

ABSTRACT

Title of Document: EVALUATION OF BASE LINERS TO REDUCE NITROGEN AND SALT LEACHING FROM POULTRY LITTER STORAGE STOCKPILES TO THE UNDERLYING SOIL – A FIELD COLUMN STUDY

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Agriculture has been linked to the eutrophication of the Chesapeake Bay. The Delmarva Peninsula is an intensive poultry producing region, where poultry litter (PL, mix of manure and bedding material) is often stored in outdoor stockpiles. Continued development of management practices is required to achieve environmentally sound PL storage. This study evaluates base liners placed between the bottom of the pile and the soil to reduce nitrogen (N), potassium (K) and sodium (Na) movement from PL stockpiles after 15 and 91 days of storage. Six conically shaped stockpiles were established with five PVC pipe columns placed in the soil under each pile. The soil surface in each column was covered with one of five treatments: alum, gypsum, lime, plastic, or control (no material). Nitrogen, K and Na concentrations increased between 15 and 91 days of storage. Ammonium losses under alum and lime treatment were not different from the control. Alum created adverse conditions by dropping the pH to 3.8. After 91 days of storage, the surface 10 cm of the soil was severely salt affected: under alum, gypsum, lime and control the conditions became moderately to strongly saline. Plastic was most effective in preventing N, K and Na leaching to the soil.

EVALUATION OF BASE LINERS TO REDUCE NITROGEN AND SALT
LEACHING FROM POULTRY LITTER STORAGE STOCKPILES TO THE
UNDERLYING SOIL – A FIELD COLUMN STUDY

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CHAPTER I. – Literature Review

Concentrated poultry production and the environment

Since the mid-century, global livestock production and especially poultry production has evolved from a local market model to a global industry (Perry et al., 1999). Between 1962 and 2002 among animal-based agriculture poultry production had the largest increase globally, about fourfold, (Sims et al., 2005). In 2009, 79.5 million tons of chicken meat were produced in the world, which is a 37 % increase since 1999 (FAOSTAT, 2010). The United States (US) produces the most broiler type chickens globally (FAOSTAT, 2010). In 2009, 21.6 million tons of broiler meat (8.5 billion chickens) were produced in the US (USDA-NASS, 2010).

The increased geographical intensification and vertical integration of the industry has led to larger facilities containing higher concentrations of livestock (Leytem et al., 2003; Perry et al., 1999). These factors have increased concern over environmental impacts, leading to increased regulations and questions about the industries long-term environmental sustainability (Angel, 2006; Sims et al., 2005).

Poultry production on the Delmarva Peninsula

The Delmarva Peninsula contains parts of Maryland, Virginia, and Delaware and is bordered by the Chesapeake Bay on the west. The poultry industry was established on the Delmarva Peninsula in the mid-20th century. Today nearly 600 million broiler chickens are produced annually by about 1700 growers (DPI, 2010). In the US Maryland

ranked 8th in the number of broilers produced in 2009, while Virginia was 9th and Delaware was 11th (USDA-NASS, 2010). The poultry industry in Maryland is concentrated in the eight counties of the eastern shore of the Chesapeake Bay and represents Maryland's largest agricultural revenue generator (Rhodes et al., 2009).

Nutrient imbalance

Many of the environmental problems the poultry industry faces are related to its size and geographically clustered nature (Sims and Wolf, 1994). With the growth and centralization of the poultry industry, the amount of manure that needs to be handled increased (Robinson and Sharpley, 1995; Sims et al., 2008; Sims et al., 2005), while the available cropland has been shrinking due to the continuing urbanization of the Mid-Atlantic region (Leytem and Sims, 2005). Historically, crop and animal production were integrated. A farmer grew enough grains to feed their animals and their manure was returned to the soil to fertilize their crop fields and pastures. Today, animals raised in concentrated animal feeding operations (CAFO's, over 1000 animal units) generate 49% of all manure N and P in the US and there is not enough cropland available locally to utilize it all in a sustainable manner (Leytem and Sims, 2005; Sims et al., 2005). In modern poultry production, farmers raise the animals that are furnished by the integrator along with the feed (Rhodes et al., 2009) that is often sourced from hundreds of miles away. It is the farmers' responsibility to provide land, house, equipment, labor and operating expenditures (Rhodes et al., 2009), which includes manure management. Poultry litter (PL, mix of excreta, bedding material, spilled food and feathers) is

considered to be a valuable resource as a fertilizer due to its high organic matter and nutrient content.

The utilization of the large amount of poultry litter produced has been a growing problem in the past decades (Robinson and Sharpley, 1995). A survey conducted in Maryland's two primary poultry producing counties reveals that the majority of the farmers transfer all their poultry litter off-farm, because they often have no cropland (Parker and Li, 2006). The majority of poultry feed is being imported from outside the region and even though a portion of the nutrients are exported with the product, much of the nutrients remain and accumulate at the farm or region level. Due to the long history of poultry litter application in Delmarva, soil P levels have built up beyond what crops can take up (Leytem and Sims, 2005), so poultry litter application might be undesirable on many soils of these regions (Sims et al., 2008). As a result of the net nutrient import on farm as well as on a watershed scale, the quality of the surface and ground waters has been declining for the past decades (Boesch et al., 2001).

Primary causes of surface water eutrophication are agricultural pollution by soil erosion and runoff, and discharge of wastewaters from municipalities, industry, storm water systems, and recreational developments, when Nitrogen (N) and Phosphorus (P) are released to the environment (CBPO, 2010; Sims and Wolf, 1994). Nitrogen and P are essential nutrients for aquatic ecosystems, but in excess they promote excessive algae growth which eventually results in hypoxia, loss of water clarity, loss of aquatic grasses and habitats and alteration of food webs (Boesch et al., 2001).

The Chesapeake Bay is the largest estuary in the United States; its watershed covers over 165000 square kilometers including portions of six states (Delaware,

Maryland, New York, Pennsylvania, Virginia and West Virginia) and the entire District of Columbia. More than 100,000 rivers and streams find their way into the Bay carrying along chemicals, sediments and any surplus nutrients.

In the Chesapeake Bay watershed, the largest developed land user and the largest source of N and P pollution is agriculture which contributes 40 to 50 % of the nutrient load (CBPO, 2010). Harmful algal blooms can be reduced by the management of nutrient inputs to the watershed (Heisler et al., 2008), however, reducing agricultural pollution, which is non-point source by nature, poses special challenges and requires a joint effort from farmers, scientists, agribusiness, policymakers and everyone who consumes the products.

Poultry litter use in crop production and environmental effects

Animal manure application as fertilizer has been in practice since the dawn of agriculture. In fact, centuries ago animal manure was the primary source of plant nutrients. However, today chemical fertilizers are generally more appealing in conventional agriculture primarily due to their ease of use and its economic advantage from the crop farmer's standpoint.

Poultry litter can be used as a carbon rich soil amendment that can provide required nutrients for crop production. The nutrient content of PL greatly varies depending on the amount of bedding material used and the frequency of house cleanout (Angel, 2006), but it consists predominantly of water and carbon with considerable amounts of nitrogen, phosphorous and potassium and trace levels of chlorine, calcium, magnesium, sodium, manganese, iron, copper, zinc, and arsenic.

Poultry Litter application to cropland with increasing N rates improves soil total carbon, microbial biomass C, soil cation exchange capacity (CEC) and soil aggregate stability (Adeli et al., 2010). Generally, increased fertilizer input enhances yield, until an optimum is reached beyond which yield benefits are no longer obtained (Adeli et al., 2010; Brady and Weil, 2008). When N exceeds crop requirements it is available to be lost through surface and subsurface pathways (King and Torbert, 2007). This may occur due to over application of N or as a result of crops yielding below expectations as a result of drought or deficiency of other nutrients (Harmel et al., 2008, Gonzalez-Dugo et al., 2010).

Nutrients most plants need in the greatest quantities are N, P and K, all of which are present in PL. However, the N to P ratio in PL is about 2-3 to 1, but plants take up these nutrients in 5-8 to 1 ratio (Sadras, 2006; Sharpley et al., 2007; Sims and Luka-McCafferty, 2002). The reason for the high P concentration of PL lies in the chickens' phytate rich grain diet, from which most (McGrath et al., 2005) or all (Penn et al., 2004) of P passes through the animal undigested. Moreover, their feed is supplemented with more digestible inorganic phosphate some of which is also excreted (McGrath et al., 2005). If poultry litter is applied to the crop land based on the plants' N-requirement, the excess P will not be taken up by plants and therefore the potential for loss from soil to water increases. If P-based nutrient management is practiced, the crop N requirements have to be satisfied by the application of additional nitrogen fertilizer.

The potential loss of P in dissolved and particulate forms depends on the soil type, topography, P concentration, and soil hydrology (McDowell and Sharpley, 2001) and land use. In many areas P has built up in soils above concentrations that are optimal for

plant growth as a result of continued application of fertilizers and manure (He et al., 2009; McDowell and Sharpley, 2001). These high concentrations increase the possibility for P loss (McDowell and Sharpley, 2001) by runoff, erosion or subsurface drainage. In fact, most soils in Delaware have excessive levels and need no or little application of P (Leytem et al., 2003), which may eliminate the option of PL use as a fertilizer at these locations. A large percentage of the non-point P pollution is in dissolved form, which is easily available for freshwater algae species that cause eutrophication (DeLaune et al., 2004).

Most of the N present in PL is available for crop uptake in the first year, so careful management has the potential to minimize losses after land application. Nitrogen content in the poultry litter decreases considerably over time due to the mineralization of organic N and ammonia volatilization. Uric acid accounts for most of total N in fresh litter. Break down of uric acid is most favored above pH 7. Another portion of N is in the form of undigested proteins. When PL lacks sufficient amounts of carbon microbes will utilize proteins as a carbon source freeing up N in the process.

