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Gulnihal Ozbay
Delaware State University, gozbay@desu.edu

Raju Khatiwada
Delaware State University, University of Arizona

Lathadevi K. Chintapenta
Delaware State University

Eunice F. Handy
Delaware State University

Stacy L. Smith
Delaware State University

SUSTAINABLE FARM PRACTICE: STUDY OF TOTAL AND SOLUBLE PHOSPHORUS IN A POULTRY FARM EQUIPPED WITH HEAVY USE AREA PROTECTION PADS, DOVER, DELAWARE

***Gulnihal Ozbay[1], Raju Khatiwada [1,2], Lathadevi K. Chintapenta[1], Eunice F. Handy[1], and Stacy L. Smith[1]**
[1]Delaware State University, Dover, DE
[2]University of Arizona, Tucson, AZ
***Email of lead author: gozbay@desu.edu**

Abstract

Poultry litter contains high concentrations of water-soluble phosphorus and is readily transported in the farm run-off. This research aims to study the efficiency of heavy use area protection (HUAP) pads in decreasing litter spillage and phosphorous run-off at a Delaware poultry facility. Soil and water samples were analyzed for pH, total phosphorous, orthophosphate, and Mehlich III phosphorous throughout 2012. It has been hypothesized that the efficiency of HUAP pads would be reduced over time. Mehlich III phosphorus ranged from 22.82-200 mg/kg at site I, and 48.17 – 1179.6 mg/kg at site II, which were greater than the optimal soil concentrations. However, in the run-off, orthophosphate and total phosphorous levels were less than 0.05mg/L, and below U.S. EPA limits. This confirms that the HUAP pads, along with vegetative buffer strips, restricted the seepage of phosphorous into the run off. The results suggest minimal loss of nutrients from poultry house to water bodies.

Keywords: Poultry Farm, Heavy Use Area Protection, HUAP, Phosphorus, Soil Testing

Introduction

The U.S. poultry industry is the world's largest egg producer and second largest exporter of poultry meat. Between 1971 and 2011, broiler production increased from 4,535 to 22,679 tons. One of the Delaware, Maryland, and Virginia (Delmarva) Peninsula's most economically and socially beneficial industries is the poultry industry. Percentage distribution of broiler production within states in the U.S. shows that a major portion (93.5%) is from the mid-Atlantic and southeastern states, with Delaware having 215.6 million heads of the makeup (USDA NASS, 2015). Sussex County in Delaware is the birthplace of the nation's broiler chicken industry and ranks number 1 in the U.S. in broiler production (USDA 2012 Census of Agriculture, 2015). Over 74% of Delaware's agricultural sector is made up of poultry.

According to Delmarva Poultry Industry, Inc. (2015), approximately 1,700 farm families grow nearly 11 million chickens per week from four chicken companies in Delmarva Peninsula alone. However, poultry waste is the largest issue that is associated with mass poultry production. Even though, poultry waste is considered as a valuable resource for natural fertilizer, if not managed properly, it can degrade environmental quality, particularly surface and ground water resources (Ogejo, 2010).

According to Ogejo (2010), regardless of the size or type of farm, animal, livestock and poultry producers need to manage manure for better economic returns and environmental protection. Similar to other basins in the mid-Atlantic, the Chesapeake basin water is excessively impacted by agricultural development, residential development, habitat loss, and effluent discharge from sewage treatment plants (Andres et al., 2007; Chesapeake Bay Program, 2007). To support nutrient and sediment reduction through tracking and accountability, federal and state agencies (within their jurisdictions), such as the Natural Resources Conservation Service (NRCS) and the Delaware Department of Natural Resources and Environmental Control (DNREC) have instituted best management practices (cover crops, installation of heavy use area protection pads, and compost sheds among a few) to decrease pollution runoff from agriculture sources entering the Chesapeake Bay (DNREC, 2008; 2010).

Poultry manure contains excessive amounts of phosphorous, more specifically inorganic phosphorus (P), in the form of orthophosphate. Kleinman et al. (2011) found that the transfer of inorganic P from soils to runoff waters is induced by both precipitation and P adsorption. Kellogg et al. (2000) reported that poultry manure typically contains two to four times more phosphorus per ton than any other livestock operations, and about 45-70% of manure P is in the organic form, while the rest in inorganic form.

Enrichment of surface waters with plant nutrients such as nitrogen and phosphorus is described as “eutrophication”. Ongley (1996) reported that agriculture is the largest contributing factor to eutrophication of surface waters. An estimated 2.2 billion head of livestock and poultry generated approximately 1.1 billion tons of manure in 2007 (U.S. Environmental Protection Agency [EPA], 2013). Due to inherent excess amounts of phosphorous in poultry feed and inability of poultry animals to fully digest and absorb it, most of the P makes its way into the poultry manure in the form of natural excretions. The organic forms of phosphorus from manure changes to soluble and more readily available form through mineralization. If excess phosphorous is not managed properly, it will make its way into rivers and other aquatic systems through run-off events contributing to excessive growth of algae. This is ultimately lethal to aquatic animals like fish because of depleted oxygen levels (Burke, 2007), and also, degrades the water quality. Ongley (1996) listed many unwanted changes and effects caused by unmanaged manure on the farm and its surrounding environment. Farms receiving poultry litter may still contaminate the runoff with soluble phosphorous, even when best management practices (BMPs) are used. This phosphorous fraction is readily transported in the run-off during the rainfall season, often in excess of 2,000 mg P kg^{-1}. This may be due to high concentrations of water soluble phosphorous in poultry litter. Implementing and maintaining strict sustainable farm practices is imperative to reduce the levels of run-off of soluble phosphorous.

