gerald L (Joe) Bullard
LeFlore County Water Quality Agent

Mitchell J. Fram
Area Water Quality Specialist, NE District

Calibrating your litter spreading truck is important. The simple procedure will help you apply litter at the exact rate you need to fertilize a crop. You will also reduce the chance for nutrient runoff, which contributes to pollution.

Materials Needed:

- Plastic sheet, bedsheet or a tarp
- Bucket
- Top-loading scale

Steps To Successful Calibration

1. Determine tons/acre rate needed to provide fertilizer using the "Application Rates for Broiler Litter" handout.
2. Record the weight of bucket and sheet.
3. Choose a large, reasonably smooth, flat area in the field and spread the sheet over the chosen area.
4. Mark the spreader gate opening with a grease pencil or non-permanent marker.
5. Proceed toward the sheet at a speed appropriate for the field.
6. Drive over the sheet, spreading litter, before, during, and after you pass over the sheet.
7. Once you've passed over the sheet, carefully fold the corners of the sheet into the center and place it into the bucket
8. Weigh the bucket and the sheet. Subtract the weight of the empty bucket and the clean sheet. The difference is the weight of the litter spread over the sheet.
9. Shake litter off the sheet.
10. Repeat the above steps three times and use the average for calculations.
11. Using Table 1 on the back of this fact sheet, determine how many pounds of litter were spread per acre.
12. If the rate calculated is higher than the rate determined in step 1, slightly close the spreader gate and mark it with a grease pencil. If the rate calculated is too low, open the spreader gate. Repeat steps 2 thru 11 until you reach the proper application rate.

This process usually takes less than an hour. If you follow this procedure, you will save hundreds of dollars in fertilizer costs alone. Considering that over-applying litter could contaminate groundwater or cause excessive runoff, you'll also have the peace of mind that comes from trying to work for, not against, the environment.

Table 1. Litter Spreading Truck Calibration
(Adapted From Alabama Cooperative Extension Service.)

Pounds of Litter Applied to Sheet	Tons Of Litter Applied/Acre			
	Size Of Sheet			
	8'x8'	8'x10'	10'x10'	10'x12'
1	0.34	0.27	0.22	0.18
2	0.68	0.54	0.44	0.36
3	1.02	0.81	0.65	0.54
4	1.36	1.08	0.87	0.73
5	1.70	1.35	1.09	0.91
6	2.04	1.62	1.31	1.09
7	2.38	1.89	1.52	1.27
8	2.72	2.16	1.74	1.45
9	3.06	2.43	1.96	1.63
10	3.40	2.70	2.18	1.82
11	3.74	2.97	2.40	2.00
12	4.08	3.24	2.61	2.18
13	4.42	3.51	2.83	2.36
14	4.76	3.78	3.05	2.54
15	5.10	4.05	3.27	2.72
16	5.45	4.32	3.48	2.90
17	5.79	4.59	3.70	3.09
18	6.13	4.86	3.92	3.27
19	6.47	5.13	4.14	3.45
20	6.81	5.40	4.36	3.63
21	7.15	5.67	4.57	3.81
22	7.49	5.94	4.79	3.99

Note: If your sheet does not match one of these sizes, calculate your rate as follows:

$$\frac{\text{lbs of manure on the sheet X 21.78}}{\text{length of sheet (ft) X width of sheet (ft)}} = \text{tons per acre}$$

Application Rates For Broiler Litter Applied To Pasture And Hay Crops

Douglas W. Hamilton

There are five steps to properly figure the application rate of broiler litter. First, determine the fertilizer value of litter. Then, the crop requirements for nitrogen and phosphorus must be considered. Third, apply National Resources Conservation Service (NRCS) guidelines for application rates to your situation. Next, calculate the amount of litter needed to meet the fertilizer needs for the entire field. Finally, calibrate litter spreading equipment to apply at the proper rate. Let's look at these steps in more detail.