Nicholson et al. (2004) determined the uric-acid-N (UAN) and ammonium-N content of broiler litter and laying hen manure before land application at a rate of 250 kg total N ha⁻¹. They found that over 28 days the NH₃-N emissions were equivalent to 67 – 118 % of the UAN applied. In addition to the loss in fertilizer value, ammonia emission may cause major environmental problems, such as aerosol formation and its subsequent deposition that may result in N enrichment, and acidification of soils and surface waters (Lovanh et al., 2007). Through nitrification, ammonia is converted to nitrate that is susceptible to leaching into the groundwater causing contamination in drinking water

supplies. Due to its high mobility, nitrate is also able to reach surface waters creating imbalance in aquatic ecosystems where N is often the limiting nutrient for certain algal growth. Consumption of nitrate in drinking water can result in cancers of the digestive tract or in methemoglobinemia, which is a concern with small babies (Powlson et al., 2008). However, there is a lack of scientific consensus on nitrate levels that are likely to be detrimental to human health (Powlson et al., 2008). A recent study found correlation between Maryland's infant mortality rates and degraded stream conditions in the state and implied similar trends in Pennsylvania and West Virginia (Paul et al., 2008).

Substantial nutrient losses are most likely when manure containing materials get in contact with rainwater. In a study using five consecutive rainfall simulations, Robinson and Sharpley (1995) found that major nutrient losses occurred at the first rainfall event after litter was land applied; 60 % of the N and 40 % of the P losses were released during the first event. They stressed the importance of careful timing of land application in order to prevent nutrient transport away from the field by runoff or leaching. However, nutrients are susceptible to losses from land applied PL, Smith et al. (2007) demonstrated PL application resulted in less runoff losses than inorganic fertilizers. In addition, King and Torbert (2007) found similar results when they compared animal manures (including PL) to manufactured slow release fertilizers. In addition, OM in PL enhances physical properties of soil by increasing aggregation, porosity, infiltration and water holding capacity. Humus colloids in soil organic matter are able to hold nutrients that are slowly available for plants, but won't readily leach away (Brady and Weil, 2008). Organic matter is beneficial for soil life as it enhances soil biological activity and provides food for heterotrophic soil organisms.

Environmental issues due to poultry litter storage

Temporary field storage of poultry litter is often necessary, allowing flexibility in timing of land application, conserves nutrients and decreases the risk of environmental contamination by synchronizing plant nutrient needs with nutrient release from the litter (Moore et al., 1995). In-field temporary storage of PL usually occurs following the total cleanout of the poultry production houses. Between flocks, only the caked material is removed from the litter surface and the bedding is reused with occasional supplement of fresh litter. In a total house cleanout, once a year to once every other year (Jennifer Timmons, Personal Communication), all PL is removed from the floor, but generally there is no storage structure capacity on the poultry farm that could accommodate that volume of litter.

A Poultry Litter Experts Science Forum was convened to provide guidelines for properly constructed stockpiles (Binford et al., 2008). They recommended that stockpiles should be created in a way that their footprint is minimized, stacking the litter into an “A” shape. If shaped properly, the stockpile acts similarly to a static compost pile and goes through a slow decomposition process. Much of the carbon content in PL originates from the bedding material used in the poultry house. Organic materials, such as woodchips, sawdust, and agricultural byproducts are often scarce or expensive and their use is pushed near the minimum or in some instances even abandoned (Jeannine Harter-Dennis, Josh Fry, Personal Communication). The narrow C:N ratio contributes to N losses in PL during storage and composting (Tiquia and Tam, 2000). A PL stockpile is a dynamic environment where continuous changes occur as a result of biological activity and physicochemical processes. The processes a PL stockpile goes through are greatly

influenced by a myriad of factors, such as weather and soil conditions, PL composition, moisture content, and pH.

Ammonia has a great potential to volatilize from the PL pile surface. Ammonium is generated by biological processes and gets dissolved in pore water where it is in equilibrium with free ammonia (NH_3). Moreover, NH_3 is a gas that dissolves in water according to Henry's law and is in equilibrium with NH_3 gas in the soil air (Masters and Ela, 2007). High pH and temperature in the PL pile encourages ammonia volatilization which then diffuses towards the surface and moves to the atmosphere. Nitrogen content of poultry manure and litter during storage can decline by 19 – 49 % and 16 % of it can be lost to the air as ammonia (Nicholson et al., 2004).

Following a precipitation event, nutrients can leave the stockpile moving with the runoff water and their concentrations can greatly vary depending on the rainfall intensity, duration and frequency. Different soil types produce different runoff conditions affecting the mass transport of nutrients (Felton et al., 2007).

In addition to the indirect pathways of nutrient loss, they can also leach directly into the soil through the litter – soil interface. A generous amount of moisture is generated within a manure stockpile as a result of the aerobic decomposition of organic matter, which is able to dissolve and carry nutrients in the pores of litter (Dewes, 1995). The temperature in a PL stockpile is able to reach levels indicative of thermophilic decomposition processes, about 55°C (Brodie et al., 2000). The elevated temperature affects the behavior of water by changing vapor pressure and the amount of dissolved constituents in the pore water. Moisture vapor might rise upwards – as materials in the gas phase tend to do – within the PL pile and leave thorough the PL pile surface while the

litter continually dries (Gary Felton, Personal Communication). Liquid water moves either towards or away from the source of heat. When a heat source is present in an unsaturated porous media, vapor can move away from the source due to the higher vapor pressure near the heat source as well as due to the overall pressure increase in the vapor phase (Bear and Gilman, 1995). First, water pressure increases near the heat source, because higher temperatures result in lower surface tension and increase in capillary pressure; therefore water flux is directed away from the heat. However, as a result of evaporation, moisture content decreases near the source of heat causing the liquid to change direction and move towards the source (Bear and Gilman, 1995). Initial moisture content is the primary factor that affects the overall direction of moisture flow (Bear et al., 1991). Due to the changing moisture and temperature conditions the direct transport of PL constituents to the soil is highly likely.

Inorganic N forms are soluble in water and are able to move with the soil solution. When studying nitrate contamination of groundwater from corn fields, Weil et al. (1990) found 74 mgL^{-1} and 104 mgL^{-1} $\text{NO}_3\text{-N}$ in monitoring wells within 20 m from stockpiled PL. Ritter et al. (1994) studied manure stockpiling on cropland in southern Delaware over a 3 year period when PL was added and removed periodically. They found that stockpiling of PL increased nitrate concentrations in monitoring wells above 10 mg L^{-1} N. They suggested that ammonia was moving downwards in the soil profile and leached into the groundwater after being nitrified (Ritter et al., 1994), however, the adjacent field had received years of PL application that probably also contributed to the nitrate pollution.

One study compared various lengths of PL storage (up to 195 days) and found that most inorganic N is lost to the soil after 30 days, but some losses even occur after 15

days (Binford, 2008). They suggested that some ammonia might be moving in the gas phase, because the pile removed after 15 days received minimal precipitation. Generally, the bulk of the PL piles appear to remain dry throughout stockpiling, while a wet layer is formed on the pile surface. This moist layer gets wider closer to the ground. Nutrient concentrations in the soil generally become higher under the wet portion of the pile; however, substantial losses occur under the dry area too (Binford, 2008). Altogether, 75 % of the lost N is concentrated in the upper 60 cm of the soil under the pile (Binford, 2008). On the other hand, years of continuous storage at the same location can result in elevated NH_4^+ -N concentrations even as deep as 370 cm (Zebarth B. J. et al., 1999). When solid turkey manure was frequently stored in open stockpiles at the same location for 6 years, NH_4^+ -N concentration reached 1000 mg kg^{-1} in the soil at depth of 120 to 150 cm, while the maximum concentration in areas where no manure was stored was 23 mg kg^{-1} (Zebarth B. J. et al., 1999). Zebarth et al. (1999) also found that NO_3^- -N concentrations were similar under the storage and non-storage area, which they attribute to the elevated ammonia concentrations in the soil solution that is toxic to the nitrifying bacteria.

Although, studies indicate that the major problem with poultry litter storage is associated with elevated inorganic N (Binford, 2008; Ritter et al., 1994), high levels of water soluble salts contained in the PL are of concern too. Studies found substantial potassium (K) (Binford, 2008; Zebarth B. J. et al., 1999) and sodium (Na) (Zebarth B. J. et al., 1999) leaching from litter . In fact, Binford (2008) found that K losses from PL stockpiles were eight times greater than N losses. Following the removal of PL stockpiles, farmers are often unable to establish crops on the PL pile footprint (Binford,

2008; Kivlin et al., 2009). Soluble salt concentrations in the soil reached levels of saline conditions or saline-sodic conditions ($> 4\text{dS m}^{-1}$; Binford, 2008), where plant germination and development is restricted (Richards, 1954). High concentrations of potassium may also induce magnesium deficiency and iron chlorosis (Richards, 1954). The salts in PL partially originate from mineral salts added to the animal diet (Li-Xian et al., 2007) and partially from poultry litter treatments that are aimed to reduce ammonia volatilization in the PL house (Choi and Moore, 2008; Guo and Song, 2009).

CAFO regulation

The Federal Clean Water Act (CWA) is the primary law in the US that regulates discharge of pollutants and establishes quality standards for surface waters (USEPA, 1972). According to the CWA it is unlawful to discharge point source pollutants to surface waters without a permit and it has been successful in achieving pollutant reductions for example from waste water treatment plants. However, agricultural non-point source pollution has been very challenging to regulate, because it is generally very disperse and difficult to identify the actual source.