The use of heavy use area protection (HUAP) pads is one of the BMPs set in place to replenish areas that undergo extensive use of vehicles, animals, or agriculture. HUAPs aid in stabilizing animal waste, nutrient runoff, and sediment from entering waterways (Maryland Department of Agriculture [MDA], 2015). According to USDA NRCS (2010), HUAPs capture any litter spilled during poultry house cleaning and protects the soil by facilitating litter cleanup, which also minimizes leaching and runoff of nutrients from the poultry houses. Carcass composters, in-house litter amendments, manure storage structures, and vegetative environmental buffers are some of the BMPs used in chicken production practices (Delmarva Poultry Industry Inc., 2015). Although these practices may not completely solve the excess nutrient issues, a combination of these methods may decrease P loss from the farm (Shapley et al., 2007). Along with BMPs, vegetative buffer surrounding the poultry houses and downstream may significantly contribute to the removal of dissolved phosphorus (Delmarva Poultry Industry Inc., 2015). The objective of this study is to assess the efficiency of heavy use area protection HUAP pads in decreasing litter spillage and phosphorous run-off at a poultry facility in Delaware.

Literature Review

Soil and water quality protection are the major challenges that must be addressed in modern day agricultural systems. The Chesapeake Bay, as the largest estuary in the U.S., has a drainage basin over 166,534 km^2 and over 150 streams and rivers that drain into the estuary from six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and the District of Columbia. The bay is 322 km long and has over 50 billion liters of water flowing per day into the bay area from its freshwater tributaries. It supports more than 2,700 species of plants and animals and produces 227 million kg of seafood each year. However, today, various factors have negatively impacted water quality and deteriorating overall health of the bay ecosystem. The Chesapeake basin water is highly impacted by agricultural development, residential development, effluent discharge from sewage treatment plants and residential development (Andres et al., 2007). Point and nonpoint source pollutions have caused ecosystem eutrophication which stimulates hypoxia, anoxia, frequent fish kills, increased turbidity, loss of submerged aquatic vegetation, and changes in food web structure (Boesch et al., 2001). Excess nutrients and sediment pollution originated by the agricultural activities in Delmarva's tributaries are a major concern.

Coastal ecosystems across the Delmarva Peninsula are experiencing deterioration due to changing land use patterns, shifts towards intensive agriculture and rural-residential development. The regions intensely developed in the watershed have a high percentage of crop agriculture and contains a number of poultry production operations. Water quality degradation continues to be an important issue in those regions (CIB, 2011).

Per the PWE Environment Group Report (2011), the number of chickens produced annually in the U.S. has increased by 1,400% with over 8 billion chickens last 5 decades. However, the number of broiler farms has declined by 98% from more than 1.6 million in 1950 to just over 27,000 in 2007. These conflicting results confirm shifts in poultry production from traditional farms to industrialized processing plants that produce more and bigger chickens at a faster rate. According to the PEW Environment Group (2011), the large-scale concentrated animal feeding operations (CAFOs) have operated with limited to no lands other than only lands for the chicken houses and access roads resulting in over one-third of modern broiler operations with no associated croplands. Although the meat processing industry provides its wealth in certain regions of the Broiler Belt, the geographic consolidation of the broiler industry is much heavier in the northern Georgia and Alabama, eastern Maryland, and southern Delaware and results in serious environmental threat and increased water pollution.

Specifically, the waste production has raised serious concerns about treatment and disposal of the chicken manure along the shores of the Chesapeake Bay, the largest estuary system in the U.S., with over 12 million cubic meters of chicken waste produced by over 523 million chickens produced each year in just Maryland and Delaware alone. The diminishing crop lands and the increasing manure loads limits the uses of the manure for cropland soil enrichment. Practically, there are more manure than needed for the crop lands resulting in excess nutrients from the poultry farms flowing into ditches, streams, and rivers feeding into the Chesapeake Bay (the PEW Environment Group, 2011).

The transfer of nutrients from the poultry houses to water bodies is potentially a severe environmental threat (Gerber et al., 2007). To support nutrient and sediment reduction, federal and state agencies (within their jurisdictions), such as the Natural Resources Conservation Services (NRCS) and the Delaware Department of Natural Resources and Environmental Control (DNREC) in Delaware, have instituted best management practices (BMPs). The BMPs include use of cover crops, installation of heavy use area protection pads and manure storage sheds, to mention a few. These practices decrease pollution run-off from diffuse agriculture sources, preventing run-off from entering nearby waters, some of which flow to the Chesapeake Bay. HUAP is the stabilization of areas frequently used by people, animals, or vehicles by establishing a suitable cover. It provides safe and stable access to frequently used areas and helps to keep the farm clean and animals healthier. Most importantly, it helps to protect soil from contamination by nutrients and improve the quality of ground and surface waters by allowing the cleanup of spilled manure and litter thereby reducing the leaching and run-off of nutrients (USDA NRCS, 2010).

Materials and Methods

To meet the study's objective, water and soil samples were collected from old and new poultry houses equipped with HUAP pads within the facility. These samples were analyzed for saturated P, total P, and Mehlich III P along with pH, and electric conductivity. Correlation of phosphorus content and precipitation data was also determined and analyzed statistically. Table 1 below shows the phosphorus forms of interest in this study.

Table 1. Phosphorus Forms of Interest, their Descriptions and Extraction Technique

Phosphorus type	**Description**	**Extraction Technique**	**References**
Total Phosphorus	Includes all forms of phosphorus in solution, solid form (bound to Al^{3+}, Fe^{3+}, Ca^{2+}) and adsorbed form.	Acid digestion at high temperature (Sulfuric acid/Nitric acid)	Bremner and Mulvaney (1982)
Extractable Phosphorus	Labile P-adsorbed P on soil solids that can rapidly go to solution form	Mehlich-III reagent	Mehlich (1984)
Soluble Phosphorus	Solution phase P in the equilibrium	Dissolved P readily available for plant uptake. Occur as primary (PO_4^{3-}) or secondary orthophosphates (HPO_4^{2-} and $H_2PO_4^-$) depending on the soil pH	Pierzynski et al. (2005)

Study Sites

Under His Wing Poultry Farm is located 6.6 km North of Delaware State University main campus in Dover, Delaware. This poultry farm is privately owned and was used for this study with the permission from the owner. This poultry farm has several ditches that drain into local streams. The first poultry house (Figure 1) shows 9 soil sample sites (1-9) around the HUAP pads (including manure pile: sample 5) that were installed in 2010, immediately when the poultry house was built (Site I- new poultry house). Figure 2 exhibits the remaining soil samples (11-17) which were also collected in proximity to the HUAP pads, that were installed in 2006 (Site II-old poultry house) which is 1 year after the poultry house was built (2005). A rain gauge was installed at the sampling location in order to monitor precipitation data.