Step 1: Determine Fertilizer Value of Broiler Litter

If chicken manure had a fertilizer label the minute it left the bird, it would look something like this:

Broiler Manure
6 - 4 - 4
(elements per dried solids)

Total N = 5.50%
Total P_2O_5 = 3.91%
Total K_2O = 4.14%
Ca = 1.86%
Mg = 0.68%
Na = 0.68%
Fe = 3.75ppm
Mn = 0.38ppm
Bo = 0.11ppm
Zn = 0.16ppm
Cu = 0.45ppm

Figure 1. "Guaranteed" Analysis for Chicken Manure. (ASAE Data, D384.1)

That's pretty good stuff! The problem is, by the time you want to use it, the fertilizer value has changed dramatically. Think about it; you add bedding, several flocks come and go, and part of the nitrogen is lost as ammonia. The fertilizer value of chicken litter is so unpredictable, it is always a good idea to take a sample and send it to the lab for analysis. Results will come back with units of pounds of nutrients per ton in a dry and "as is" basis. "As is" means the amount of nutrients available per ton, given the moisture content of the litter on the day you took the sample. Table 1 shows some different "as is" fertilizer values from a number of studies.

Broiler Litter Fertilizer Values

Source	N	P_2O_5	K_2O
	(lbs/ton)		
Arkansas	56	48	36
Oklahoma	80	42	54
Missouri	54	26	32
Delaware	59	64	41
Alabama	78	74	50
Georgia	70	30	44
Tennessee	67	71	47
Texas	67	62	46
Average	**66**	**60**	**44**

Table 1. Broiler Litter Values, compiled by Jim Britton, Area Poultry Specialist.

Not all nitrogen listed in Table 1 is available to plants. A small portion of the remaining N will carry over into future growing seasons. A good rule of thumb is that 50 pecent of the total N is available for the crop the first year after application.

Step 2:Determine Crop Needs For N, P & K

Take advantage of the Cooperative Extension Service and have soil tested on each field you apply litter. An example soil test results and interpretation is given in Figure 2. Crop nutrients needs are given in the interpretations and requirements section of the soil test results. You can also determine crop nutrient needs using OSU Extension Facts #2225, OSU Soil Test Interpretations.

Step 3: Apply NRCS Guidelines to Determine Application Rate.

The NRCS guidelines take soil P fertility level, crop N needs, and field slope into account to determine litter application. The guidelines require you to calculate both an N and a P_2O_5 application rate. The N rate is always based on plant uptake. The P_2O_5 rate is based upon the criteria in Table 2. Once you have calculated both the N and the P_2O_5 rate, use the lowest of the two rates.

Let's work an example using the average broiler litter fertilizer values in Table 1 and the soil test results in Figure 2. The field slope in this example is three percent.

Nitrogen Application Rate:

Plant available N in litter

$$\frac{66 \text{ lbs total N}}{\text{Tons litter}} \cdot \frac{1 \text{ lb plant available N}}{2 \text{ lbs total N}} = \frac{33 \text{lbs PAN}}{\text{Ton Litter}}$$

Nitrogen Application Rate

$$\frac{200 \text{ lbs. N}}{\text{Acre/Year}} \cdot \frac{\text{Ton Litter}}{33 \text{ lbs PAN}} = \frac{6 \text{ tons Litter}}{\text{Acre-year}}$$

P_2O_5 Application Rate:

Soil P Index is 100 lbs/acre; therefore, according to NRCS guidelines, P_2O_5 Application Rate is 200 lbs P_2O_5 Acre-year.

$$\frac{200 \text{ lbs } P_2O_5}{\text{Acre-year}} \cdot \frac{\text{Ton Litter}}{60 \text{ lbs } P_2O_5} = \frac{3.3 \text{ Tons Litter}}{\text{Acre-year}}$$

The P_2O_5 rate is lowest, so our litter application rate is 3.3 Tons/Acre-year.

Spreading at this rate will not give all the N needed to grow four tons of Bermuda Grass per acre. The N requirement for four tons/acre is 200 lbs PAN/acre-year. 3.3 tons of litter provides:

$$\frac{3.3 \text{ Tons Litter}}{\text{Acre-year}} \cdot \frac{33 \text{ lbs PAN}}{\text{Ton Litter}} = \frac{110 \text{ lbs PAN}}{\text{Acre-year}}$$

You will need to add 90 lbs N/Acre in the form of commercial fertilizer to meet the 4 tons Bermuda/Acre yield goal.

Also, since the P_2O_5 application rate is determined by the soil's capacity to absorb P_2O_5, you will have to wait one year before spreading additional litter on the field. Over time, both P_2O_5 and organic nitrogen will accumulate in the soil with repeated applications. This is why it is important to test soil fertility levels every two to three years

Step 4: Determine Amount Of Litter Needed To Spread In The Field

Take the rate you calculated in Step 3 and multiply it by the number of acres in your field.