The Maryland Department of Environment (MDE), as an effort to protect the Chesapeake Bay, local waterways and drinking water, issued a general permit to regulate discharges from the state's largest agricultural animal feeding operations (AFO). This General Discharge Permit (MDE, 2008) came into effect on January 12, 2009. The United States Environmental Protection Agency (USEPA) required states to regulate poultry farms that are considered Confined Animal Feeding Operations (CAFO). According to the permit, an operation is a CAFO if the animals or their waste come into

contact with surface water. In addition, *medium* and *large* size operations become CAFO's if they have the potential to discharge pollutants from the production area (manure, PL, runoff from stored PL) due to improper handling or as a result of a rain event smaller than a 25-year, 24-hour storm. A *medium* sized poultry operation with dry manure handling produces between 37,500 and 124,999 chickens, while an operation is considered *large* if their yearly production exceeds 124,999 animals. Maryland added a stricter rule requiring *large* farms that do not fall into the CAFO category to apply for a Maryland permit. *Medium* operations may also have to apply if they are likely to pollute. These operations are termed Maryland Animal Feeding Operations (MAFO).

Poultry litter is a significant contributor to the large nutrient surpluses in the Delmarva region. The scarcity of available crop land and the timing of poultry house cleanout may result in the need for extended PL storage solutions. In order to avoid pollution, the discharge permit requires operators to ensure appropriate management measures in animal waste handling and storage systems. Under Maryland's law, CAFO's can only store PL in an uncontained stockpile for 14 days and MAFO's have a 90-day allowance, but it will be reduced to 30 days without future research justifying 90-day storage. These storage restrictions might encourage farmers to apply PL on cropland in excess or at an inappropriate time that doesn't meet crops' fertilizer requirements. Application of nutrients to soil in excess inevitably results in nutrient loss that has to be avoided. On the other hand, outdoor PL storage on bare ground carries environmental risks as well, including nutrient enrichment of groundwater and potential salinization of the PL pile footprint.

Study objectives

No replicated studies have been found in the literature using as large as 20-ton PL piles to evaluate N and salt movement in 14 and 90 days and base liner materials between PL and the soil surface that could reduce N and salt losses. The goal of the present study is to evaluate the effect of storage duration on direct N, K and Na losses from PL stockpiles to the underlying soil. The relative risk between two different PL removal dates, 15 and 91 days were tested. The second objective was to evaluate and suggest management options that restrict vertical movement of N, K and Na from the PL storage pile to the soil. This was accomplished by testing physical and chemical barriers applied onto the soil surface and evaluating their ability to reduce direct nutrient losses from PL piles into the underlying soil.

CHAPTER II. – Evaluation of base liners to reduce nitrogen and salt leaching from poultry litter storage stockpiles to the underlying soil – A field column study

Introduction

Temporary poultry litter storage in open stockpiles on crop fields before land application is a common practice on the Delmarva Peninsula where intensive broiler chicken production is a predominant sector of the agricultural industry (USDA-ERS, 2010a; USDA-ERS, 2010b). The term poultry litter (PL) refers to the bedding material of poultry houses mixed with excreta, spilled food and feathers. When all PL is removed from the production house it is termed total house clean out. The timing of cleanout is determined by many factors and is typically dictated by the integrator. Farmers commonly store PL adjacent to the production house or on crop fields until the right time for application. Recently this practice has become the subject of much concern due to high nutrient, salt and other trace material content of PL that could result in environmental degradation when released from the storage area. Nitrogen contributes to eutrophication of the Chesapeake Bay, resulting in hypoxia, increased turbidity and aquatic habitat degradation (Boesch et al., 2001). Due to its high solubility, nitrate can reach groundwater. Consumption of nitrate in drinking water can result in blue baby syndrome (methemoglobinemia) and cancers of the digestive tract (Powlson et al., 2008). Poultry litter contains salts that can result in the increase of soil salinity levels under the PL pile footprint to a degree where plant germination is restricted causing crop loss to the

farmer who stores PL on the field before using it for fertilization. (Binford, 2008; Kivlin et al., 2009).

During stockpiling, PL constituents can be lost through runoff or convection (Binford, 2008; Felton et al., 2007; Kivlin et al., 2009). In a precipitation event, when runoff is generated, constituents are washed away from the PL pile surface in dissolved or particulate form (Binford, 2008; Felton et al., 2007). Studies also found that significant amounts of nitrogen (N), potassium (K) and sodium (Na) can be lost to the soil directly from stockpiled PL (Binford et al., 2008; Ritter et al., 1994; Shah et al., 2009; Zebarth B. J. et al., 1999). The pathways of direct losses from stored PL to the underlying soil are not completely understood. The processes a PL stockpile is going through are greatly influenced by a myriad of factors, such as weather, PL composition, moisture content, and pH. Interestingly, when Binford (2008) studied covered versus uncovered PL stockpiles, he found that covering (when the pile was not directly affected by rainwater) didn't significantly reduce soil N concentrations and suggested that most of the losses occur in the soil air phase. However, a wet layer is formed on the PL pile surface after the first precipitation event (Binford, 2008; Felton, 2010; Shah et al., 2007). This wet layer gets thicker and thicker on the side of the piles closer to the ground, where can reach about 1 m in thickness (Binford, 2008). Most losses would be expected under this area of the pile (Felton, 2010). When stockpiling PL in the summer, Shah et al. (2007) found 90 % higher NH_4^+ -N concentration under the edge than under the center. In the 2.5 to 7.6 cm soil layer, NH_4^+ -N concentrations were 1480 mg kg^{-1} under the half diameter, being about 90 % more than under the center of 20 Mg turkey litter stockpiles stored for 6 months. On the other hand, stockpiling through the winter for 6 months resulted in

concentration of 770 mg kg^{-1} at both locations. Interestingly, Binford (2008) found substantially lower concentrations of inorganic N ($\text{NH}_4^+\text{-N}$ plus $\text{NO}_3^-\text{-N}$), but he obtained samples from a much larger depth increment. In the surface 15 cm, the inorganic N concentration varied between 36 and 100 mg kg^{-1} when he was testing different storage lengths from 16 days to 185 days. In this experiment the pattern that losses were greater towards the edge was not apparent; however the overall conclusion of his study indicated the tendency of the edges having higher N concentrations. Elevated concentrations of water soluble constituents under the center of the PL pile footprint, however, suggest that nutrient movement is also likely from those areas of the pile, which were not influenced by rainwater.

Besides considerable N losses that can cause groundwater pollution and surface water eutrophication, farmers are often unable to establish crops on the PL pile footprint (Binford, 2008; Kivlin et al., 2009). When the stockpiles are established on bare ground salts from PL move to the underlying soil (Binford, 2008; Kivlin et al., 2009; Shah et al., 2009). High salt concentrations in soil might result in leaf burning, restricted plant germination or development, and decreased yield (Morris et al., 2009; Brady and Weil, 2008; Izzo et al., 1991; Paramasivam et al., 2009). In saline soils the reduced osmotic potential can severely affect plant water uptake (Izzo et al., 1991; Sparks, 2003). High concentrations of potassium may also induce magnesium deficiency and iron chlorosis (Richards, 1954).

The level of soil salinity can be quantified in terms of the total concentration of soluble salts in the soil solution (Richards, 1954). The constituents of major salts are cations of Na, Ca, Mg and K and anions such as Cl^- and SO_4^{2-} . Electrical Conductivity

(EC) of a soil solution is an indirect measurement of the total salt concentration and based on the ability of water to conduct electricity to an increasing degree as more and more salts are dissolved in it. An accurate EC value can be obtained by extracting the soil solution from a field moist sample or from a saturation extract (EC_{SP}). If the saturation extract has a greater EC than 4 dS m^{-1} the soil is classified as saline (Richards, 1954). Obtaining the EC_{SP} is an expensive and tedious process (Lesch et al., 2008; Zhang et al., 2005), therefore a more commonly used laboratory measurement is on a 1:1 soil-to-water mixture ($EC_{1:1}$). Attempts have been made to establish correlations to convert $EC_{1:1}$ to equivalents of EC_{SP} (Hogg and Henry, 1984; Richards, 1954; Zhang et al., 2005). The relationship Zhang et al. (2005) established on 170 salt affected soils from petroleum and agricultural production sites is: $EC_{SP}=1.85 \times EC_{1:1}$. In addition, to readily interpret EC results from 1:1 soil-to-water extracts recommendations has been established in the Northeastern United States (Morris et al., 2009). Based on $EC_{1:1}$, the classification for silt loam soils is the following: $0 - 1.3 \text{ dS m}^{-1}$: non-saline, $1.4 - 2.5 \text{ dS m}^{-1}$: slightly saline, $2.6-5.0 \text{ dS m}^{-1}$ moderately saline, $5.1 - 10 \text{ dS m}^{-1}$: strongly saline, and $10.1+ \text{ dS m}^{-1}$: very strongly saline.

Salts in PL partially originate from mineral salts added to the animal diet (Guo et al., 2009; Li-Xian et al., 2007) and partially from poultry litter treatments that are aimed to reduce ammonia volatilization in the PL house (Choi and Moore, 2008; Guo and Song, 2009; Guo et al., 2009). Typical broiler feed contains about 3 g kg^{-1} K and 1.5 g kg^{-1} Na (McDonald et al., 2002). Much of these salts are excreted by the birds. Almost 100% of the total K and Na in PL are in water soluble form, thus readily leachable to soil (Guo et al., 2009). Common salts that are used to control ammonia in the poultry houses include

alum (aluminum sulfate $\text{Al}_2(\text{SO}_4)_3$) (Choi and Moore, 2008; Guo and Song, 2009) and Poultry Litter Treatment (PLT, sodium bisulfate, NaHSO_4) (Choi and Moore, 2008; Guo et al., 2009). Generally, a great number of bird flocks are raised in the production houses before the complete clean out of litter, which results in the accumulation of the added salts. The varying timing of total house cleanouts is apparent from the wide range of electrical conductivity values reported in the literature: 3.4 dS m^{-1} (Paramasivam et al., 2009), 11.6 dS m^{-1} (Shah et al., 2009), 25.1 dS m^{-1} (Guo et al., 2009).