Figure 1. Soil Sampling Location at the New Poultry House (Site I): (1) 2nd poultry house facing from back right side surface; (2) 2nd poultry house side edge deep (10cm); (3) 2nd poultry house front edge deep (10cm); (4) 2nd poultry house front edge surface (5cm); (5) Manure storage pile located inside the storage shed; (6) 2nd poultry house side edge surface (5cm); (7) Drainage swale between houses 3 and 5; (8) Before grass buffer strip; and (9) After grass buffer strip.

Figure 2. Soil Sampling Location at the Old Poultry House (Site II): (11) the nearest side edge to the right of the house (10cm); (12) the second nearest side edge to the right of the house (10cm); (13) the nearest site right front of the HUAP pad; (14) mid-front side of the HUAP pad; (15) the nearest site left front of the HUAP pad; (16) the second nearest side edge to the left of the house (10cm); and (17) the nearest side edge to the left of the house (10cm).

Sample Collection

On a monthly basis, preceding rainfall events and chicken removal, water and soil samples were collected from a poultry farm located in Dover, Delaware. Samples were collected from March through December 2010. Water samples (A-F) were obtained in 500 mL amber plastic bottles from the ditches surrounding the farm. The old poultry house was farther from the water bodies present on this farm. So, water sample locations in this study were considered in relation to their distance from the new poultry house, including: (A) area prior to the mixing of ditch water and the retention pond; (B) area where ditch water mixes with water from the retention pond; (C) in front of the third chicken house from 1st station; (D) at the far end of 4th chicken house; (E) further down from Station D; and (F) very far in woods from Station E. The retention pond discharge meets stream water at point B. Other points were selected downstream at specific intervals.

Nine soil samples from March until July 2012 were collected in ziploc bags from both old (equipped with HUAP pad in 2005) and new (equipped with HUAP pad in 2010) poultry houses. A metal spade was used to collect soil samples at a depth of 5 to 10 cm, from all edges of the HUAP pads within 300 cm distance. Soil and water samples were then transferred in a cooler to Delaware State University's College of Agriculture and Related Science (CARS) Water Quality and Analytical Laboratory.

Sample Processing

Water samples were stored in a -4°C freezer until needed for analysis. A portion of water sample was used to perform pH analysis. Soil samples were sieved to pass 4mm sieve to obtain small portions of sample for testing, triplicates of each sample was stored in airtight plastics containers. Once sieved, a portion of each soil sample was used to analyze the three forms of phosphorus.

Soil Analysis

Soil samples were analyzed for soil phosphorus using Mehlich III reagent (extractable phosphorous), total phosphorous and phosphorous saturation ratio (PSR). Soil pH was measured using 1:1 (v/v) soil water ratio method and determined by a Fisher Scientific Accumet pH meter (Fisher Scientific Inc., MA, USA) and a VWR Symphony electrode (VWR Scientific Inc, Pennsylvania). Analysis of Mehlich III phosphorus (mg/kg) was performed by soil extraction method using 1:10 (w/w) soil to deionized water (Sims et al., 2002). Mehlich III soil extracts were further analyzed using a Thermo Electron Iris Intrepid II Duo View XSP Inductively Couple Plasma Spectrometer (Thermo Electron, Madison, Wisconsin). Soil Phosphorous Saturation Ration (PSR) is the ratio of the amount of P in soil and the capacity of soil to retain this P. PSR is estimated as the ratio of soil P to soil aluminum and iron (Sims et al., 2002). Information from PSR will help understand the potential contribution of soil P in run-off during leaching and erosion. Total phosphorus (mg/kg) in soil samples was analyzed using the EPA-3051 method USEPA (1986). According to this method, soil samples were digested by heating in a microwave (CEM Mars5) and acidifying with nitric acid. The digested soil extracts were further diluted with deionized water and analyzed using ICP-MS (inductively coupled plasma-mass spectrometry). The EPA-3051 method is more accurate than the conventional methods as it extracts all forms of P from the soil (Dancer et al., 1998).

Water Analysis

A total of six water samples (A-F) from March until July 2012 were collected from the ditch at the points shown in Figure 3. Water samples were analyzed for pH, electrical conductivity, soluble phosphorous (orthophosphate), and total phosphorous. The pH of water samples was analyzed using a Fisher Scientific Accumet pH meter and a VWR Symphony electrode (Fisher Scientific Inc., MA, USA). Electrical Conductivity (mmhos/cm) was measured using a VWR Conductivity Meter 1052 with dip probe (VWR International Inc. PA, USA). Water samples were filtered through 0.45-µM Millipore filter immediately after sample collection (Sims et al, 2002) and used for the analysis of orthophosphate (mg/L). It was calorimetrically measured using a Bran & Luebbe Auto Analyzer II flow injection system (Bran & Luebbe, Inc., Buffalo Grove, IL). Total phosphorus (mg/L) was also measured calorimetrically using the above method, but the samples were digested with nitric acid prior to analysis (Dancer et al, 1998).

