CHARACTERIZATION OF AGRICULTURAL RUNOFF ASSOCIATED WITH ProAgri^{TM} TREATMENT OF POULTRY LITTER ADDED TO SOILS

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ABSTRACT

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CHARACTERIZATION OF AGRICULTURAL RUNOFF ASSOCIATED WITH ProAgri^{TM} TREATMENT OF POULTRY LITTER ADDED TO SOILS

One of the greatest problems facing crop producers, who utilize poultry litter as a fertilizer for their fields, is phosphorus (P) runoff. Although phosphorus is a necessary element for optimal crop production, it can also have an adverse reaction when introduced into the aquatic environment. This problem is thought to have been helped by a new litter treatment product, ProAgri^{TM} that became available for use in the poultry houses, which allegedly binds up the excess P. The purpose of this study was to examine the effect of the ProAgri^{TM} on water quality of runoff.

Four different treatments which included a control with no poultry litter, untreated poultry litter, ProAgri^{TM} treated poultry litter, and ProAgri^{TM} plus Activator treated poultry litter were applied at the rate of 2 tons per acre. Natural and simulated rainfall events produced runoff that was analyzed for water quality.

No statistical differences ($p>0.05$) were found in soluble phosphorus, total suspended solids, turbidity, conductivity, dissolved oxygen, alkalinity, hardness, and pH in runoff water between treatments.

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I am very grateful to all of my friends for their support and assistance during this time. I thank them for this.

A very special thank you to my family, who has supported me my whole life in all that I chose to do. To my Dad, sisters, Stevie and Viz, Aunt Karla and Uncle Rankin and fiancé, Brandon: thank you so much, I would not be here if not for you!

I dedicate this thesis to my mother, Fern; you taught me so much and left too soon.

CLH

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LIST OF ABBREVIATIONS

P…………………………………………………………...Phosphorus

N…………………………………………………………..Nitrogen

K…………………………………………………………Potassium

TKN………………………………………..Total Kjeldahl nitrogen

TP………….…………….……………………Total phosphorus

DP………….…………………..solved reactive phosphorus

COD……….……………………………Chemical oxygen demand

UT………..……………………………………Untreated litter

NL………………………………………………………No litter

PA………………………………………ProAgri™ treated litter

Act…………………………ProAgri™ plus Activator treated litter

TSS………………………………………Total suspended solids

Chapter I

Introduction

Agriculture today is under a lot of pressure from humanity, due to the increase in concern for environmental quality. Animal manure is utilized as a fertilizer in many areas, and is useful as such; however, it can lead to excessive nutrients in surface water due to runoff following rainfall events. In regions having a large poultry industry, poultry litter is one of the most widely available sources of animal waste fertilizers for crop producers. As with most animal waste products, poultry litter is high in nitrogen (N) and phosphorus (P). It can range between 18-96 lbs/ton of P_2O_5, 22-98 lbs/ton of N, and 23-80 lbs/ton of K_20 (VanDevender, 2000). These nutrients also cause severe damage to the environment when in excess. In recent years, concerns have arisen over the amount of P entering the aquatic environment, particularly on the east coast, where *Pfisteria* outbreaks have occurred. One of the main sources of phosphorus in rivers and lakes is agricultural runoff (nonpoint source phosphorus runoff) (Moore et. al., 1999). This is not just a concern that is confined to a specific area, it is worldwide. High-quality surface waters in Ireland continue to decline (Dunne et al., 2005). Cleneghan (2003) proposed that nutrient losses such as N and P from Irish agricultural practices also continue to contribute to surface water pollution. Cloern (2001) observed a rise in nitrate concentrations within three rivers in different areas of both North America and Europe. These trends of increasing N concentration are representative of changes in the nutrient (N and P) chemistry of rivers throughout the developed world, with many showing progressive increases that accelerated during the period of 1960 through 1990 (Cloern, 2001).

Because over application of fertilizer is an uneconomical practice for the producer, it is an uncommon practice among them particularly when using commercial fertilizer. However, field applications of poultry litter at rates to meet forage N requirements normally result in an over-application of P (Shreve, B. R., *et al*., 1995). In the 1992 (a, b) and 1993 studies conducted by Edwards and Daniel, they found that poultry litter applications to pastures resulted in relatively high P runoff, even when litter was applied at recommended rates of N, P and K. VanDevender *et. al* (2000) suggests the application of no more than 2 tons per acre for each application, and annual application of no more than 4 tons per year.

Phosphorus is an essential element to the sustained productivity of a pasture; however, it can also be a pollutant to the environment with negative effects on water quality. When lakes and rivers are polluted with P, excessive growth of algae often results. High levels of algae reduce water clarity and can lead to decreases in available dissolved oxygen as the algae decays, conditions that can be very detrimental to game fish populations (Busman, L. A. *et al*., 2002). Different species of aquatic-life-forms react differently to hypoxia, or the reduction of available dissolved oxygen. Brietburg (1992) and Diaz and Rosenberg (1995) found that physiological and behavioral responses to oxygen deficiency are highly dependent upon the magnitude, duration, and frequency of hypoxia, and the life-history stage and age of the exposed species. Phosphorus can be contained in the soil, and during erosion, can be transferred with the sediment to bodies of water. Even though P is exposed to the water, it isn't always released into the water. Soil can retain P as long as there is sufficient contact with the soil.

Eutrophication is the increase in chemical nutrients, for instance P or N, in a given ecosystem, to optimum levels for plant and animal growth. Eutrophication is a natural process. However, it can also be attributed to human activities, like the continued dumping of sewage in confined areas, or fertilizer runoff. Accelerated eutrophication, the biological enrichment of a water body due to anthropogenic inputs of nutrients, is one of the major causes of surface water impairment in the United States (US-EPA, 2003). Destruction of water sources from these nutrients can have detrimental effects on the environment, mainly in regards to the algae produced in surface water.