Continuing with the example:

$$\frac{3.3 \text{ Tons}}{\text{Acre}} \cdot \frac{50 \text{ Acres}}{\text{field}} = \frac{165 \text{ Tons}}{\text{field}}$$

If the spreader truck holds six tons of litter, it will take 28 trips over the 50-acre field to spread the litter.

Step 5: Calibrate The Spreader Truck To Apply The Rate Determined in Step 3.

The exercise we just went through is meaningless if you don't know how much litter your equipment is spreading. Follow the procedure in the handout "Calibration of Litter Spreading Trucks" to apply the proper rate.

Soil Test Report

McEntire County Extension Office
1500 Reba Avenue
Gill, OK 74000

Name: Joe Farmer
Location: McEntire County

Lab I.D. No.: 105582
Customer Code: 686
Sample No.: 6
Received: 5/28/96
Report Date: 5/30/96

-Soil Reaction -		-NO3-N (lbs/acre) -		-Availability Index-	
pH:	6.2	Surface:	11	P (lbs/Acre):	100
Buffer Index:	7.3	Subsoil:		K (lbs/Acre):	223

Secondary nutrients		Micro nutrients
Subsurface SO4-S (lbs/acre) :	Ca (lbs/acre) :	Fe (ppm) :
Subsoil SO4-S (lbs/acre) :	Mg (lbs/acre) :	Zn (ppm) :
		B (ppm) :

INTERPRETATIONS AND REQUIREMENTS FOR Bermuda Grass (yield goal = 4 Tons/Acre)

Test	Interpretation	Requirement
pH	Adequate	No lime required
Nitrogen	.	200 lbs/acre N annually
Phosphorus	100% sufficient	No P_2O_5 Required
Potassium	98% sufficient	10 lbs/acre K_2O annually

Figure 2. Example Soil Test Report.

Soil test P index	Field Slope: 0 - 8%	8-15%	15% +
low (0 - 65)	200 lbs/acre	200 lbs/acre (Split into two 100 lb applications)	No application
Moderate (65-250)	200 lbs/acre	100 lbs/acre	No application
High (250 - 400)	100 lbs/acre	100 lbs/acre	No application
Severe (400 +)	plant uptake	plant uptake	No application

Table 2. Annual P_2O_5 Application Rates Based On Soil Fertility Level and Field Slope (NRCS, 1995)

SOIL FERTILITY DEMONSTRATION
JIMMY THOMAS RANCH PONTOTOC COUNTY
RESULTS OF FIRST CLIPPING 7/13/95

TOTAL FORAGE DRY MATTER PRODUCTION (LBS/ACRE)

$P > 0.0132$

Treatment #	Treatment	DM Production
4 a	P + 200 lb N	7596
3 a	P + 100 lb N	7196
7 ab	P + 200 lb N + aeration	7004
6 abc	P + 100 lb N + aeration	6349
1 bcd	Control	3918
2 cd	P only	3454
5 d	P + aeration	2479

TOTAL BERMUDAGRASS DRY MATTER PRODUCTION (LBS/ACRE)

$P > 0.0005$

Treatment #	Treatment	DM Production
7 a	P + 200 lbs N + aeration	4158
4 a	P + 200 lbs N	3470
6 ab	P + 100 lbs N + aeration	2990
3 bc	P + 100 lbs N	1743
1 c	Control	1247
2 c	P only	688
5 c	P + aeration	336

Jim Enis

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895 • VOLUME 100 – NUMBER 255 THURSDAY, JUNE 20, 1996 14 PAGES POTEAU, OKLAHOMA 74953

THURSDAY 35¢

Spectators watch as tented workers collect runoff water samples produced by a portable rain simulator. (Photo/Ken Milam)

Experts seek pollution solution

By Ken Milam
PDN&S Managing Editor

Using lake sludge and artificial rain, Oklahoma scientists showed a new way to "clean" water before it runs into lakes and streams.

The demonstration Wednesday at the Kerr Center for Sustainable Agriculture drew about 75 observers invited from area industries.

Scientists from Oklahoma State University plan a larger "field day" demonstration on Aug. 7.