When testing nutrient leaching from PL amended to soil columns to a 5 cm depth, Guo et al. (2009) found an EC of 66.5 dS m^{-1} in the first batch of PL leachate under natural rainfall conditions. Soluble salt concentrations in the soil under stockpiled PL reached levels of saline conditions ($> 4 \text{ dS m}^{-1}$) in Binford's study (2008). Shah et al. (2009) found EC values of 2.7 dS m^{-1} in the 7.6 to 30.5 cm soil layer following summer stockpiling and they concluded that EC was 56 to 109 times larger where PL was stockpiled for 6 months then at the adjacent non-storage locations.

Studies found high amounts of K (Binford, 2008; Zebarth B. J. et al., 1999) and Na (Shah et al., 2009; Zebarth B. J. et al., 1999) leaching from stored PL. In fact, Binford (2008) found that K was the nutrient lost in the largest amounts from PL storage piles and K losses were eight times greater than N losses. Binford (2008) concluded from his study that K and sulfur caused the high soluble salt concentrations. This partially contradicts the findings of Shah et al. (2009), who concluded that organic ions, inorganic anions (mainly phosphates), and cations (e.g., Na^+) contributed to elevated EC beneath the stockpiles.

Zebarth (1999) found approximately 800 mg kg^{-1} K and 125 mg kg^{-1} Na extracted with $0.25 \text{ M HOAc} + 0.015 \text{ M NH}_4\text{F}$ in the 0 – 30 cm soil layer where PL was stored through the summer and winter months for 6 years. In addition, these salts affected the entire sampling depth of 370 cm. Interestingly, K and Na concentration patterns along the soil profile were very similar and they both peaked at the 90 – 120 cm depth indicating similar vertical movement pathways. Ammonium nitrogen concentration also peaked at the 90 – 120 cm depth and the concentration pattern along the soil profile was somewhat similar to K and Na, but the concentration decrease with increasing soil depth was not as smooth as in the cases of the two salts indicating some differences in loss mechanisms.

The clay minerals such as illite and vermiculite have a high selectivity for K due to ditrigonal cavities in the tetrahedral sheet of the clay structure. Since K^+ and NH_4^+ are of similar size, they readily compete for these structural cavities and become non-exchangable.

A few studies have been conducted to evaluate soil cover materials that can reduce nutrient movement from stored PL to the soil beneath. Felton (2010) evaluated a cement pad, a soil cement pad, and clay pads and found some reduction in nutrient leaching. However, such pads would reduce the amount of cropland and the construction might require large capital investments. Plastic lining has also been suggested previously, however farmers generally find it impractical and cumbersome to use, partially because of the heavy machinery used to deliver PL and the plastic waste that is generated. Binford (2008) tested different base materials, such as bentonite clay, sawdust and Poultry Guard, but these materials provided no reduction in nutrient loading.

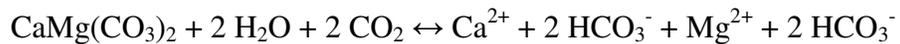
This study focused on evaluating base materials such as alum, gypsum, lime and plastic, serving as physical or chemical barrier between the PL stockpile and the underlying soil. Alum (aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$) is used as a best management practice to acidify PL in chicken houses to reduce ammonia volatilization (Moore et al., 2004; Sims and Luka-McCafferty, 2002). Sims and Luka-McCafferty (2002) found that the addition of alum decreased the water solubility of P, As, Cu and Zn and decreased pH. Alum also increased the fertilizer value of PL by retaining N and increasing sulfur concentration when compared to the houses where no alum was applied. Alum has never been studied as a base liner under PL stockpiles, however, its acidifying property might be able to create a condition where ammonia movement in the soil air and water becomes restricted.

Gypsum ($\text{CaSO}_4 \times 2\text{H}_2\text{O}$) is a broadly available material both in natural deposits and as an industrial byproduct from the building industry or power plants. Fossil fuel burning power plants emit a significant amount of sulfur, and when it is removed from the flue gas, gypsum is produced as a byproduct. The most widely used flue gas desulfurization method uses limestone as absorbent: SO_2 from the flue gas reacts with CaCO_3 and diluted CaSO_4 is produced, which is then crystallized into gypsum (Kallinikos et al., 2010). In agriculture, gypsum is used to ameliorate the effects of aluminum toxicity at low pH. However, it is considered to be a neutral salt, thus it doesn't increase pH nor the cation exchange capacity (CEC) (Brady and Weil, 2008). In the reclamation of sodic soils, gypsum, which dissolves in water relatively rapidly, can be applied to remove exchangeable Na^+ (Sparks, 2003). The following equilibrium equation describes the reaction:



where the letter X represents the soil exchange complex (Richards, 1954).

Alkaline-Earth Carbonates (generally termed lime) occur in substantial amounts in soils as calcite, dolomite, and magnesite (Richards, 1954). Lime is commonly used in agriculture to remediate acidic soils (Brady and Weil, 2008; Richards, 1954; Sparks, 2003). Most liming materials are oxides, hydroxides and carbonates of Ca^{2+} and Mg^{2+} and react with CO_2 in the soil air and water to create bicarbonate when applied to an acid soil:



These bicarbonates are more soluble than carbonates and readily react with the soil's exchangeable and residual acidity (Brady and Weil, 2008).

The objective of the study is to determine the relative risk of nutrient losses between 15 and 91 days of PL storage and evaluate nutrient loss reductions to the soil by base liner materials.

Materials and Methods

Study site set up

Temporary poultry litter storage study was conducted using 6 conically shaped piles containing approximately 19 Mg PL. The study was located at the Wye Research and Education Center, Queenstown, Maryland, USA. The study site is dominated by Mattapex – Butlertown silt loam soil with 0 to 2 % slopes, moderately well drained and typically has 46 – 122 cm water table. The soils of Mattapex series are fine-silty, mixed, active, mesic Aquic Hapludults. The Butlertown series is characterized as fine-silty,

mixed, mesic Typic Fragidults. Butlertown is similar to Mattapex soil, but has a fragipan starting at a depth of 76 to 96 cm (USDA-SCS, 2010; WSS, 2010). Some basic characteristics of the soil in the study site are listed in Table 1. The average daily temperature on the site varied between 12°C and 32°C and cumulative rainfall was 323 mm between May 17 and August 16, 2010 (WREC, 2011).

The research plot had 0% slope and was a rectangle measuring 33.3 m × 21.2 m. Six square shaped, 9.1 m × 9.1 m plots with 3 m wide buffer zones were laid out with flags. The site contained three rows with two plots in each row (Figure 1).

Six tractor trailer loads (approx. 120 Mg) of poultry litter were obtained from multiple local growers on the Maryland Eastern Shore during October 2009. The litter was stored in a 2 m tall pile with a 7.6 m x 11 m footprint, covered with 6 mm black poly plastic sheets and secured in place with tires until the weather conditions allowed access to the site in May 2010. Over the course of these 7 months, PL moisture content increased by 74 %, EC increased from 18.9 dS m⁻¹ to 23.9 dS m⁻¹, and pH decreased from 8.9 to 6.5.

On 17 May 2010 six conical poultry litter piles were established. Using a front-end loader each plot received 24 loads of PL which was built in an “A” shape. Consistent compositions among the piles were achieved by consecutively dumping PL onto each plot and when all received a load, the circle was started again until all the available litter was used up in 24 rounds. Poultry litter weight of each pile was estimated by weighing the 1st, 5th, 11th and 17th loads of PL before transported onto each one of the 6 plots. The weight measurements were taken by truck scales on each axle of the front end loader. The average PL weight in the 24 loads was 801 kg with ± 201 kg standard deviation. The

established piles contained approximately 19 Mg of PL, they were 2 m tall, and had a circular base with a radius of 3.9 m.

Six months prior to establishment of the PL piles five 110 cm long PVC pipes with 10.2 cm diameter were driven into the ground in the center of each plot to a depth of 1 m. A 10 cm segment of each pipe was left above ground to provide a well defined location for treatment application and exclude lateral water movement on the soil surface. Some of the pipes reached a fragipan layer and couldn't be pushed all the way to 1 m depth and a longer segment of the pipe was left above ground (maximum plus 5 cm). The five pipes on each plot were arranged in a rectangle measuring 1 m × 1 m positioned under the center of each PL pile (Figure 1).

Treatments were randomly applied to the soil surface in the columns to simulate a base material as a barrier between PL and soil. The five treatment levels were no material (control) and four kinds of base material: 6 mm Clear Polyethylene Sheeting (Husky brand, Poly-America Lp, Grand Praire, TX), aluminum sulfate (Bonide Products, Inc., Oriskany, NY), limestone (Oldcastle® Industrial Minerals, Thomasville, PA) and gypsum (flue gas desulfurization byproduct from US Gypsum Company, Baltimore, MD). The chemical amendments were broadcast on the soil surface at 2.4 kg m⁻² application rate. The plastic sheeting used was cut to 50 cm x 50 cm squares, pushed into the extended segment of the column and secured by a rope on the outside of the PVC pipe. Three PL stockpiles were removed on June 1, 2010 and three on August 10, 2010, after 15 and 91 days of storage respectively.

The PL piles that were removed after 91 days were equipped with moisture and temperature monitoring sensors. Three temperature probes, built from TT-T-24-1000

Thermocouple Wire (Omega Engineering, Inc., Stamford, CT), were placed 5 cm, 60 cm and 120 cm above the ground, at the center of the pile footprint. For moisture content monitoring, EC5 capacitance probes (Decagon Devices, Inc., Pullman, WA) were used at 5 cm and 60 cm above the center of the PL pile footprint. These probes were custom coated with epoxy to tolerate the higher temperatures induced by the decomposing poultry litter. For data acquisition, Campbell Scientific 21X(L) data loggers with CSI AM416 multiplexers (Campbell Scientific, Inc., Logan, UT) were used to log data from EC5 moisture and the thermocouple temperature sensors. Moisture readings were taken every hour using 2500 mV excitation voltage. Differential temperature readings were taken every 60 seconds and automatically averaged over each hour. Power was supplied by a deep cycle marine battery that was recharged by a Sunsei SolarCharger 1200 (ICP Solar Technologies, Inc., Montreal, Canada).