The amount of runoff produced during a rainfall event is correlated with the concentration of nutrients found in the runoff. Increasing the litter application rate significantly increased runoff concentrations of P in all litter constituents investigated. Over time, nutrients soak into the ground and fewer nutrients are lost during a rainfall event due to water runoff. Concentrations of TKN, TP, DP, and COD significantly decreased with increasing rainfall intensity because of more runoff and the associated dilution (Edwards, et al., 1992a, b; 1993).

A new product has become available to help with the control of excess nutrients entering local water sources. This product has already shown potential in poultry houses to be effective in increasing binding of P by research conducted by Envirovest LLC and Atoka, Inc. Treatment of poultry litter prior to application to the field may be beneficial if it binds the P and prevents it from solubilizing in the runoff.

Chapter II
Literature Review

Phosphorus Run-off into Surface Water

Phosphorus is found naturally in the environment, including water, living organisms, and the Earth's crust. Phosphorus is an essential element for plant growth. Plants take up P from soil mostly in the orthophosphate form (Daniels *et al*, 1998). Most of the P in animal manure is in an organic form and must be converted to plant-available forms via soil biological activity, a process known as mineralization (Daniels *et al*, 1998). The net effect of this characteristic is that P derived from animal manure may act more like a slow-release fertilizer than commercial inorganic fertilizers, which are more soluble and readily available to plants (Daniels *et al*, 1998). Certain areas can have low P content in the soil, and require fertilizer to be added to bring up the P content. Phosphorus saturation in the soil causes P runoff into surface water. The saturation of soil can be calculated by the following formula: [P/(Fe+Al)] (Khiari, L. and L. E. Parent, 2000). However, when in excess, P can cause many different problems with water quality.

Eutrophication is a term used to describe the excess nutrients that begin to collect in bodies of water, such as slow-moving streams, lakes, and estuaries (USGS, 2008). Eutrophication has many water quality hazards associated with it, especially when dealing with an increase in P levels. Higher levels of P cause algae to grow rapidly (Mullins, 2001). The algae blooms from these growing plants can kill fish and harm livestock and wildlife by reducing the amount of available oxygen content in the water, as well as produce large quantities of toxins (USGS, 2008). Large amounts of algae are a problem for filtration devices used to purify drinking water. Also, once the algae begins to decay, it releases odors, contaminates the water with scum, and is a perfect breeding ground for many species of insects (Mullins, 2001). In 1992, the EPA reported that accelerated eutrophication was one of the leading problems facing the Nation's lakes and reservoirs (Mueller *et al.*, 1996).

The United States Environmental Protection Agency (USEPA) has set standards for the amount of P allowable in streams to help control eutrophication. Streams that enter into lakes are allowed 0.05 ppm of TP; whereas flowing streams are allowed 0.1 ppm of total P (USEPA, 1986).

Arkansas is known for its vast poultry industry, especially concentrated in the north and northwestern areas of the state. Arkansas as a state, ranks second in the United States of America in poultry production, and the vast majority of that production is in Northwest Arkansas (Soerens, *et al.*, 2003). According to the 2007 USDA Census of Agriculture, there were 9,043 poultry houses in the state of Arkansas. The number of poultry houses (7,903 houses) has increased since 2002. With this number of poultry houses, an immense amount of poultry litter is being produced. A typical grow out in a poultry house lasts seven weeks. The chicks are brought to the house the day they are hatched. They are looked after daily by the farmer, who also inspects the mechanical equipment, checks the water lines, removes sick or dead birds, monitors feed bins, and keeps records (Doye, 2004). At the end of the seven weeks, the houses can either be completely cleaned out, where fresh bedding is reapplied, or only the cakes of moisture and fecal matter can be removed.

Litter beetles, also known as Darkling beetles or Lesser Mealworms (*Alphitobius diaperinus*), are found in chicken houses where they scavenge for food. These beetles feed on poultry feed, poultry carcasses, and bird droppings (Townsend, 1998). They can become contaminated with pathogens such as *Salmonella*, *Escherichia coli*, or infectious bursal disease virus (Townsend, 1998). In addition to spreading disease, the beetles can invade neighboring homes and buildings, in addition to damaging the current structure they inhabit. For this reason, growers treat the poultry houses with an approved pesticide (Carpenter, 2000). Some growers prefer to treat poultry houses the same day the birds leave, while others treat the houses after the clean out (Carpenter, 2000).

Beginning in 2005, the state of Oklahoma began talking with the poultry producers in Arkansas about concern that the Illinois River was becoming polluted due to the high amount of water runoff from poultry litter fertilized fields. The Illinois River originates in Northeast Arkansas and forms Tenkiller Lake by flowing into Oklahoma. In the 1980s, turbidity increases in Tenkiller Lake caused concern that the aesthetic quality of the lake and the Illinois River might be threatened (Soerens, *et al.*, 2003). Nutrient enrichment was identified as the source of the problem, with P being identified as the limiting nutrient (Soerens, *et al.*, 2003). Frustrated that nearly four years of talks failed to produce a solution, the state of Oklahoma sued eight firms -- including Arkansas giant Tyson Foods Inc. -- on the grounds that the chicken waste applied to crops near the river contains hazardous chemicals that are damaging the ecosystem and jeopardizing the region's tourist industry (Eilperin, 2006). As of 2009, the case was tied up in federal courts. Similar cases have been filed in other states. In 2004 in Waco, Texas, officials sued Excel Dairy of Dublin and its operators, after the dumping of manure from out-of-town dairy farms into the North Bosque River polluted their drinking water. The officials won the case, and the water was monitored until 2006. (Smith, 2004; Eilperin, 2006).