Phosphorus is a problem at Wister Lake, the source of most of LeFlore County's drinking water. Runoff from land fertilized with chicken litter from area poultry operations is a major source of the chemical, experts say.

The idea behind the EPA-funded experiment is to show area industries how to reduce phosphorus in runoff.

The No. 1 factor is the amount of poultry litter used on the soil, said OSU's Dr. Doug Hamilton.

"We're trying to get them to look at the economics of putting on less litter and getting better water quality, Hamilton said.

Grass height is another factor affecting the runoff content, Hamilton said.

The demonstration will also show the effect of using sludge removed from treated lake water to reduce phosphorus.

Phosphorus and other impurities are removed from the lake water by treating it with alum, according to Poteau Valley Im-

(See WATER, Page 2)

WATER

provement Authority Director Pat Searles.

The impurities are removed as "hydrosolids," or sludge, according to Dr. Nick Basta of the OSU Agronomy Department.

Basta said that in lab tests, spreading the dried, crumbly alum-sludge over a plot of soil reduced the phosphorus content in runoff by 50 percent. Using the sludge as a buffer, rather than broadcasting it, reduced the chemical by 75 percent, Basta said.

In the Kerr Center demonstration, several plots of land were prepared using different amounts of sludge and poultry litter and differing heights of grass.

A mobile, rotary sprayer simulated a 2.5-inch per hour rainfall for 75 minutes. Assistants huddled in small tents, collecting runoff water samples at specific intervals. The sample will be tested before and after filtering to determine if the method works on a field scale.

If successful, the method could have multiple benefits, Basta said.

Growers could use the material to help reduce the phosphorus runoff, perhaps helping to avoid regulations limiting the use of poultry litter.

A secondary benefit is that the harmless material is produced by many water treatment plants.

"This stuff is free," Basta said.

In many cases, plant officials pay to dispose of the material in landfills.

PVIA stores the sludge, using it as filler material on pipeline and other projects, Searles said.

Phosphorus is not a direct health hazard to humans. The main concerns are that it affects other life in lakes, including potential fish kills, and makes the water harder to treat, Searles said.

Wednesday's demonstration was the first in the country, Basta said. Publication of the initial lab test results brought "calls from all over the country," he said.

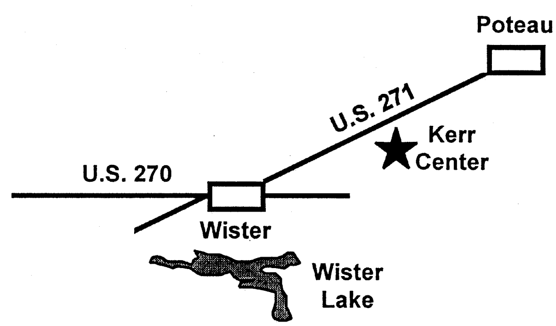
The project is funded by the EPA, with the money funnelled through the Oklahoma Conservation Commission to the OSU Agronomy and Agriculture Engineering Biosystems departments.

Also conducting the experiment was Dr. Dan Storm of the OSU Agriculture Engineering department.

Oklahoma Cooperative Extension Service
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

Waste Management

Summer Field Day Pre-View
June 19, 1996
Kerr Center for Sustainable Agriculture



Rain will Commence at 1:00 pm

See demonstration of Rainfall Simulator plots illustrating Best Management Practices for Poultry Litter and Livestock Manure Application.

Later this summer, farmers will have an opportunity to view these same techniques along with manure spreader calibration, hay and pasture equipment demonstration, manure management equipment display, riparian zone protection demonstration, and a full extension program on application rate determination.

Producer Field Days

July 10	**Poultry/Dairy**	**Hudson Foods, Adair Co.**
Aug 7	**Poultry/Swine**	**Kerr Center, LeFlore Co.**

OKLAHOMA COOPERATIVE EXTENSION SERVICE
CHEROKEE COUNTY CONSERVATION DISTRICT
ADAIR COUNTY CONSERVATION DISTRICT

AGRICULTURE AND WATER QUALITY COOPERATING

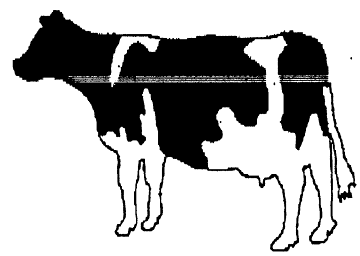
RAINFALL SIMULATOR

A WATER QUALITY EXPERIMENT / DEMONSTRATION

OPEN TO THE PUBLIC
FREE OF CHARGE
REFRESHMENTS SERVED

QUESTION: **Animal manures** -- water pollutant or valuable fertilizer?