According to the moisture monitoring results in the center portion of the PL pile, volumetric moisture content was about 20 % when the study started and gradually increased both 5 cm and 60 cm above the soil surface for almost 2 months (Figure 2). Three and six days after 90 cm rain fell on July 10th (the 54th day of the study) the moisture content leveled off after peaking at 34 % at 5 cm and 36 % at 60 cm. These data are not sufficient to predict what portion of this moisture content increase was due to dry matter loss and volume change and how much moisture generation during microbial decomposition should be accounted for. Interestingly, moisture content increase stopped after a heavy rain. Probably rainwater that soaked into the crust of the pile prevented aeration inside the pile, therefore microbial decomposition, hence moisture generation and dry matter loss might have slowed down.

Temperature inside the PL piles was not affected by the ambient temperature changes (Figure 2). After the establishments of the piles, temperature at 120 cm started to increase rapidly for 2 weeks and leveled off at about 63°C. After the heavy rain temperature dropped to 53°C indicating that microbial decomposition was affected. Closer to the ground temperature was lower: it peaked at 36°C at 5 cm and 53°C at 60 cm before the heavy rain on July 10. The patterns of temperature changes were somewhat similar, but their range was narrower closer to the soil surface.

Sampling and analysis

During the establishment of the study, grab samples were taken from PL each time the front-end loader hauled a new load of litter to the plots. Litter samples from each plot were collected separately, thoroughly mixed, placed into plastic bags and frozen until analysis. On each removal date, PL grab samples were taken from the center and in a circle inside the edge of the pile, 0.05 m and 0.6 m above the soil surface. Immediately upon arrival to the laboratory the gravimetric moisture content of the PL samples were determined by drying at 105°C for 24 hours. Upon delivery from the production houses in October 2009, grab samples were also taken from the fresh PL separately from each truck load.

At each PL removal time, the columns were also removed from the soil using a back hoe. A trench was created along the columns and they were carefully pulled out sideways to avoid any loss of soil. The soil cores were cut in half along their length (Figure 1) and cut up to 10 cm segments, starting at the soil surface. In some cases, the fragipan didn't allow the penetration of the PVC pipe all the way to 1 m, therefore the

last two (80 – 90 cm and 90 – 100 cm) samples were created by cutting the segment under 80 cm into halves. Each 10 cm segment was placed into a plastic bag and transported to the University of Maryland Laboratory of Agricultural and Environmental Studies for analysis.

Upon arrival to the lab, a subset of each soil sample was air dried at room temperature, crushed and passed through a 2 mm sieve. Another subset of the samples were kept in the plastic bags and stored in a refrigerator at 4°C until their gravimetric moisture content was determined by drying at 105°C for 24 hours.

For reference, bulk soil samples were collected from each plot in October 2009 and immediately after the final PL removal in August 2010. Using a tractor-mounted 2.54-cm diameter and 1-m long soil auger, five random samples were obtained per plot and divided into 10-cm segments. The five cores were pooled to create a composite sample from each depth range. In addition to this, a set of samples were taken two days before the initiation of the study on 15 May 2010. Each plot was sampled separately to five depths: 0 – 2.5 cm, 2.5 – 7.5 cm, 7.5 – 15 cm, 15 – 30 cm and 30 – 60 cm. Subsamples were composited to obtain a 100 – 150 g soil sample. All sampling holes in the field were filled up with a 1:1 mix of bentonite clay and sand to avoid preferential flow. All samples were air dried, crushed and sieved similarly to the column samples. For comparison purposes, the results of 2010 May samples will be used in some cases, because the N content of samples from October 2009 became a concern due to improper storage prior to analysis.

In order to minimize changes in the N composition, both PL and soil samples were first extracted with 2M KCl and $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ concentrations were determined

by automated ascorbic acid colorimetric method (Keeney and Nelson, 1982) using Lachat QuikChem 8500 Flow Injection Analysis System (Hach Company, Loveland, CO). The pH and EC were determined on 1:2 water slurry in case of PL and 1:1 water slurry in case of soil with Mettler Toledo InLab® Expert Pro pH and Mettler Toledo InLab® 731 EC meter. After drying for 24 h at 105°C, all samples were analyzed for total C, H and N using a LECO® Corporation 2000 Elemental Analyzer by the method of Nelson and Sommers (1996). In this analysis, the minimum value for nitrogen is 0.01% N based on sample weight of 0.200 g.

Soil Mehlich 3 (M3) extractions were carried out by shaking 2.5 g sample with 25 mL of Mehlich 3 solution (0.2 M CH₃COOH, 0.25 M NH₄NO₃, 0.015 M HNO₃, and 0.001 M EDTA) for five minutes on a reciprocating shaker (Mehlich, 1984). The extracted solution was filtered through Whatman # 41 filter paper (Whatman International, Maidstone, UK). Water extractions (WE) of the soil samples were carried out by shaking 2.5 g of soil samples with 25 ml of deionized water then filtered through 0.45µm filters using the Millipore filtration apparatus.

EPA guidelines 3050B (USEPA, 1996) were used for the total elemental digestion of PL samples on an Environmental Express hot block model at 95°C. The M3 extracts, water extracts and acid digests of the PL were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES, "Spectro-flame Modula E" from Spectro GMBH, Kleve, Germany) and K, Na, Ca, P, K, Al, Fe, S concentrations were determined.

Experimental design

Complete randomized split plot design was used for the study. The main plots were “Day of removal” and had two levels (15 and 91 days) and three replications. Each of the main plots had five subplots (five columns) with different treatments levels. The blocking factor was location on the field and each block contained a 15- and a 91-day litter pile that were randomly assigned. From the treatment factor’s perspective, the main plots served as blocks.

For statistical evaluation of the collected data, ANOVA Proc MIXED procedure was used in SAS software (SAS-Institute-Inc., 2004). Response variables of PL were analyzed as a Completely Randomized Design. The analysis of the soil data was conducted as a Completely Randomized Split-Plot Repeated Measure Design. Split-plot factors were the topical treatments within day of removal main plots. The repeated measure factor was depth (0 – 80 cm, in 10-cm increments) within the treatment split-plots. Significant differences between means were determined at $\alpha = 0.05$. The appropriate covariance structure was determined by the lowest AIC fit statistics. Considering the inherent variations in a field study, Tukey adjustment was used for the mean comparisons to detect treatment effects.

Response variables from the initial soil samples taken in October 2009 and May 2010 were used to aid discussion of the results, however, they were not included in the statistical analysis. Moreover, the 80 – 100 cm segments were removed from the analysis because of their shorter depth range than the intended 20 cm as a result of restricted penetration of soil columns through the fragipan. It is important to mention that the fragipan layer might have changed the hydrology in some of the soil columns, which can

cause unexpected variations among the response variables. Under typical field conditions, water percolating downward could move laterally after encountering the fragipan. However, due to the pipes being inserted in the soil this lateral movement would be prohibited. Mottling was identified in some of these columns indicating that a reduced layer occurred where water could not drain naturally due to the intersection of the pipes and the fragipan.

Results and Discussion

Changes in poultry litter properties

Except for inorganic N forms, the concentration of all other constituents remained unchanged within the PL piles over the course of the study (Table 2). However, the lack of concentration change does not indicate that there were no losses from the pile. Nonvolatile constituents might have been lost through multiple pathways (e.g. leaching, runoff) or concentrations might have increased due to loss of dry matter through C respiration. At the PL removal dates, the piles were not weighed; therefore it is not possible to predict the simultaneous dry matter losses.

Ammonium-N concentrations in the PL remained the same as on Day 0, about 10 g kg⁻¹, after 15 days of storage, but by Day 91 they had increased to 13 g kg⁻¹ (Table 2). This increase in concentration might have resulted from the weight loss of the piles. Another potential explanation could be that towards the end of the study, microorganisms might have used most of the easily decomposable carbon sources and switched to N containing organic materials, which can result in increased ammonium generation. Nitrate-N was very low in the pile, decreasing from 0.53 g kg⁻¹ on Day 0 to 0.03 g kg⁻¹ on

Day 91. Gravimetric moisture content increased from 0.37 g g^{-1} (day 0) to 0.44 g g^{-1} (day 91), but this increase was not determined to be statistically significant. This high moisture content could have prohibited the pile from sufficient aeration. The lack of oxygen, along with high NH_4^+ -N concentration, might have inhibited nitrification. Gravimetric moisture content was 0.35 g g^{-1} when the fresh PL was delivered in October 2009.

Electrical conductivity was between 24 and 25 dS m^{-1} and didn't change significantly over the course of the study. However, it did increase from 19 dS m^{-1} to 24 dS m^{-1} between October 2009 and May 2010 while it was stored under a plastic tarp over the winter months. Sodium and K had the highest concentration in PL among the analyzed cations. Total extractable and water extractable K and Na concentrations were very similar, indicating the high solubility of these constituents in the litter and in agreement with the findings of Guo et al. (2009).

Inorganic nitrogen losses

Soil NH_4 -N concentrations two days before the initiation of the study were 6.4 mg kg^{-1} in the $0 - 30\text{ cm}$ segment of the soil profile (Table 1). However, it is important to note that bulk soil conditions were probably different from inside the columns, because the columns were in place for seven months before the initiation of the study. Due to the columns intersecting the fragipan water was ponding in the tops of the columns at the initiation of the study, whereas no water was ponding on the soils outside the columns. However, after the PL piles were in place, no more precipitation affected the columns and it is likely they eventually drained. Gravimetric soil moisture content decreased

significantly from the top 10 cm to the 10 – 20 cm depth and then remained relatively constant (Figure 4).