Effects of Poultry Litter on Water Runoff

Poultry litter application is commonly based on the N requirements of the field in order to reduce the loss of N from leaching (Hatfield, *et al.*, 1997). Generally, the N:P ratio is low in animal manure fertilizers, resulting in excess P levels (Hatfield, *et al.*, 1997) when application rates are based in the N requirements of the crop. Moore, *et al.*(1995b) found that the nutrient requirements for most hay and grain crops is 8:1 ratio, while poultry litter only provides roughly 2 or 3:1.

Edwards and Daniel (1993) found that the majority of P found in the agricultural water runoff was dissolved reactive P, or water-soluble. This poses a particular problem, because water soluble P is utilized by algae (Snozogni *et al*., 1982). Concentrations of P found in water runoff are often greater in fields that have been recently fertilized with poultry litter (Edwards and Daniel, 1992a, b, 1993; Shreve *et al.*, 1995). Shreve *et al* (1995) found that the P levels dropped after the second or third rainfall that resulted in water runoff. DeLaune, *et al.* (2006) conducted a runoff study utilizing poultry litter and found that by controlling soluble P levels, the runoff P was reduced. This was because the lowest amount of P concentration in the runoff occurred from plots fertilized with the least amount of soluble P.

Reduction of Excessive Phosphorus Deposits to Fields

One of the greatest problems facing farmers today is phosphorus runoff following manure application to fields. Various methods of chemical amendments to poultry litter have been tested with good results. Moore and Miller (1994) found that adding mineral compounds, including aluminum, iron, and calcium, to the poultry litter reduced the amount of soluble P. This study indicated that by reducing the amount of soluble P in the manure, the amount of P runoff would be decreased. Aluminum sulfate [$Al_2(SO_4)_3$], also known as alum, is commonly added to poultry litter. Shreve *et al*. (1995) indicated that alum applications to poultry litter reduced P concentrations in runoff water by 87%. Moore *et al.* (1997a) found that during a three year study utilizing alum treated litter; P levels in water runoff were reduced by 75% on average. Furthermore, Moore *et al.* (2000) found that soluble reactive P in runoff was decreased by 73% using alum treated litter when compared to untreated litter.

Other benefits can come from utilizing chemical additives in poultry houses. Line (2002) found that an aluminum additive significantly reduced or completely eradicated the presence of *Campylobacter* and *Salmonella* both on the bird carcasses and in the litter itself. Moore *et al.* (2000) reported that alum decreased litter pH, which resulted in dramatically decreased atmospheric ammonia levels. The birds in the alum treated houses grew larger than the birds in the control houses (1.73 kg versus 1.66 kg bird weights), this increase in growth can be attributed to the reduced atmospheric ammonia.

How, when and where P sources are applied have a critical impact on the mobility of P in runoff (Davis, *et al.*). Poor timing of the application of poultry litter can be detrimental to the successful reduction of P in water runoff. Phosphorus applications should be made at times when significant runoff events are not expected (Davis, *et al.*). Sharpley (1997) determined that the potential for P to be transported in water runoff after litter application decreased with each rainfall event. Therefore, manure application to fields should not be done prior to a large rainfall event to prevent a large amount of P runoff.

Chapter III

Methods and Materials

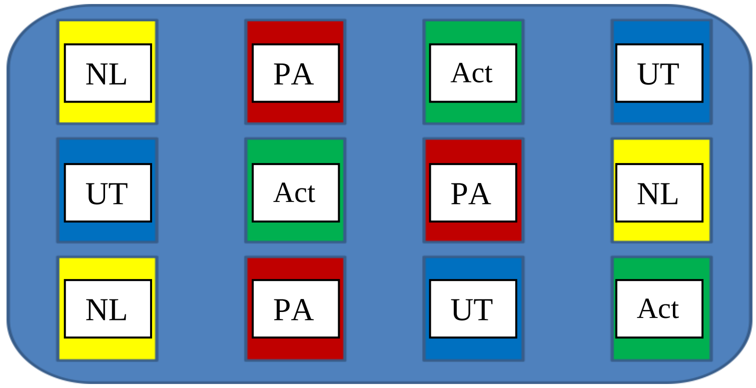
This experiment was conducted at the Arkansas State University Farm Complex from May 2008 to December 2008. An area was selected for placement of 12 individual plots. Using the specifications SERA-17 group (SERA-17, 2008), these plots were two meters long by one meter wide, with the long axis oriented down the slope. Plot frames were constructed from 0.6 centimeter aluminum that were 5.1 centimeters wide. One end of the plot frame was a tapered end, so water could be funneled into a collection container, creating a runoff flume (Figure 1). A hole was dug one meter deep just below the tapered end of the platform, where a 20-liter square plastic collection container was placed for collection of the runoff. Plastic funnels directed runoff from the runoff flume into the collection container. Plot frames were placed in the ground 3 centimeters. Steel deflectors of similar size to the plots were placed in the ground at approximately a 45° angle from the front of the plot, on each side angled away from the plot, to help deflect water away from the hole. Two of same deflectors have been anchored into the ground at the same depth in the rear of the plot, forming a triangle to prevent the flow of water up over the back or upward angled end of the plot (Figure 2). In order to combat the potential for runoff collection that did not originate in the plot, a piece of plywood, coated with exterior paint, was used to cover the triangular runoff flume of the aluminum plot, as well as the collection hole itself.

Natural rainfall was collected from selected rainfall events. Due to drought during the summer of 2008, it was decided to collect a combination of both natural and simulated rainfalls. To simulate rain, a “sprinkler system”, made from four steel pipes in an A-frame design was designed to fit directly over one plot at a time (Figure 3). The A-frame supported a piece of PVC pipe, which had multiple spaced holes drilled into its length. One end of the 2 meter long PVC pipe was plugged with a cap, while the other was connected to a water tank. The water was applied at a steady, gentle flow, so not to disturb the soil more than a normal rainfall. Water was applied to each plot until each collection container contained the same amount of runoff.