Figure 3. Water Sampling Locations in the Poultry Farm in Relation to Study Sites I and II: (A) before ditch water is mixed with water from the retention pond; (B) where ditch water mixed with water from the retention pond, the retention pond discharge met stream water at this point; (C) in front of the third chicken house from 1st station; (D**)** at the far end of 4th chicken house; (E) further down from Station (D; and (F) very far in woods from Station E.

The different forms of phosphorus detections in soil and water as mentioned above would give significant information about the levels of soil and water contamination by the poultry manure. Detection of PSR in soils also provides information on the soil type, which will help predict better management practices. The available amount of phosphate is critical with respect to the soil and water quality. The lower the PSR concentration, the better the soil quality is from an environmental point of view. Based on the availability of resources, some methods were modified for the testing of samples at Delaware State University.

Rainfall Measurements

A rain gauge was installed at the poultry farm on March 2012 and rainfall data was recorded using a data logger (PC 200W, Campbell Scientific, Inc., UT, USA) continuously until January 2013. The rainfall information from the data logger was exported and the average monthly rainfall (mm) was calculated. This data were further correlated with the soil and water phosphorous results. The primary purpose of installing the rain gauge is to study the relation between the precipitation and the phosphorus levels of the study sites.

Statistical Analysis

The results from this study were organized using Microsoft Excel. The data were later exported to PRIMER-E statistical software (PRIMER-E Ltd, Plymouth, UK) for further analysis. Principal Component Analysis (PCA), a multivariate technique, was performed to identify the most contributing factor in the poultry farm. The 2 dimensional PCA plot was used to understand the relationship between sites and samples. Significance of PCA was interpreted by the % variation of the eigenvalues generated from the PCA analysis. Variation equal to or greater than 95% was considered as significant. For orthophosphate analysis among the study sites, correlations were graphed from the mean and standard deviation values using Microsoft Excel. Correlations between precipitation and orthophosphate levels in the water and soil samples were also graphed to monitor variable relationships.

Results and Discussion

The study focused on determining the loads of phosphorous variables in a poultry farm, which uses HUAP pads for BMP. The research objective was met by analyzing soil and water samples for pH and phosphorus species (Table 1). Figures 4 and 5 provide mean soil pH levels for both study sites monitored over time. The pH values for soil samples at site I ranged from 5.5 to 8.0; whereas, pH values for site II ranged from 6.1 to 7.1. This shows that the variations in soil pH were wider at site I when compared to site II. These results also confirm that site I samples were both acidic and alkaline compared to samples from site II. Figure 4 illustrates that pH for locations 6, 7, 8, and 9 from site I, had both lower and higher pH values (4.8-7.9). However, pH differences at locations 1, 2, 3, and 4 (near to the HUAP pads) were much smaller (6.9-8.3), and the soils were mostly neutral to alkaline. Sample location 7 had much lower pH range (4.5-5.5); this is the drainage swale between houses 3 and 5 and is one of the few spots with low elevation and remained wet for longer periods. The pH of the manure pile from storage building (sample location 5) was found to be near neutral. In general, the pH of chicken manure is neutral to slightly alkaline and contributes to regulation of the soil pH. Studies have shown that all Delaware soils are naturally acidic (Gartley et al., 2015). Shifts to alkaline pH for some soil samples in this study might be due to litter seepage through the pads. The pH changes during different months of this study seem to be mostly consistent.

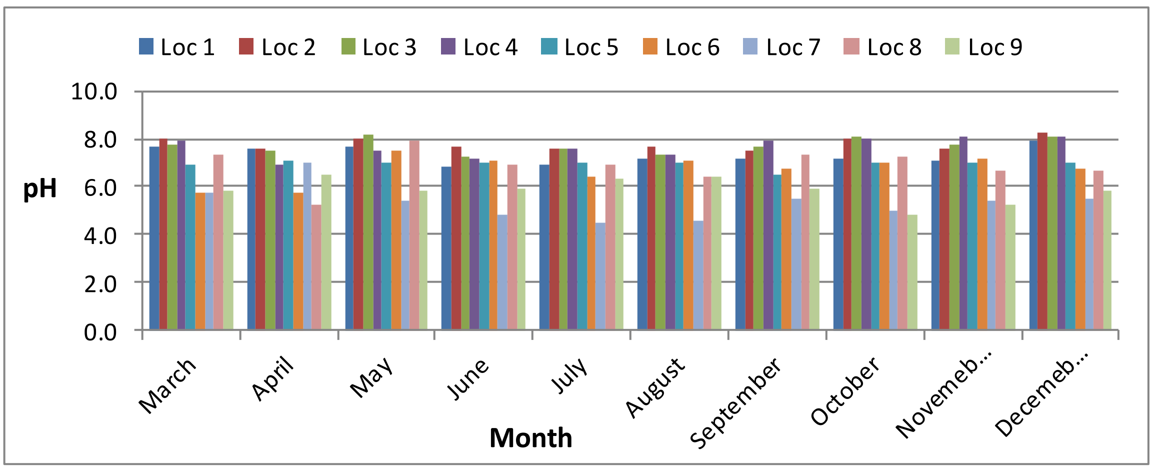

Figure 4. Soil pH at Various Locations from March until December for Site I (New Poultry House)