Three way (Day*Trt*Depth) interactions were significant both in the case of soil NH_4^+ -N and NO_3 -N concentrations (Table 3). In the columns collected after 15 days of storage, there were no significant differences in NH_4^+ -N concentrations between any depths from 10 to 70 cm depth (Table 4), indicating that there was no significant movement of NH_4^+ -N beyond the top 10 cm after only 15 days. Soil NH_4^+ -N concentrations were highest and not significantly different between the control (no liner 149 mg kg^{-1}), gypsum (102 mg kg^{-1}), and lime (108 mg kg^{-1}) treatments after 15 days in the top 10 cm. Ammonium-N concentrations in the top 10 cm under the alum treatment (50 mg kg^{-1}) were not significantly different from gypsum, lime or plastic. However, NH_4^+ -N concentrations in the top 10 cm under the alum treatment were not significantly higher than at any other depth under any treatment either, indicating that the alum was somewhat effective at interfering with NH_4^+ -N movement into the soil. After 15 days the plastic liner appeared to be the most effective with an NH_4^+ -N concentration of 19 mg kg^{-1} in the 0-10 cm segment, which was significantly lower than concentrations in the top 10 cm under the control, gypsum, or lime treatments. In addition, there were no statistical differences between the top 10 cm under the plastic and any of the deeper samples.

In the top 10 cm after 91 days of storage NH_4^+ -N concentrations increased significantly under the alum (278 mg kg^{-1}), control (303 mg kg^{-1}), gypsum (229 mg kg^{-1}), and lime (236 mg kg^{-1}) relative to all treatments and depths after only 15 days. Once again the plastic treatment seemed to be somewhat effective at inhibiting NH_4^+ -N movement. Soil NH_4^+ -N concentrations under plastic after 91 days of storage were eight

fold greater (153 mg kg^{-1}) than after 15 days, but were not significantly greater than concentrations under the control, gypsum, or lime after only 15 days. In addition, the longer storage time allowed for greater vertical movement of $\text{NH}_4^+\text{-N}$. In general, $\text{NH}_4^+\text{-N}$ concentrations increased at all depths after 91 days compared to 15 days. However, these differences were only significant in the case of the control (147 mg kg^{-1}), gypsum (146 mg kg^{-1}) and lime (129 mg kg^{-1}) treatments at 10 – 20 cm depth compared to all treatments and depths greater than 10 cm after 15 days. Ammonium movement downward was greatest under the lime after 91 days where in the 20 – 30 cm segment soil $\text{NH}_4^+\text{-N}$ concentrations (33 mg kg^{-1}) were not significantly different than at the 10 – 20 cm depth under alum and plastic after 91 days or alum and gypsum after 15 days in the 0 – 10 cm depth. However, $\text{NH}_4^+\text{-N}$ concentrations under the lime at the 20 – 30 cm depth after 91 days were not significantly different than any of the other treatments below 20 cm.

It appears that alum and plastic can achieve an $\text{NH}_4^+\text{-N}$ concentration reduction in 15 days compared to when no material (control) was used. However, by Day 91 concentrations under the alum treatment were similar to control. Plastic had the lowest concentration of $\text{NH}_4^+\text{-N}$, about half of the control, but it wasn't more beneficial than gypsum. The most effective barrier to reduce $\text{NH}_4^+\text{-N}$ movement seems to be the 6 mm plastic lining, however it wasn't able to completely prevent ammonium losses. Nonetheless, $\text{NH}_4^+\text{-N}$ movement was restricted to the top 20 cm even when there was no barrier material applied.

Soil $\text{NO}_3^-\text{-N}$ concentrations were relatively low under the stored poultry litter. Nitrate-N concentrations in the surface 10 cm were higher after Day 15 than after Day 91,

however statistically only the plastic treatment differed (Table 5). The $\text{NO}_3\text{-N}$ concentration under the plastic lining after 15 days (8.24 mg kg^{-1}) was significantly higher than for any other barrier, depth, or time except for the control at day 15, 10 – 20 cm (6.29 mg kg^{-1}), which was not significantly different. After 91 days all nitrate-N concentrations were below 1 mg kg^{-1} and there was no difference between treatment levels. The low nitrate concentrations were probably due to high $\text{NH}_4^+\text{-N}$ concentrations that inhibited nitrifying bacteria (Zebarth B. J. et al., 1999). At Day 15, oxygen levels might have been still sufficient for nitrification to occur near the soil surface, but probably not by Day 91.

Generally, alum and plastic were effective in N loss reduction at Day 15 and gypsum and plastic were effective at Day 91. Storage time had an influence on the leaching depth and concentration. In 15 days no significant loss was evidenced beyond 10 cm. When the soil columns were removed and destructively sampled, special care was taken to remove all visible PL residues, from the soil surface. Nonetheless, it is impossible to tell whether the high ammonium concentrations near the surface are the result of PL being mixed into the soil sample or actual movement. However, in plastic treatment PL could not get in contact with the soil surface and movement still occurred. Poultry litter contained over a 1000 times greater concentration of ammonia than the soil before the stockpiles were established. At 91 days $\text{NH}_4^+\text{-N}$ movement affected the 10 – 20 cm layer in the control, gypsum and lime treatments, so longer storage time clearly resulted in higher concentrations to greater depths, which is supported by numerous studies (Binford, 2008; Ritter et al., 1994; Shah et al., 2009; Zebarth B. J. et al., 1999).

Soil pH and salt leaching

pH

Statistical analysis of pH showed a significant interaction of day*depth and treatment*depth (Table 3). Table 6 shows the means of trt*depth. Generally, different treatments resulted in nonsignificant pH differences (5.99 to 6.68) in all cases except under alum treatment in the top 10 cm. In the 0 – 10 cm layer under alum the average pH was 3.79, which is probably due to the dissolution and hydrolysis of highly soluble aluminum sulfate.

Electrical conductivity

Electrical conductivity (EC) of a 1:1 soil-water mixture provides an indirect measurement of the salt content in the soil. Soil soluble salt concentration increases with increasing EC. Before the study, EC was 0.04 dS m^{-1} in the 0 – 30 cm soil layer (Table 1). Statistical analysis of the soil EC results reveal a three-way (day*trt*depth) interaction (Table 3). Alum treatment resulted in significantly higher EC than the rest of the treatments in the surface 10 cm: after 15 days, EC indicated moderately saline conditions (3.51 dS m^{-1}). The lowest EC, 0.16 dS m^{-1} , was measured under plastic treatment in the 0 – 10 cm depth after 15 days, however it didn't differ statistically from the control (1.11 dS m^{-1}) or lime (0.75 dS m^{-1}) (Table 7). Gypsum (1.37 dS m^{-1}) was not statistically different from the control and lime either, but it was different from plastic. Only in the case of alum and gypsum was the EC significantly higher in the 0 – 10 cm from the rest of the soil profile after 15 days. For the plastic, lime and control treatments no significant impact was detected throughout the entire soil profile.

In the top 10 cm between 15 and 91 days, EC differed significantly in the case of all treatments except plastic. In fact, plastic was the only treatment that prevented an EC increase between 15 and 91 days and it didn't change significantly at any depth throughout the entire study.

At Day 91 in the 0 – 10 cm depth, lime (2.40 dS m^{-1}) and gypsum (2.98 dS m^{-1}) treatments did not differ statistically from the control (2.52 dS m^{-1}), but they reached the upper limit of slightly saline and the lower limit of moderately saline conditions (Morris et al., 2009). Moreover, the EC of the control and gypsum in the top 10 cm after 91 days was similar to the EC under the alum after 15 days. After 91 days, the soil was strongly saline (6.44 dS m^{-1}) for the alum treatment in the top 10 cm. The EC was two to three times more than when no material (control) was added where the increase in salt content could only originate from the PL pile and not the base liner. Aluminum sulfate dissolves in water well, which is probably the reason for the higher EC. The high aluminum and sulfur concentrations under the alum treatment also support this finding.

Electrical conductivity results of the control treatment in the present study were greater than what Binford (2008) found when studying different PL removal days. After 16 days of storage in his study, EC in the 0 – 15 cm soil layer was 0.6 dS m^{-1} and after 93 days it was 1.2 dS m^{-1} . Zebarth (1999) showed that continued PL storage at the same location for 6 years results in EC increase to a 370-cm depth.

Soil potassium and sodium concentrations

Besides the problem of excess N remaining in the PL pile footprint beyond what a conventional crop, such as corn might be able to take up, high salt levels might prevent

crop growth on the footprint altogether at least in the first growing season. The lack of vegetation would not only promote nutrient loss, but bare soil is prone to erosion as well.

Initially, soil water extractable K (WEK) and water extractable Na (WENa) concentrations in the 0 – 30 cm soil layer were 31 mg kg⁻¹ and 7 mg kg⁻¹ respectively (Table 1). Water extractable concentrations of K and Na in the soil under the PL piles had significant Day*Trt*Depth interactions (Table 3). Even after 91 days of storage, WEK and WENa only affected the top 10 cm of the soil column in all of the treatments, except the plastic treatment where no significant loss was detected (Table 8, Table 9). After 15 days, the largest amount of WEK and WENa was detected under the control: 358 mg K kg⁻¹ and 153 mg Na kg⁻¹. Alum (167 mg K kg⁻¹ and 105 mg Na kg⁻¹), gypsum (224 mg K kg⁻¹ and 81 mg Na kg⁻¹) and lime (197 mg K kg⁻¹ and 85 mg Na kg⁻¹) treatments resulted in similar losses to the upper 10 cm after 15 days for both WEK and WENa. In the case of WENa, alum was not different from the control either after 15 days. The rest of the soil profile was unaffected in every case and was similar to plastic (38.1 mg K kg⁻¹ and 8.93 mg Na kg⁻¹) at Day 15, 0 – 10 cm.