Four different treatments of litter (UT, NL, PA, and Act) were tested, with each being replicated three times. These plots were arranged in a Randomized Complete Block design (Figure 4). The plots were located on an area of the ASU Farm with a fairly even slope overall. The slope on this area was greater than two percent (>2%), which is standard protocol (SERA-17, 2008). Soil samples were taken at the beginning of the study to have a baseline soil nutrient status. Prior to a rainfall event, each plot was mowed to a uniform height of 10 centimeters and the grass clippings were removed. Soil samples are taken at the 0-5 cm and 5-10 cm depths on each plot (SERA-17, 2008). These samples were air dried, and sent to the University of Arkansas, Soil Testing and Research Laboratory in Marianna, Arkansas for nutrient analysis.

Figure 4: Plot layout-complete randomized block design

(NL=No litter, PA=ProAgri litter, Act=ProAgri+Activator litter, UT=Untreated litter)



There are several acceptable tests to measure the level of nutrients in the soil. "Mehlich 3 may be preferable, since it can also remove available forms of macronutrients (Ca, Mg, K, and Na) and micronutrients (Cu, Zn, Fe, and Mn) for analyses of these soils" (Elrashidi, M. A., 2009) This is the procedure that was used to identify the levels of all nutrients in runoff samples in this study.

Runoff was analyzed for soluble P, with a 1:10 litter to water ratio, for all litter treatments (SERA-17, 2008). Within 24 h of the runoff collection, samples were analyzed for total suspended solids, dissolved oxygen, and *E. coli*. Additionally, 30 mL of the sample was filtered through a 0.45 µm (micron)- filter disc for analysis of dissolved reactive P and frozen. Filtered samples were kept frozen until analyzed.

Dissolved oxygen (mg/L) was measured using a VWR™ SympHony meter. Determination of soluble reactive phosphorus (PO_4^{3-}) followed the ascorbic acid method with a detection limit of 0.05 mg/L and was analyzed by Flow Injection Analysis (Lachat Corp.). Total suspended solids was analyzed by the filtration method. *E. coli* was analyzed by filter membrane specifically for *E. coli*. All water quality parameters followed the APHA (2005) standard protocols.

Figure 1: Runoff collection device

Figure 2: Close up photograph of one of the poultry litter plots showing the runoff collection apparatus.

Figure 3: Rain simulator

Chapter IV

Results and Discussion

Analyses of water runoff are shown in Figures 5-12 and Appendix A. No treatment differences ($p>0.05$) were observed for soluble P levels (Figure 5). Soluble P levels did drop slightly for all treatment types between the August and September collection dates, with a slight increase from September to October, then decreased again by December's collection. This can be explained by the initial application of litter in May, and the second application in October. The pH of runoff water followed the same pattern as the P levels, with the same explanation (Figure 6).

Total suspended solids (Figure 7) showed no differences ($p>0.05$). Apparently, the litter remained on the plot and did not migrate into the runoff water.

No differences ($p>0.05$) in turbidity of the runoff water were found between treatments (Figure 8). An increase in the turbidity level for the month of December was observed in all treatments in comparison to the other collection months; however, no valid statistical analyses could be performed due to differences in the method of water application between months (natural rainfall versus simulated rainfall). One possible explanation for this is that in December there was less vegetation and more exposed soil, combined with this sample being collected through simulated rainfall, the rainfall rate could have been too fast or hard, dislodging more of the soil.

There were no differences ($p>0.05$) for the DO tests (Figure 9). The level of DO in all samples stayed similar over all collection dates.

There were no differences ($p>0.05$) in the level of conductivity between treatments (Figure 10). No valid statistical analyses could be performed due to differences in the method of water application between months (natural rainfall versus simulated rainfall), however, conductivity was higher in October and December samples for all treatments compared to August and September. This was due to the August and September samples being natural rainfall versus simulated rainfall (tap water) for the October and December samples.

No differences ($p>0.05$) in alkalinity between treatments were found (Figure 11). No valid statistical analyses could be performed due to differences in the method of water application between months (natural rainfall versus simulated rainfall), however, October and December had higher alkalinity levels compared to August and September levels. This could be explained by the simulated rainfall event. The simulated rainfall was done using city water, which may have been more alkaline then natural rainfall.

No differences ($p>0.05$) between treatments for hardness in runoff water was observed between treatments (Figure 12).