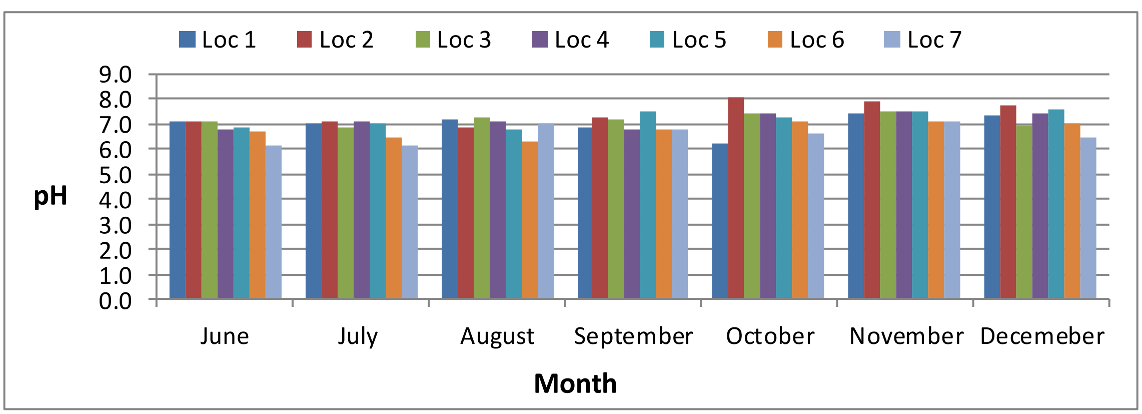

Figure 5. Soil pH at Various Locations from June until December for Site II (Old Poultry House)

Soil samples from site II had pH values ranging from 6.1 to 8.0, and during the months of November and December pH for most of the samples reached from 7.1 to 7.7. There was no difference in pH for the site II locations unlike site I. All samples at site II were collected surrounding HUAP pads and pH for these were lower than samples from site I surrounding the pads.

The pH of all the water samples (Figure 6) were near neutral (6.35 to 7.19), except for the water sample B collected on November 1, 2012, i.e., right after the Hurricane Sandy that dropped to 6.05. According to USDA NRCS (2011), soil electrical conductivity is one of the good soil quality indicators. The higher the amount of salts in water, the higher will be the electrical conductivity of water (Fondirest Environmental Inc., 2015). Electrical conductivity of sample B (where stream water meets farm pond discharge) was higher (7.5 mmhos/cm) than rest of the samples analyzed with few samples near 0 mmhos/cm. The water samples from June and July had higher EC which might be due to higher poultry activity and lower water levels in ditch due to high temperature (Figure 7). The samples collected after rainfall events and removal of chickens from the houses did not show significant increase in the concentration of nutrients analyzed.