In the top 10 cm, WEK and WENa concentrations increased significantly between 15 and 91 days of storage for all treatments, except plastic. In the top 10 cm, the WEK and WENa concentration doubled for the control (735 mg K kg⁻¹ and 358 mg Na kg⁻¹) and alum (325 mg K kg⁻¹ and 209 mg Na kg⁻¹) treatments after 91 days, compared to day 15. In case of gypsum (1125 mg K kg⁻¹ and 463 mg Na kg⁻¹) this increase was over fivefold, while the concentration in the lime (754 mg K kg⁻¹ and 354 mg Na kg⁻¹) treatment increased by nearly fourfold. Plastic (54.2 mg K kg⁻¹ and 13.3 mg Na kg⁻¹) was the most effective in WEK and WENa leaching prevention both after 15 and 91 days,

because their concentration didn't change significantly over the course of the study at any depth. After plastic, alum appeared to be the second most effective at 91 days: both WEK and WENa concentrations were significantly lower than for control, gypsum and lime in the 0 – 10 cm soil depth. Lime was similar to the control, but gypsum had the highest levels of these problem salts after 91 days in the surface 10 cm, which was significantly greater compared to the rest of the treatments for both WEK and WENa. Gypsum has a relatively high solubility in water, so the released Ca^{2+} might have occupied the exchange sites on soil colloids forcing more K^+ and Na^+ to remain in the soil solution.

However, there was a trend of downward K and Na movement observed by Day 91 in the 10 – 20 cm soil profile, the concentrations were not significantly different from those observed at greater depths at the same time, nor were they different from Day 15 in 10 – 80 cm soil profile.

In the case of WEK by Day 91 in the 10 – 20 cm depth, alum, gypsum and lime reached similar concentrations to what they were at Day 15 in the 0 – 10 cm depth. A similar pattern was observed in case of WENa, but only for gypsum and lime. At Day 91, plastic was as effective in K loss reduction as alum at Day 15.

Interestingly, the ratios of salt concentrations of 91 and 15 days are similar in the case of WEK and WENa indicating that K and Na might be having similar movement patterns in the soil pores. This is also supported by Figure 5 and Figure 6.

Plants are able to take up potassium from the soil solution as well as from the exchange complexes of soil particles (Brady and Weil, 2008). Mehlich-3 extraction is widely used to assess plant available potassium in soil. Results show higher concentrations of M3K than WEK in the soil columns. Potassium was leaching from the

PL pile enriching the soil solution which is in equilibrium with the colloid surfaces of soil. In order to establish equilibrium, some of the K moved to the exchange complex, and became non-extractable by water, but still available for plants to take up.

Maryland Cooperative Extension established recommendations for potassium fertilization based on soil test K. The relative level of plant available nutrients is expressed in fertility index values (FIV), which can be calculated from M3K concentration in the surface 20 cm of the soil profile (Coale, 2006). The FIV ranges for the four soil test interpretive categories are: low = 0 to 25; medium = 26 to 50; optimum = 51 to 100; and excessive = >100 (MDA, 2009). Following 15 days of storage, FIV values were 118, 312, 198, 212, 103 for alum, control, gypsum, lime, plastic, respectively. This shows that even after 15 days of storage soil potassium reached excessive levels regardless of the treatment applied. When PL was stored for 91 days, FIV increased even further: 230, 712, 560, 460, 142 under alum, control, gypsum, lime, plastic treatments, respectively.

Both in Maryland and Delaware, corn and soybean are among the top five agricultural commodities (USDA-ERS, 2010a; USDA-ERS, 2010b). In case of corn, Mallarino and Blackmer (1994) determined that 70 ppm is the profit-maximizing critical value for M3K. A study by Slaton et al. (2010) predicted that the critical M3K concentrations in the top 10 cm of soil needed to produce near-maximal soybean yields ranged from 108 to 114 mg kg⁻¹ in silt loam soils with relatively low CEC. Under PL stockpiles, soil M3K concentrations in the top 10 cm were 231, 776, 464, 506 and 175 mg kg⁻¹ following 15 days of storage and 488, 1786, 1362, 1079 and 240 mg kg⁻¹ after 91 days of storage for alum, control, gypsum, lime and plastic, respectively. The

excessive soil K under the PL stockpile footprint might result in luxury consumption of K. No information in the literature was found on soil K levels that prevent corn and soybean seed germination.

Conclusions

Longer storage time resulted in higher concentrations of nutrients in the soil profile. Ammonium-N, K^+ and Na^+ concentrations increased in the soil between 15 and 91 days of PL storage for all the treatments in the 0 – 10 cm depth. Ammonium-N concentration increased by 450 % with alum, 100 % for the control, 120 % for gypsum and lime and by 740 % for plastic. In the 0 – 10 cm layer, WEK concentration increased by 90 %, 100 %, 400 %, 280 % and 40 % and WENa concentration increased by 100 %, 130 %, 470 %, 310 % and 40 % under alum, control, gypsum, lime and plastic respectively between Day 15 and Day 91.

Potassium and Na only affected the top 10 cm of the soil profile, even after 91 days of storage. However, elevated ammonium concentration was detected at the 10 – 20 cm depth for the control, gypsum and lime treatments. This indicates potential differences in the movement patterns of NH_4^+ -N and K and Na. A regression analysis suggested that K and Na are moving together, which happens most likely in the soil solution phase. However, since ammonium was able to reach a greater depth, it is likely that they have differences in the loss mechanisms. As suggested by other studies, ammonia is in equilibrium between the soil air and solution phase (Masters and Ela, 2007) and has the potential to move in the soil pores as vapor (Binford, 2008; Zebarth B. J. et al., 1999).

Overall, plastic base liner was the most effective in reducing N, K and Na losses. It was able to prevent significant increases in K and Na concentrations of the soil between Day 15 and Day 91. Surprisingly, it was not able to prevent ammonium concentration increase. In the 0 – 10 cm layer, NH_4^+ -N concentration increased by 700 % under plastic base liner. Interestingly, following 15 days of storage, NO_3^- -N concentration was the highest under the plastic in the 0 – 10 cm depth. It raises the question whether ammonium is able to move through the plastic liner in the gas phase and to a much lesser extent in the liquid phase, which is supported by the lack of increase in water soluble constituents. In this case, the exceptional NO_3^- -N concentration under plastic at Day 15 might be due to ammonium moving through the plastic and going through nitrification as long as sufficient oxygen is available.

After plastic, alum was the second most effective in nutrient loss reduction. Ammonium-N, K and Na did not significantly affect the soil profile beyond 10 cm. However, by Day 91, NH_4^+ -N concentrations were not different from the control at either depth. In the case of K and Na, the alum treatment achieved some reduction in the 0 – 10 cm compared to control. Despite that alum had some advantage over gypsum, lime and control in terms of nutrient reduction; it also caused some adverse conditions. The average pH under alum treatment was 3.79 in the 0 – 10 cm depth. The low pH is likely a result of aluminum sulfate dissolution and leaching into the soil profile. In these conditions Al-toxicity is highly likely. Gypsum and lime treatments were generally not different than having no barrier material. However, gypsum was able to reduce NH_4^+ -N concentrations in the 0 – 10 cm at 91 days, it also resulted in significantly higher WEK and WENa concentrations at the same depth and time. The EC results reveal that after 91

days the surface 10 cm of soil was slightly to severely salt affected under all treatments, except the plastic base liner.

In conclusion, plastic appears to be the most effective base liner. However, farmers generally find it impractical and cumbersome to use. They drive heavy machinery to transport PL to the storage location and the plastic sheeting can easily be destroyed. Secondly, following the removal of PL the plastic sheeting might not be reusable and therefore additional waste would be created. There is no experience reported in the literature about the large scale use of alum, gypsum or lime as base liners and whether they would be affected by driving a truck over them. However, Binford (2008) experimented with bentonite clay liner and reported that the delivery truck destroyed the bentonite layer and the material got stuck into the truck tires. On the other hand, alum, lime and gypsum act most likely as a chemical barrier, therefore driving a truck through these liners might not cause their damage (Joshua McGrath, Personal Communication).

The results of this study should be used with caution, because the conditions in the soil columns might have been very different from the bulk soil. The difference is probably largely due to the fragipan layer that many of the soil columns were probably intersecting. This was evidenced by water ponding in the soil columns after heavy winter precipitations for much longer than outside the columns. These unfavorable conditions in the columns might have affected the results more than the treatments. In the columns the greatest depth where elevated nutrient concentrations were evidenced was 20 cm, while in the bulk soil nutrient movement probably reached the 60 to 70 cm layer as well (Figure 7).

Recommendations

Bulk soil samples collected from each plot randomly on the final PL removal day in August 2010 reveal that in natural soil conditions, $\text{NH}_4^+\text{-N}$ is likely to reach a much greater depth by 91 days (Figure 7) than in the columns. In the columns only the top 20 cm was influenced. However, this reduction cannot be attributed to the treatment effects, because the column that had no base liner material showed no movement beyond 20 cm either. The lack of vertical movement to greater depths could also be a result of centering the columns under the PL piles where nutrient loss can be lower than towards the edge of PL piles. This study was designed as a preliminary evaluation, but the experimental methods were limited (i.e. using the columns) and therefore might have interfered with findings. However, some of the treatments appeared to have some promise (i.e. plastic, gypsum) at intercepting $\text{NH}_4^+\text{-N}$ and therefore this might justify a full scale study with separate piles for treatments.

The use of alum is not recommended as a base liner, because it severely lowers pH and increases Al concentration. By Day 91, Al^{3+} concentration under the alum treatment was 225 times greater than under plastic. Aluminum ions tend to hydrolyze in the soil solution, splitting water into H^+ and OH^- ions (Brady and Weil, 2008). Aluminum attaches to OH^- leaving H^+ in the soil solution that lowers its pH. Excess soluble aluminum is highly toxic to most plants and other organisms (Delhaize and Ryan, 1995). Naturally, in acid soils where pH is below 5.5, Al-toxicity causes severe problems due to the dissolution of Al^{3+} from the clay minerals. Alum application to the soil surface enhances the problem. When affected by aluminum, plants suffer from damage primarily on their roots (Delhaize and Ryan, 1995). Poorly developed roots have reduced ability to

absorb water. Other deficiency symptoms might occur as well. Excessive Al^{3+} can reduce the availability of other cations through competitive replacement from the soil exchange sites and also has the affinity to precipitate with P. Aluminum-phosphate precipitation from the soil solution is supported by the low water soluble P concentration under the alum treatment, which was 44% of what was observed under the control.