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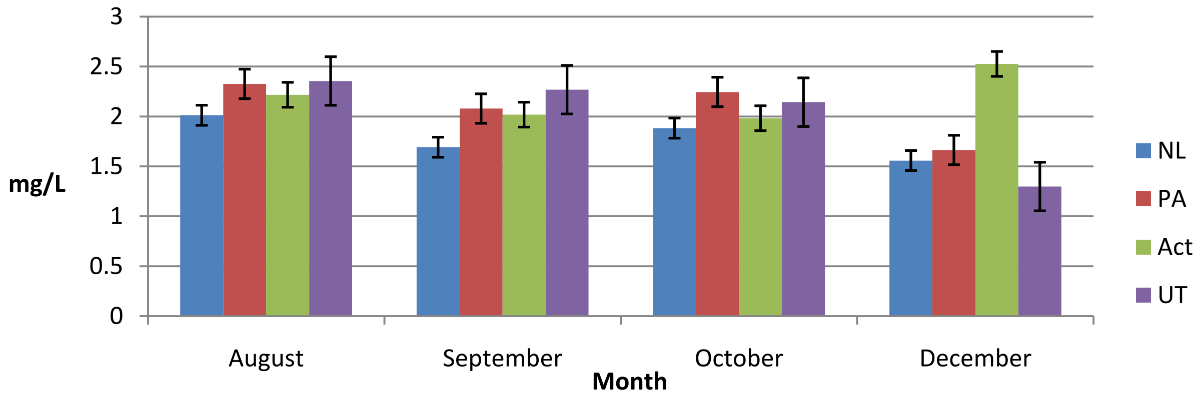
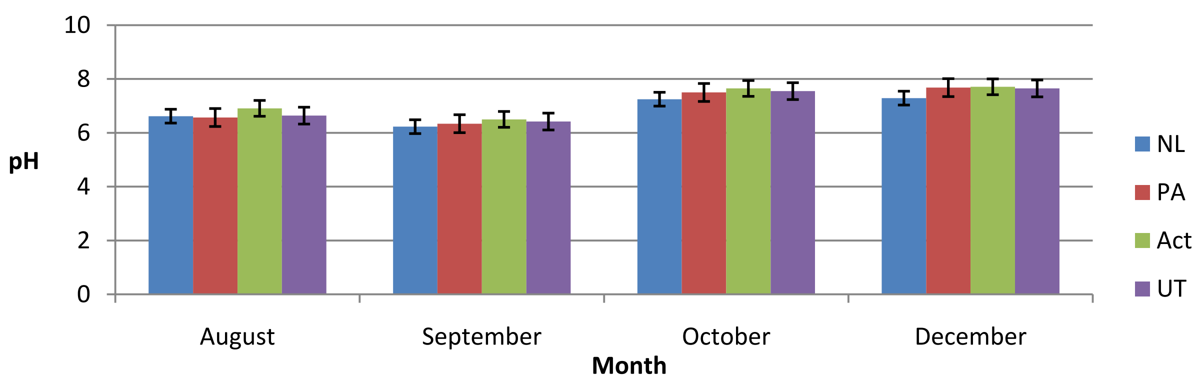
Figure 5. Soluble phosphorus level in runoff water following application of poultry litter



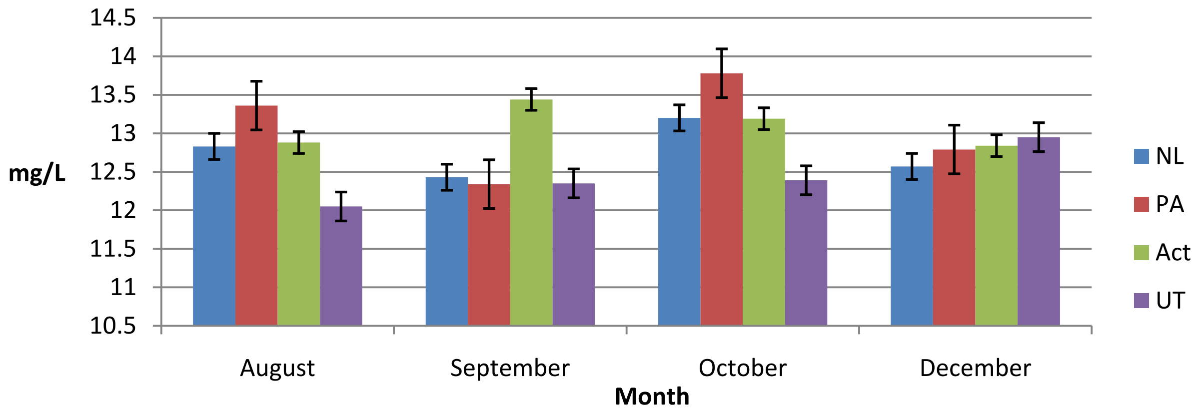
NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 6. pH of runoff water following application of poultry litter



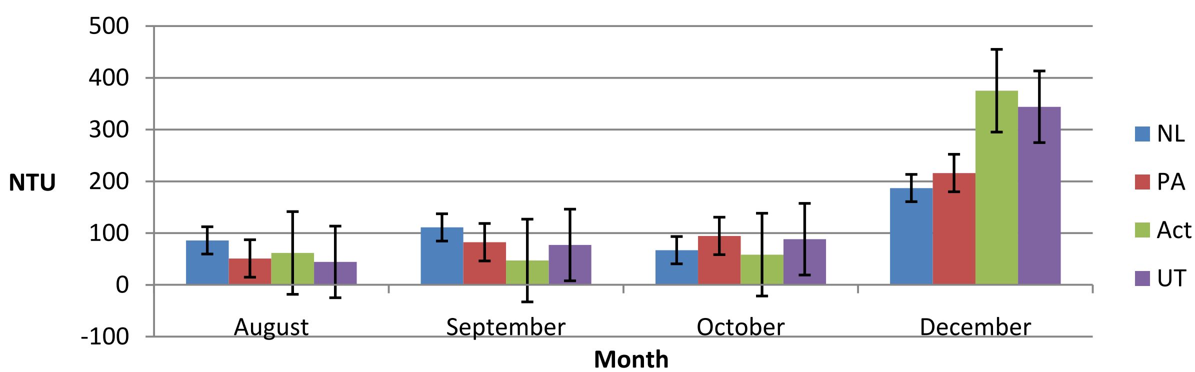
NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 7. Total suspended solids of runoff water following application of poultry litter



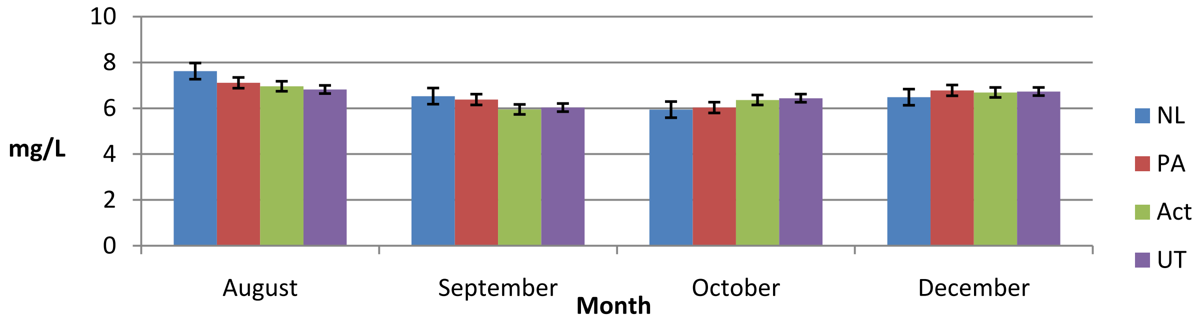
NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 8. Turbidity of runoff water following application of poultry litter