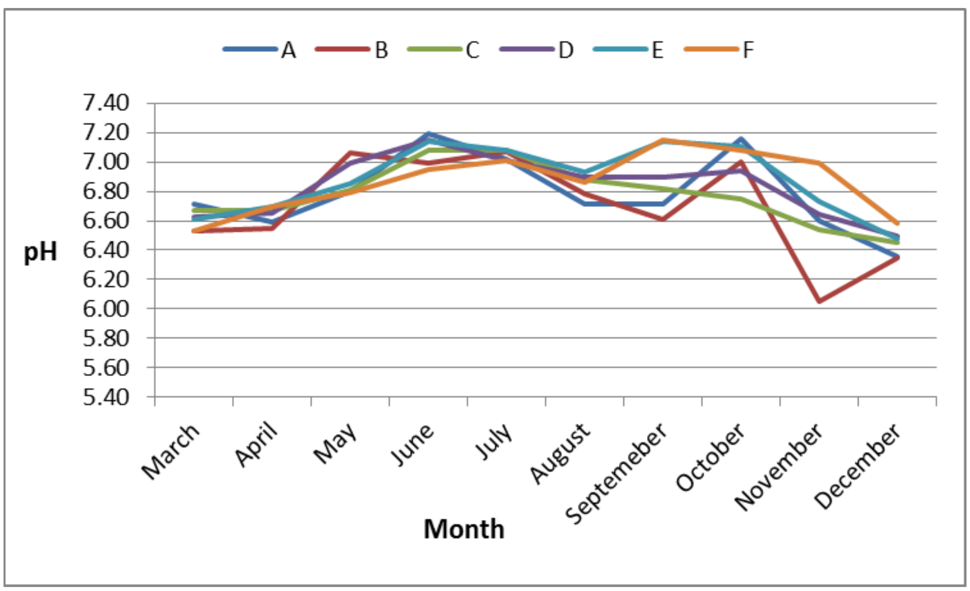

Figure 6. Water pH of Six Water Sampling Locations over Time

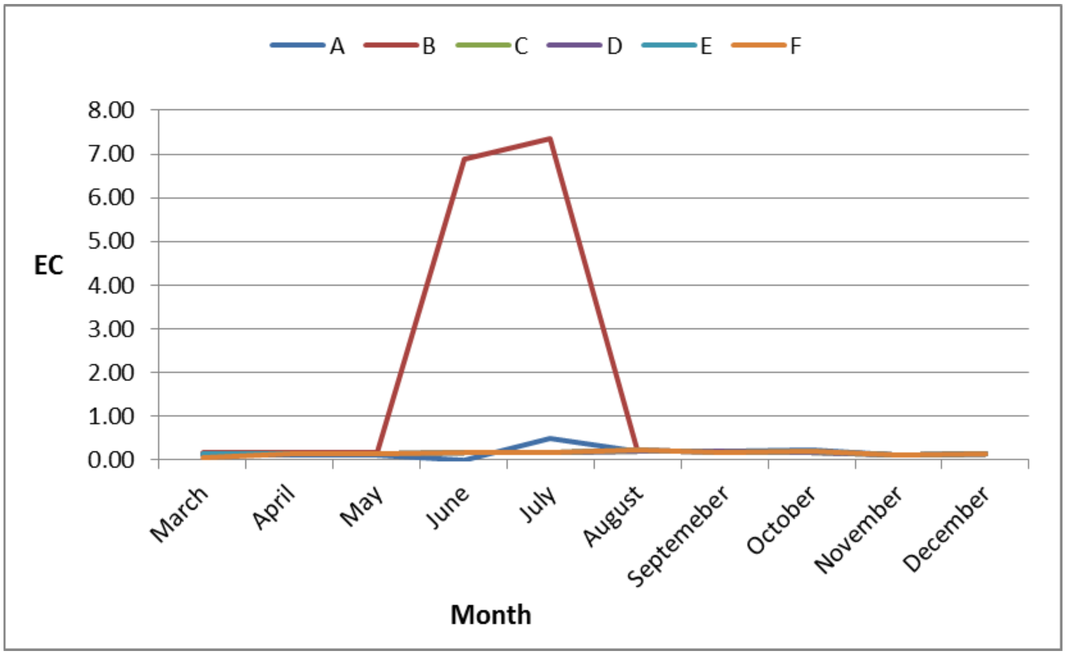

Figure 7. Electrical Conductivity of Water Samples over Time

The means for the orthophosphate levels from 6 sampling sites were calculated and presented in the graph as monthly averages in order to have a better understanding on the overall run-off quality of the poultry farm. Orthophosphate and total phosphorous levels were recorded below 0.05mg/L except for the months of July, August, September, and October. The peak levels of total phosphorous (0.25mg/L) and orthophosphate (0.17 mg/L) were observed in August (Figure 8). Total phosphorous levels (0.21 mg/L) remained the same in September and October and then dropped to 0.07 mg/L. Total phosphorous levels were very high for the months of June (7.66 mg/L) and July (6.8 mg/L) at location B (where ditch water mixes with the retention pond). A maximum value of 3.87 mg/L was recorded for orthophosphate during June for sample location.

October had the highest rainfall due to week long rains and Hurricane Sandy. According to USEPA (1986) total phosphorous levels for streams must not exceed more than 0.1 mg/L (Water Research Center, 2014). The results in this study had total phosphorous levels below the USEPA limits for most of the time, which confirms that the HUAP pads along with vegetative buffer strips seem assisting restricting the seepage of phosphorous into the run-off.

Soil samples from site II (old poultry house) were collected only from June until December 2010, whereas samples from site I (new poultry house) were collected from March until December 2010. Means of total P (TP), Mehlich III-P and P Saturation Ratio (PSR) levels from sample locations of site I (8 samples excluding manure) and site II (7 samples) were calculated

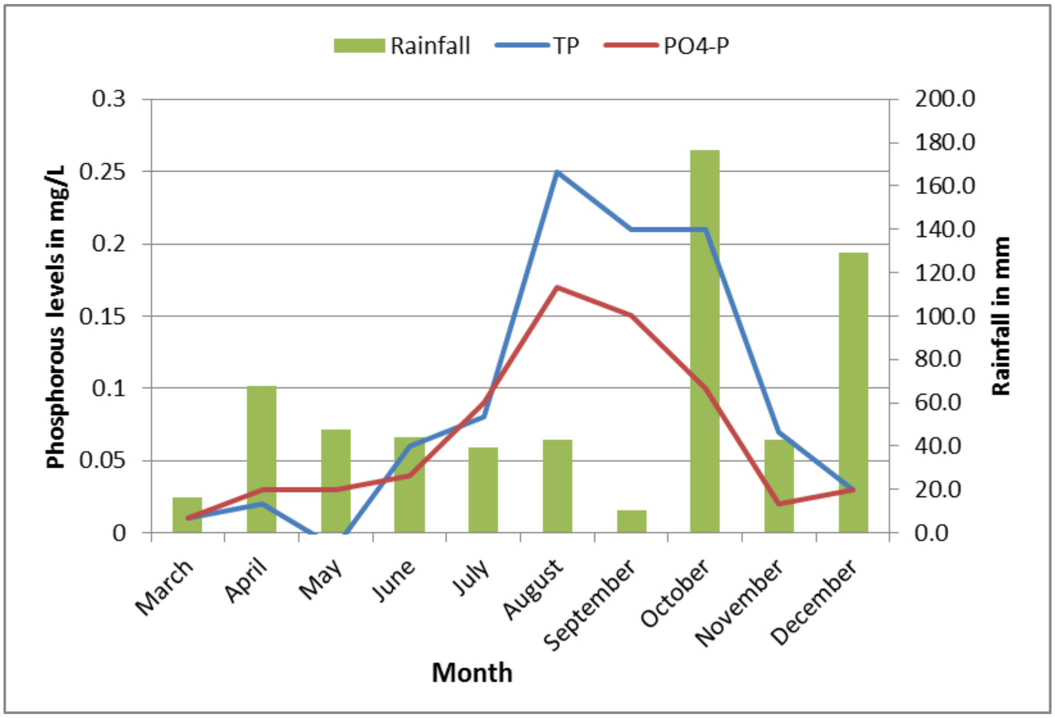

Figure 8. Average Water Orthophosphate Levels in Relation to Rainfall in the Farm Run-off

and graphs were plotted as shown in Figure 9. The Mehlich III-P (insoluble phosphorous), TP and PSR levels were higher in site II than those at site I. The PSR is defined as the ratio between the amount of P present in the soil and total capacity of the soil to retain P (Sims and Gartley, 2001).

The soil samples had a significantly high amount of Mehlich III phosphorus ranging from (22.82- 200 mg/kg) at site I and (448.17 – 1,179.6 mg/kg) at site II, respectively. For agronomic soils the optimal Mehlich III-P concentrations are recommended at less than 100 mg/kg (Sims et al., 2002). The older poultry houses showed significant accumulation of phosphorus as compared to the new poultry houses.

According to Sims et al. (2002), the PSR is calibrated for acid soils (pH < 6.8). In this study of 75 pH samples, only 28 samples recorded pH levels at < 6.8. Based upon the 28 pH points, (37% of the samples), it can be interpreted that the soil pH was below 6.8 for almost 49% of the study period. Only 14 samples from these 28 testing resulted in soil PSR of less than 25. This indicates that these soils were in low to medium risk condition. In cases where soil pH is higher than 6.8, soil PSR estimates are considered inaccurate (Sims et al., 2002).