Or, does it depend on how it's managed?

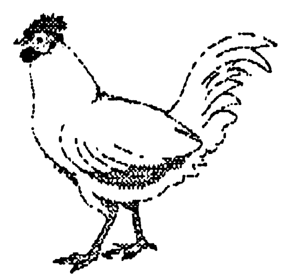


ANSWER: See for yourself -- join us for a rainfall runoff experiment / demonstration on **pasture fertilized with manures** in the Illinois River Watershed, in Adair County.

A 50-foot diameter Rainfall Simulator will be set up over pasture plots fertilized with varying amounts of poultry litter, dairy manure, and commercial fertilizer. "Rainfall" will be released on the plots. Runoff of water and other materials will be captured and measured on the spot. The effects of Best Management Practices will be illustrated.

OTHER ACTIVITIES:
- Poultry Equipment Display
- Manure Spreader Calibration
- Pond Protection Demonstration
- Manure Handling Equipment Display

LOCATION: HUDSON FARM COMPLEX #8, Chance, OK (see map, on reverse➢)



DATE / TIME: July 10, 1996 at 9:00 a.m.

WHO SHOULD COME: Poultry and other livestock producers, farmers, gardeners, - anyone concerned about using manures responsibly for optimum benefits.

FOR MORE INFORMATION:

Adair County Extension Office
918 696-2253

Area Water Quality Extension Office
918 687-2466

APPENDIX D

Producer Surveys

FOLLOW UP RAINFALL SIMULATOR DEMONSTRATION SURVEY

Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

Date 8-29-97 Interviewer J. Bullard County Leflore

1. Do you farm pasture? 74 acres pasture 26 acres hayland

2. Do you farm row crops? — acres — type(s)

3. Which of the following do you have on your farm:

Swine		Beef (cow/calf)	X
Dairy		Beef (stocker/feed lot)	
Broilers		Other (specify)	
Laying Hens			

4. How practical do you rate the following practices:

	Very Practical		Practical		Not Practical
Manure Spreader Calibration	1	2	3	4	5
Floating Fence for Limiting Pond Access	1	2	3	4	5
Vegetative Buffer Strips	1	2	3	4	5
Soil Testing for Nutrient Management	1	2	3	4	5

5. Do you think high rates of fertilizer or manure application can cause off-site water quality problems?

yes, without proper management

6. Do you think balancing nutrient application of poultry litter with commercial nitrogen fertilizer is a viable option?

yes

7. Since the rainfall simulator demonstration during the summer of 1996, what changes in management have you considered,

Soil testing
buffer strips

and which have you implemented on your farm?

buffer strips

8. What do you recall learning from the summer of 1996 field day?

excessive rates of litter or fertilizer increases run-off
buffer strips have value

9. Do you have any suggestions or comments?

need more producers

FOLLOW UP RAINFALL SIMULATOR DEMONSTRATION SURVEY

Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

Date 8-29-97 Interviewer J. Bullard County Leflore

1. Do you farm pasture? 40 acres pasture 15 acres hayland

2. Do you farm row crops? – acres – type(s)

3. Which of the following do you have on your farm:

Swine		Beef (cow/calf)	✓
Dairy		Beef (stocker/feed lot)	✓
Broilers		Other (specify)	Horses
Laying Hens			

4. How practical do you rate the following practices:

	Very Practical		Practical		Not Practical
Manure Spreader Calibration	1	2	3	4	5
Floating Fence for Limiting Pond Access	1	2	3	4	5
Vegetative Buffer Strips	1	2	3	4	5
Soil Testing for Nutrient Management	1	2	3	4	5

5. Do you think high rates of fertilizer or manure application can cause off-site water quality problems?

NO, not with proper management buffer strips avoid steep slopes, etc,

6. Do you think balancing nutrient application of poultry litter with commercial nitrogen fertilizer is a viable option?

yes

7. Since the rainfall simulator demonstration during the summer of 1996, what changes in management have you considered,

more frequent soil testing

and which have you implemented on your farm?