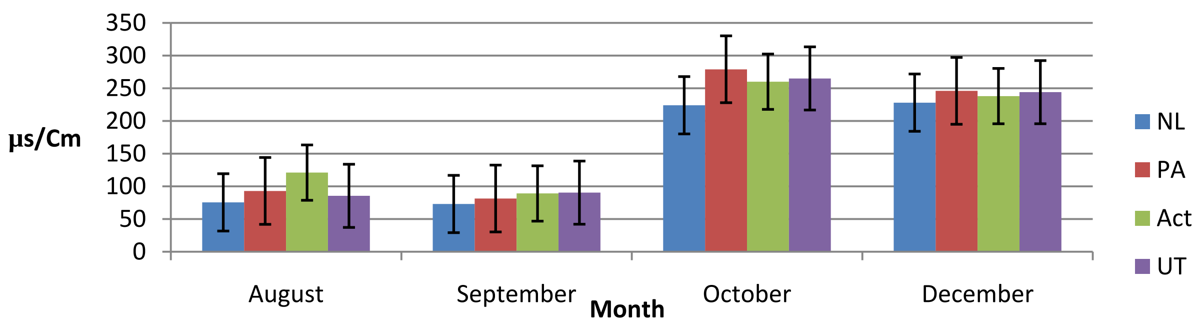
NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 9. Dissolved oxygen in runoff water following application of poultry litter



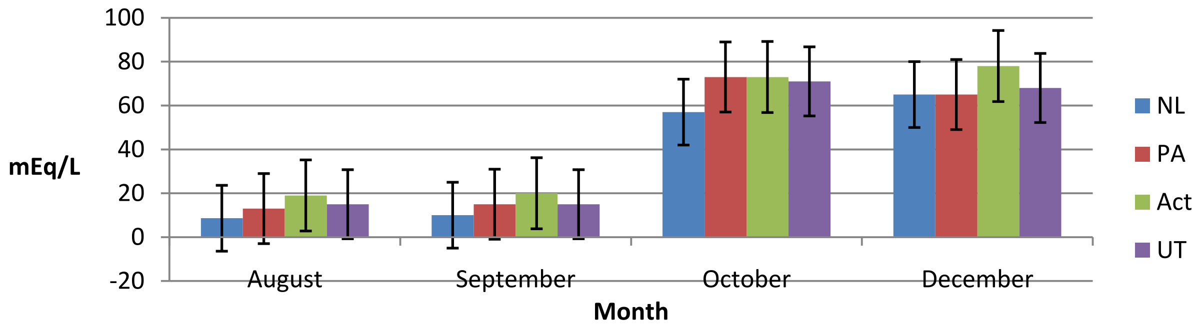
NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 10. Conductivity of runoff water following application of poultry litter



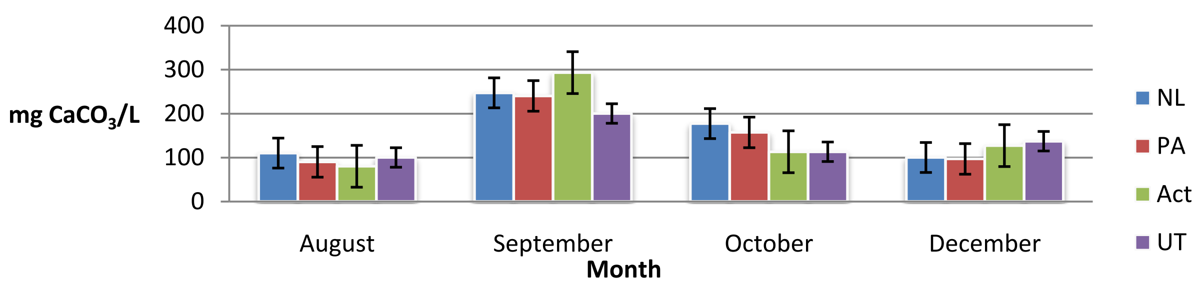
NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 11. Alkalinity levels in runoff water following application of poultry litter



NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Figure 12. Hardness level of runoff water following application of poultry litter



NL=No litter, PA=ProAgri litter, Act=Proagri litter, UT=Untreated litter

Chapter V
Summary and Conclusion

The objective of this study was to determine if treatment of poultry litter with ProAgri™ affected the soluble P runoff following the application of the litter to pasture. The plots that this study was carried out on were located on the ASU farm. The collection devices functioned correctly, however during times of extremely heavy rainfall, the holes containing the collection jug tended to over flow with water making the collection jugs float before they filled with runoff. This was modified by creating the jug stabilizer that held the collection jugs down long enough to fill with runoff water during the rainfall events.

A total of four rainfall events were collected, one in August, September, October and December. The first two rainfall events (August and September) were natural rainfalls, whereas the last two (October and December) were simulated rainfalls. In May, litter was applied, and then re-applied in October, since the initial rainfall was not collected after the May litter application.

No statistical differences ($p>0.05$) were found on any of the parameters tested between treatments. Soluble P levels in runoff were similar from all plots, including the control. This was speculated to have been caused by previous application of animal fertilizer in this area.

Further studies should be conducted to test the effects of the ProAgri™ treated poultry litter. Studies conducted in a laboratory setting would be ideal, where soil type and vegetation, collection times, water quality and amounts could be controlled. This would allow for statistical analysis to be conducted between time periods providing more useful information.