According to Sims et al. (2002), soils of the mid-Atlantic region was found moderately acidic with median pH of 5.7, low in organic matter with median value of 16 g kg^{-1}, and high in soil phosphorus with median Mehlich III Phosphorus of 115 mg kg^{-1}. Most of the Mehlich III soil

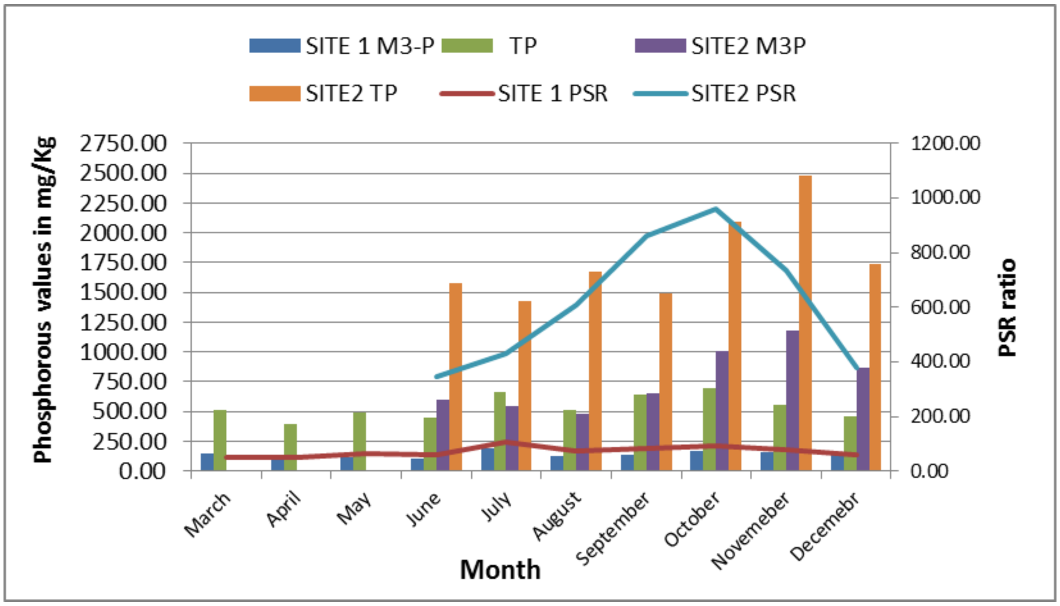

Figure 9. Phosphorous Variables in the Soil Samples at Sites I and II over Time

concentration in the study was higher than 115 mg kg^{-1}, showing the signs phosphorus build up in the farm.

Principal Component Analysis (PCA) was used to determine the relationship between the independent abiotic variables (total phosphorous, soluble phosphorous and Mehlich III phosphorous) and the dependent (study sites) variables. PCA analysis was performed on data collected from June to December. In this PCA analysis, PC1 and PC2 together contributed to 98% of the variation. According to the PCA plot, soil PSR levels were negatively correlated to TP and Mehlich III-P. The levels of total phosphorous and Mehlich III-P were also low as explained by PC1, which contributed for 90% of the analysis. A clear grouping among the data points was observed for phosphorous variables at the two sites. There were also differences in phosphorus patterns between the sampling locations and over time in site II. The soil samples from site II share similar patterns during November and December while soil samples from June and July also share the same trend. Total phosphorous and Mehlich III phosphorous levels at all locations in site I was low compared to site II. Site II had slightly elevated levels of total phosphorous and Mehlich III phosphorous in November and December (Figure 10).

The PCA analysis for nutrient trends between the sample locations within the study sites explains that all the sample locations at site I share similar nutrient trends. Figure 11 shows that sample locations (12 and 14) from site II during some months had high levels of total phosphorous and Mehlich III phosphorous. Same trends were also observed for locations 16 and 17. Site II is an old poultry house and did not have the Heavy Use Area Protection (HUAP) pads for 1 year while the poultry operations were taking place; whereas, site I is a new poultry house and the HUAP pads were installed immediately after the construction of poultry house. This may explain why the nutrient levels of soils were relatively lower and consistent among locations within site I.

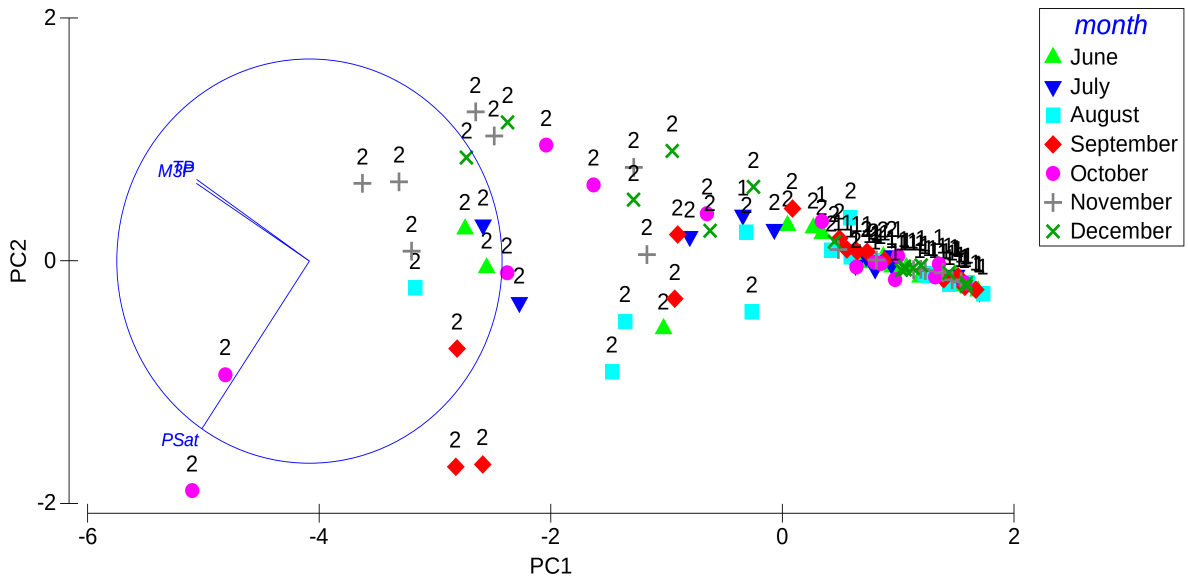

Figure 10. Principal Component Analysis to Study the Concentrations of Phosphorous Species in Soil over Time