none

8. What do you recall learning from the summer of 1996 field day?

none

9. Do you have any suggestions or comments?

none

FOLLOW UP RAINFALL SIMULATOR DEMONSTRATION SURVEY
Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

Date 8-29-97 Interviewer J. Bulland County Leflore

1. Do you farm pasture? 450 acres pasture 125 acres hayland

2. Do you farm row crops? — acres — type(s)

3. Which of the following do you have on your farm:

Swine	–	Beef (cow/calf)	X
Dairy	–	Beef (stocker/feed lot)	–
Broilers	X	Other (specify)	–
Laying Hens	–		

4. How practical do you rate the following practices:

	Very Practical		Practical		Not Practical
Manure Spreader Calibration	1	2	3	4	5
Floating Fence for Limiting Pond Access	1	2	3	4	5
Vegetative Buffer Strips	1	2	3	4	5
Soil Testing for Nutrient Management	1	2	3	4	5

5. Do you think high rates of fertilizer or manure application can cause off-site water quality problems?

yes

6. Do you think balancing nutrient application of poultry litter with commercial nitrogen fertilizer is a viable option?

yes

7. Since the rainfall simulator demonstration during the summer of 1996, what changes in management have you considered,

testing
use commercial N to balance nutrients

and which have you implemented on your farm?

soil testing

8. What do you recall learning from the summer of 1996 field day?

soil test to determine litter application

9. Do you have any suggestions or comments?

none

FOLLOW UP RAINFALL SIMULATOR DEMONSTRATION SURVEY

Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

Date 8-22-97 Interviewer J. Bullard County Leflore

1. Do you farm pasture? 8/80 acres pasture 55 acres hayland

2. Do you farm row crops? 0 acres ______ type(s)

3. Which of the following do you have on your farm:

Swine		Beef (cow/calf)	X
Dairy		Beef (stocker/feed lot)	
Broilers		Other (specify)	
Laying Hens			

4. How practical do you rate the following practices:

	Very Practical		Practical		Not Practical
Manure Spreader Calibration	1	2	3	4	5
Floating Fence for Limiting Pond Access	1	2	3	4	5
Vegetative Buffer Strips	1	2	3	4	5
Soil Testing for Nutrient Management	1	2	3	4	5

5. Do you think high rates of fertilizer or manure application can cause off-site water quality problems?

yes

6. Do you think balancing nutrient application of poultry litter with commercial nitrogen fertilizer is a viable option? could be, may not be practical

7. Since the rainfall simulator demonstration during the summer of 1996, what changes in management have you considered,

Pond exclusion

and which have you implemented on your farm?

plan to put in freeze proof water to exclude cattle

buffer strips already in use

8. What do you recall learning from the summer of 1996 field day?

rainfall simulator results

9. Do you have any suggestions or comments?

good

FOLLOW UP RAINFALL SIMULATOR DEMONSTRATION SURVEY

Demonstrating BMPs to Protect Surface Water Quality From Land Application of Animal Wastes

Date 8-29-97 Interviewer J. Bullard County Leflore

1. Do you farm pasture? 250 acres pasture 100 acres hayland

2. Do you farm row crops? 0 acres 0 type(s)

3. Which of the following do you have on your farm:

Swine		Beef (cow/calf)	130
Dairy		Beef (stocker/feed lot)	
Broilers		Other (specify)	
Laying Hens			

4. How practical do you rate the following practices:

	Very Practical		Practical		Not Practical
Manure Spreader Calibration	1	2	3	4	5
Floating Fence for Limiting Pond Access	1	2	3	4	5
Vegetative Buffer Strips	1	2	3	4	5
Soil Testing for Nutrient Management	1	2	3	4	5

5. Do you think high rates of fertilizer or manure application can cause off-site water quality problems?

yes

6. Do you think balancing nutrient application of poultry litter with commercial nitrogen fertilizer is a viable option?

yes

7. Since the rainfall simulator demonstration during the summer of 1996, what changes in management have you considered,

floating fence

and which have you implemented on your farm?

buffer strips

8. What do you recall learning from the summer of 1996 field day?

Aeration was not valuable

9. Do you have any suggestions or comments?

more demonstrations like this