Literature Cited

Breitburg, D.L., 1992. Episodic Hypoxia in Chesapeake Bay: Interacting Effects of Recruitment Behavior, and Physical Disturbance. Ecol Monogr. 62(4):525-546.

Busman, L., J. Lamb, G. Randall, G. Rehm, M. Schmitt, 2002. The Nature of Phosphorus in Soils. University of Minnesota Extension. http://www.extension.umn.edu/distribution/cropsystems/DC6795.htsml.

Carpender, G. H., 2000. Poultry Growers Newsletter. North Carolina Cooperative Extension. http://www.ces.ncsu.edu/chatham/newsletters/poultry/2000/sumfall00.html

Cleneghan, C., 2003. Phosphorus Regulations: National Implementation Report. Environmental Protection Agency (EPA). Wexford, Ireland.

Cloern, J. E., 2001. Our Evolving Conceptual Model of the Coastal Eutrophication Problem. Marine Ecology Progress Series. 210: 223–253.

Daniels, M., T. Daniel, D. Carman, R. Morgan, J. Langston, K. VanDevender, 1998. Soil Phosphorus Levels: Concerns and Recommendations. University of Arkansas, Division of Agriculture, Cooperative Extension. Agriculture and Natural Resources. http://www.sera17.ext.vt.edu/Documents/Soil_P_Levels_Concerns_and_Recommendations.pdf

Davis, Jessica, Bob Stevens. Phosphorus Sources, Application Timing and Methods. SERA-17. http://www.sera17.ext.vt.edu/Documents/BMP_application_timing.pdf

DeLaune, P. B., P. A. Moore, Jr. and J. L. Lemunyon, 2006. Effect of Chemical and Microbial Amendment on Phosphorus Runoff from Composted Poultry Litter. J Environ Qual. 35:1291-1296. http://jeq.scijournals.org/cgi/content/full/35/4/1291#TBL1

Diaz, R.J., R. Rosenberg, 1995. Marine Benthic Hypoxia: a Review of its Ecological Effects and Behavioral Responses of Benthic Macrofauna. Oceanogr Mar Biol Annu Rev 33: 245-303.

Doye, D., B. Freking, J. Payne, 2004. Broiler Production: Considerations for Potential Growers. Oklahoma Cooperative Extension Service. F-202. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-3099/AGEC-202web.pdf

Dunne, E. J., N. Culleton, G. O'Donovan, R. Harrington, K. Daly, 2005. Phosphorus Retention and Sorption by Constructed Wetland Soils in Southeast Ireland. Water Research. 39:4355-4362.

Edwards, D. R., and T. C. Daniels, 1992a. Potential Runoff Quality Effects of Poultry Manure Slurry Applied to Fescue Plots. Am. Soc. Agric. Eng. 35:1827-1832.

Edwards, D. R., and T. C. Daniels, 1992b. Environmental Impacts of On-Farm Poultry Waste Disposal-A review. Bioresource Technology. 41:9-33.

Edwards, D. R., and T. C. Daniels, 1993. Effects of Poultry Litter Application Rate and Rainfall Intensity on Quality of Runoff from Fescue grass Plots. J Environ Qual. 22:361-365.

Eilperin, Juliet, 2006. Pollution in the Water, Lawsuits in the Air: Pollution in the Water, Lawsuits in the Air. Washington Post Staff Writer. Page A03.

Elrashidi, M.A. Testing Methods for Phosphorus and Organic Matter, Soil Biologic Methods. Natural Resources Conservation Service. http://soils.usda.gov/technical/methods/. Accessed 2/24/2009.

Hatfield, J. L., B. A. Stewart, 1997. Animal Waste Utilization: Effective Use of Manure as a Soil Resource. CRC Press. 96-122.

Khiari, L. and L. E. Parent, 2000. An Agri-Environmental Model for Potato Phosphorus Recommendations. Better Crops. Vol 84, No. 4, 1-3.

Line, J. E., 2002. *Campylobacter* and *Salmonella* Populations Associated with Chicken Raised on Acidified Litter. *Poult. Sci.*, 81(10), 1473-1477.

Moore, Jr., P.A., and D.M. Miller. 1994. Decreasing Phosphorus Solubility in Poultry Litter with Aluminum, Calcium, and Iron Amendments. J Environ Qual. 23: 325-330.

Moore, Jr., P.A., T. C. Daniel, D. R. Edwards, and D.M. Miller, 1995b. Effect of Chemical Amendments on Ammonia Volatilization from Poultry Litter. J Environ Qual. 24: 293-300.

Moore, Jr., P.A., B. E. Haggard, T. C. Daniel, D. R. Edwards, B. R. Shreve, and T. J. Sauer, 1997a. Demonstration of Nutrient Management for Poultry Litter using Alum Precipitation of Soluble Phosphorus. Final Report to U.S. EPA for Federal Assistance Project No. 9006749920.

Moore, Jr., P.A., T. C. Daniel, and D. R. Edwards, 1999. Reducing Phosphorus Runoff and Improving Poultry Production with Alum. Poultry Science. 78:692-698.

Moore, Jr., P.A., T. C. Daniel, and D. R. Edwards, 2000. Reducing Phosphorus Runoff and Inhibiting Ammonia Loss from Poultry Manure with Aluminum Sulfate. J Environ Qual. 29:37-49.

Mueller, D.K., and D.R. Helsel, 1996. Nutrients in the Nation's Waters--Too Much of a Good Thing?: U.S. Geological Survey Circular 1136, 24 p. http://pubs.usgs.gov/circ/circ1136/circ1136.html#PARTS

Mullins, G., 2001. Phosphorus, Agriculture, and the Environment. Virginia Cooperative Extension. http://www.ext.vt.edu/pubs/grains/424-029/424-029.html

Sauer, T. J., T. C. Daniel, P. A. Moore, Jr., K. P. Coffey, D. J. Nichols and C. P. West, 1999. Poultry Litter and Grazing Animal Waste Effects on Runoff Water Quality. J Environ Qual. 28:860-865.