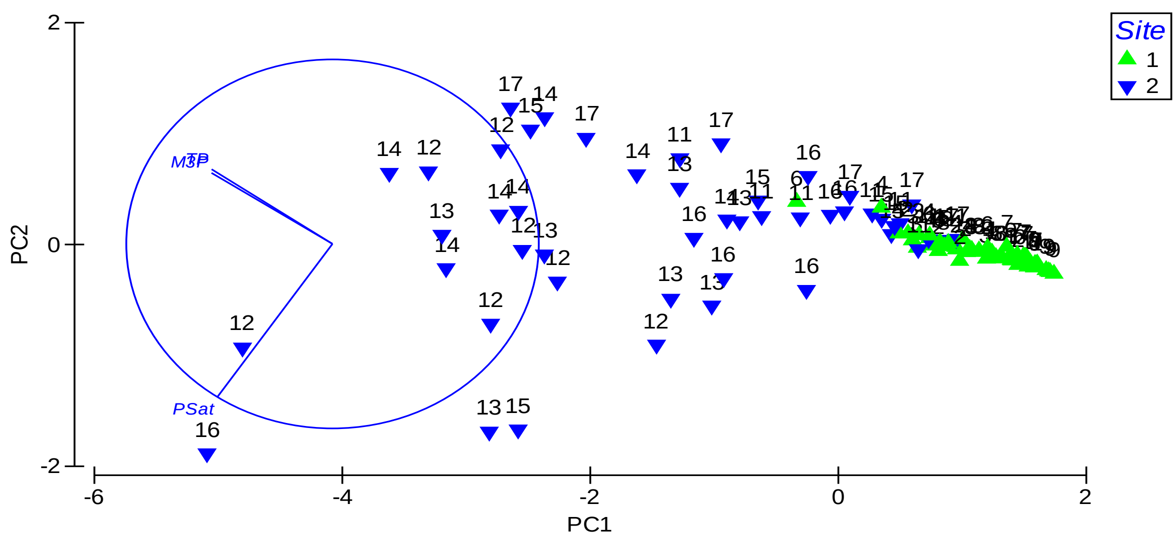

Figure 11. PCA Plot to Show the Relationships between Sites with Regards to Soluble and Total Phosphorous

As stated by Sims and Gartley (2001), “Phosphorus Site Index” is recommended to identify “high P soils.” Mehlich III as an agronomic soil test primarily was developed to evaluate inputs of P in fertilizers, manures, and other soil amendments. According to this fact sheet “the Phosphorus Site Index integrates site characteristics (topography, drainage, leaching potential, proximity to water) with P source management (soil test P, application method, rate, and timing of fertilizer and manure P) to identify fields where the risk of P losses to water will be of most concern.” How “saturated” a soil is with P by analyzing the soil PSR is another important consideration for interpreting the Phosphorus Site Index. Although the authors did not target phosphorus site index in this study, the major concern was to evaluate how saturated soils around HUAP pads get, and if there were potential risks for leaching excess P into the ditch/stream.

Most of the data in this study had pH levels much higher than 6.8, which is why it was difficult to conclude from results on PSR. However, the Mehlich III tests showed the soils had more than 100mg/kg of phosphorous, but water orthophosphate data suggest that the levels were mostly within range. This may confirm the role of HUAP pads along with the vegetative buffer in the farm management of nutrients from soil to the run-off.

Conclusion

Phosphorus is a limiting factor in the freshwater aquatic habitat and soluble phosphate is the most readily available nutrient for plant growth. Although contamination risk is obviously decreased by the use of HUAP pads and buffer strips between the poultry house and ditches, farm runoff, concentration of phosphorus may reach beyond the recommended level by U.S. EPA (0.05 mg/L for orthophosphate and 0.1 mg/L for total phosphorus). This requires periodic checking to ensure HUAP pads work effectively. The comparison of soil and water samples does not show a significant carryover of contaminants from poultry house to soil and the water bodies. The point at which the retention pond discharge meets stream water had the highest concentration of phosphorus; the concentration was almost neutralized in downstream water sampled at the furthest point from the discharge point, suggesting that flow leaving the site had little or no nutrients from the farm.

Although water and soil pH decreased and total phosphorus and Mehlich III concentration increased right after the Hurricane Sandy, majority of the sampling months yielded similar results. In June and July, EC was higher which might be due to higher poultry activity and lower water levels in ditch due to high temperature. The effect of poultry house cleaning and storm events did not seem to increase contaminants loads to the soil and water bodies on the farm. The HUAP pads might have contributed significantly minimizing the contaminant loads to the soil and water bodies. These results suggest that nutrients in the runoff from the poultry houses to the water bodies are minimal. In addition, the continuation of soil and water quality monitoring would significantly help to understand the role of HUAP pads and contribution towards minimizing contaminant load to the water bodies.

Future studies are recommended. First, the continuation of this study will allow determining and confirming trends in nutrient profiles in selected study sites. Second, a comparison between use of HUAP pads and non-use of HUAP pads will allow a better understanding of the usefulness of HUAPs. Third, analysis on soil nutrient profile from deep soil layers will allow ensuring that nutrients are not carried into the aquifers in the farm. Long-term monitoring of soil and water quality on poultry farms is vital to assess the efficiency of the HUAP pads for environmental benefit.

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