Saylar, G. S., K. Nikbakht, J. T. Fleming, and J. Packard. Applications of Molecular Techniques to Soil Biochemistry. Soil Biochemistry.

SERA-17, 2008. http://www.sera17.ext.vt.edu/. Accessed 4/1/2009.

Sharpley, Andrew, 1997. Rainfall Frequency and Nitrogen and Phosphorus Runoff from Soil Amended with Poultry Litter. J Environ Qual. 26:1127-1132.

Shreve, B. R., P. A. Moore, Jr., T. C. Daniel, and D. R. Edwards, 1995. Reduction of Phosphorus in Runoff from Field-Applied Poultry Litter Using Chemical Amendments. J. Environ. Qual. 24: 106-111.

Smith, R. L., 2004. City, Dairy Settle Lawsuit on N. Bosque Pollution. Waco Tribune-Herald. Page 1-7A. http://www.milk4texas.org/articles/Waco121404.pdf

Soerens, T. S., E. H. Fite III, J. Hipp, 2003. Water Quality in the Illinois River: Conflict and Cooperation Between Oklahoma and Arkansas. Diffuse Pollution Conference Dublin. 9A Transboundary. 1-4.

Sonzogni, W. C., S. C. Chapra, D. E. Armstrong, and T. J. Logan, 1982. Bioavailability of Phosphorus Inputs to Lakes. J. Environ. Qual. 11: 555-563.

Townsend, L., 1998. Lesser Mealworms or Litter Beetles. University of Kentucky, College of Agriculture. http://www.ca.uky.edu/entomology/entfacts/ef507.asp

United States Environmental Protection Agency, 1986. Quality criteria for water 1986: Washington, D.C., U.S. Environmental protection Agency Report 440/5-86-001, Office of Water.

United States Environmental Protection Agency, 2003. National Section 303(d) List Fact Sheet. http://oaspub.epa.gov/waters/national_rept.control USEPA, Washington, DC.

United States Geological Society, 13 Mar 2008. United States Department of the Interior. Eutrophication. http://toxics.usgs.gov/definitions/eutrophication.html

Vandevender, K., J. Langston, and M. Daniels, 2000.Utilizing Dry Poultry Litter-An Overview. University of Arkansas, Cooperative Extension Services. Publication FSA8000.

Zimmermann, N. G., R. Angel, and W. Saylor, 2008. Effect of ProAgri™ amendment, before and after cleanout, on broiler litter moisture, calcium, nitrogen, and total and soluble phosphorus. Poultry Science. 86(Suppl. 1):90.

APPENDIX A. Analysis of runoff water from pasture following application of no litter (NL), ProAgri™ (PA), ProAgri+Activator (Act), and untreated litter (UT)

		August	September	October	December
Phosphorus, (mg/L)					
	NL	2.0120	1.6923	1.8833	1.5583
	PA	2.3260	2.0793	2.2453	1.6640
	Act	2.2170	2.0177	1.9817	2.5263
	UT	2.3553	2.2683	2.1433	1.2980
		p=0.912	p=0.223	p=0.831	p=0.485
TSS, (mg/L)	NL	12.8330	12.4330	13.2000	12.5730
	PA	13.3630	12.3370	13.7770	12.7930
	Act	12.8830	13.4430	13.1900	12.8370
	UT	12.0470	12.3500	12.3900	12.9470
		p=0.362	p=0.740	p=0.352	p=0.869
Turbidity, (NTU)	NL	85.9	110.9	66.8	186.7
	PA	51.0	82.4	94.5	215.7
	Act	61.6	47.0	58.4	375.0
	UT	44.3	77.0	88.2	344.1
		p=0.289	p=0.461	p=0.878	p=0.649
pH	NL	6.62	6.22	7.25	7.29
	PA	6.57	6.34	7.50	7.68
	Act	6.91	6.50	7.65	7.71
	UT	6.64	6.42	7.55	7.65
		p=0.412	p=0.314	p=0.054	p=0.126

APPENDIX A. (Cont)

		August	September	October	December
DO, (mg/L)	NL	7.62	6.53	5.94	6.48
	PA	7.11	6.38	6.03	6.78
	Act	6.96	5.95	6.36	6.69
	UT	6.82	6.03	6.44	6.73
		p=0.450	p=0.526	p=0.511	p=0.378
Conductivity	NL	75.5	73.0	224.0	227.9
	PA	93.0	81.4	279.4	246.2
	Act	120.7	89.1	259.9	238.4
	UT	85.5	90.4	265.1	244.3
		p=0.326	p=0.478	p=0.029	p=0.028
Alkalinity	NL	9	10	57	65
	PA	13	15	73	65
	Act	19	20	73	78
	UT	15	15	71	68
		p=0.266	p=0.300	p=0.188	p=0.006
Hardness	NL	110	247	177	100
	PA	90	240	157	97
	Act	80	293	113	127
	UT	100	200	113	137
		p=0.734	p=0.656	p=0.007	p=0.483

APPENDIX B. Initial soil phosphorus levels in plots

	Depth	
	0-5 cm	5-10 cm
Plot		
1	67	17
2	48	35
3	61	31
4	56	20
5	37	21
6	42	21
7	35	17
8	41	20
9	43	22
10	35	22
11	44	21
12	43	20

** reported as ppm

APPENDIX C. Phosphorus levels in poultry litter samples

	Phosphorus (SPLP)	Units
UT	168	mg/L
PA	83.8	mg/L
Act	40.6	mg/L

* UT= Untreated litter, PA= ProAgri^{TM} litter, Act= ProAgri^{TM} litter