The K effect may be lessened by increasing Ca content, which replaces K from the soil exchange sites (Richards, 1954). Using gypsum as base liner and leaching of monovalent salts after PL removal might create conditions where plants could germinate, but this practice might leach N too, creating a nutrient pollution issue.

When PL is stockpiled on a field where PL will be applied as a fertilizer, avoid the fertilization of the stockpile footprint, because the amounts of nutrients in the soil are already beyond what a conventional crop can take up. After 91 days, the ammonium results would be equivalent to 411, 449, 338, 349, 226 kg N ha^{-1} in the upper 10 cm under alum, control, gypsum, lime and plastic treatments, respectively. This calculation was based on the surface area of the soil columns. Even though the area of a PL pile footprint does not reach such magnitude, crop yield responses are usually expressed as the function of N concentration in the soil on a kg ha^{-1} basis. These amounts of N are in excess of the N requirement for most crops and therefore are subject to loss even if there is no additional fertilizer applied to the PL pile footprint (Adeli et al., 2011; Harmel et al., 2008). Moreover, studies (Binford, 2008; Shah et al., 2009) show that the lowest amounts of nutrients are leached under the center of the PL pile footprint and higher losses can be expected near the edge of the pile which is influenced by the ambient weather conditions.

After PL pile removal, planting salt tolerant cover crops such as barely, bermuda grass, canola, cotton, rye, fescue, and wheat (Brady and Weil, 2008) might remediate the salt problem if they would be able to germinate at all. This practice would have multiple environmental advantages: both N and salts would be taken up by these plants, therefore pollution would be decreased and the soil surface would not be left prone to erosion.

Invest in research of impermeable pads of natural materials and grass buffer strips. Test and use already existing recommendations for PL storage such as Agricultural Waste Stacking and Handling Pad by the Cooperative Extension of Penn State University (Tyson et al., 2010).

Find other industries with high carbon waste materials and connect them with poultry growers to cooperate in composting programs. Nitrogen losses from a PL could be reduced by balancing the C:N ratio. It is about 8:1 in PL, but for proper composting, hence stabilization of constituents a 20:1 to 30:1 C:N ratio is necessary (Preusch et al., 2002).

On a final note, it is becoming apparent that that a predominant reason of pollution problems related to the poultry industry is its size and geographically clustered nature, which creates local nutrient imbalances and nutrient pollution issues (Sims and Wolf, 1994; Sims et al., 2005). Holistic management of agricultural production, where crop and animal production is integrated, biological diversity is enhanced and the management of resources promotes ecological balance, could be a pathway to reduce or eliminate pollution. Research in sustainable and holistic agriculture may be necessary to provide system based local tools to remediate nutrient imbalances on sensitive watersheds. Management of PL during storage, handling and field application should be

viewed and practiced within the context of the broader agricultural and ecological systems. When making recommendations for proper field storage, regional supply and demand for nutrients both spatially and temporally should be considered. In addition, the agricultural system and how it creates nutrient imbalances should be evaluated when addressing the potential for nutrient losses from systems involving PL.

Tables

Table 1: Selected properties of experimental site and soil. Listed soil properties are averages from 0 – 30 cm soil depth.

Latitude		38°54'34"
Longitude		76°08'51"
Area (m ²)		716
Slope (%)		0
Soil Series		Mattapex – Butlertown
Soil Taxonomy		Fine-silty, mixed, active, mesic Aquic Hapludults and Typic Fragidults
<u>Surface (0-30 cm) soil properties</u>		
pH (1:1)		6.09 (0.05) ^a
EC (1:1) (dS m ⁻¹)		0.04 (0.01) ^a
CEC _e (meq 100g ⁻¹) ^b		5.50 (0.04) ^{ab}
Total carbon (%)		0.95 (0.03) ^a
Bulk density (g cm ⁻³)		1.48
Soil texture (%) ^c	Sand	14.2
	Silt	71.8
	Clay	14.0
Inorganic N (mg kg ⁻¹)	NH ₄ ⁺ -N	6.40 (0.67) ^a
	NO ₃ ⁻ -N	1.17 (0.07) ^a
Total N (g kg ⁻¹)		0.67 (0.03) ^a
Water Extractable K (mg kg ⁻¹)		31.14 (2.58) ^a
Water Extractable Na (mg kg ⁻¹)		6.90 (0.47) ^a

^a standard error is listed in parentheses (n=6), samples taken on May 15, 2010.

^b effective CEC estimated from M3 Ca, Mg and K concentration (Morris et al., 2009)

^c source: (USDA-SCS, 2010)

Table 2: Poultry litter properties on the day of the initiation of study (Day 0) and on the two PL removal days (Day 15 and Day 91). Means followed by different letters indicate significant differences in PL properties on the three sampling days. Laboratory analysis was carried out on ‘as is’ PL samples, except for Total C and N, where the samples were oven dried prior to the analysis.

Properties†	Day0	Day15	Day91
Gravimetric moisture content (g g ⁻¹)	0.37 (0.01) a	0.38 (0.01) a	0.44 (0.01) a
EC dS m ⁻¹	23.90 (0.62) a	24.65 (0.58) a	24.89 (1.46) a
pH	6.91 (0.06) a	7.07 (0.25) a	7.20 (0.19) a
Total C (%)	29.51 (0.62) a	31.60 (0.82) a	31.85 (0.81) a
Total N (g kg ⁻¹)	45.64 (0.88) a	45.48 (0.31) a	48.04 (1.39) a
NH ₄ ⁺ -N (g kg ⁻¹)	10.62 (0.26) a	9.73 (0.18) a	12.99 (1.01) b
NO ₃ ⁻ -N (g kg ⁻¹)	0.53 (0.02) a	0.20 (0.05) b	0.03 (0.01) c
Total K (g kg ⁻¹)	34.00 (1.16) a	37.17 (1.03) a	35.69 (1.38) a
Water extractable K (g kg ⁻¹)	35.68 (1.10) a	37.73 (1.14) a	36.61 (1.04) a
Total Na (g kg ⁻¹)	12.60 (0.42) a	13.81 (0.47) a	12.76 (0.33) a
Water extractable Na (g kg ⁻¹)	12.57 (0.48) a	13.23 (0.27) a	12.49 (0.43) a

† All chemical properties are reported on an oven-dry (105°C) basis, except EC and pH that were measured in a 1:2 PL – water slurry.

‡ Standard errors of the mean are reported in parenthesis (n=6)

Table 3: Significance of treatment effects on inorganic nitrogen concentration determined by KCl extraction of the soil samples, pH and EC determined on a 1:1 soil – water slurry, water extractable K and Na (WEK and WENa) and gravimetric moisture content of the field moist samples (WetGMC). Statistical analysis was conducted as complete randomized split plot repeated measures design. Values indicate the probability of a greater F-value ($\alpha=0.05$).

Source of variation	Num DF	NH ₄ ⁺ -N	NO ₃ ⁻ -N	pH	EC	WEK	WENa	WetGMC
-----Pr > F-----								
Day	1	<.0001	<.0001	0.0024	0.0009	<.0001	<.0001	0.0751
Trt	4	0.0144	0.3773	0.0032	0.0001	0.0016	0.0002	0.4447
Day*Trt	4	0.9325	0.196	0.9558	0.2198	0.0003	0.0022	0.4383
Depth	7	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Day*Depth	7	<.0001	<.0001	0.0045	<.0001	<.0001	<.0001	0.4958
Trt*Depth	28	<.0001	0.0121	<.0001	<.0001	<.0001	<.0001	0.6598
Day*Trt*Depth	28	0.0163	0.0021	0.3251	0.0027	<.0001	<.0001	0.9934

Table 4: Average ammonium-nitrogen concentrations in the soil columns, determined by KCl extraction of the soil samples. Means followed by different letters indicate significant differences between means (n=3). In all cases $\alpha=0.05$.

Depth (cm)	-----NH ₄ ⁺ -N concentration----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	50.00 fgh	149.03 d	101.73 defg	108.03 def	18.65 h
10-20	12.50 h	4.54 h	9.58 h	8.29 h	7.21 h
20-30	3.07 h	3.65 h	3.69 h	6.63 h	3.20 h
30-40	3.19 h	5.70 h	2.90 h	2.12 h	3.34 h
40-50	3.55 h	2.97 h	3.54 h	2.50 h	2.37 h
50-60	4.14 h	3.33 h	3.73 h	3.20 h	2.56 h
60-70	2.46 h	2.39 h	1.82 h	2.28 h	2.66 h
70-80	4.14 h	1.89 h	2.36 h	3.26 h	3.45 h
<u>Day 91</u>					
0-10	277.67 ab	303.33 a	228.67 bc	235.67 ab	152.67 cd
10-20	73.37 defgh	147.00 de	145.73 de	129.37 de	71.03 efgh
20-30	22.90 h	27.10 h	26.60 h	32.87 gh	27.83 h
30-40	10.93 h	9.92 h	12.22 h	16.17 h	13.23 h
40-50	7.87 h	7.40 h	6.70 h	8.06 h	10.85 h
50-60	7.22 h	8.01 h	7.54 h	7.94 h	8.42 h
60-70	6.99 h	4.49 h	5.10 h	14.19 h	20.89 h
70-80	11.32 h	7.84 h	9.83 h	5.36 h	9.31 h

Table 5: Average nitrate-nitrogen concentrations in the soil columns, determined by KCl extraction of the soil samples. Means followed by different letters indicate significant differences between means (n=3). In all cases $\alpha=0.05$.

Depth (cm)	-----NO ₃ ⁻ -N concentration----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	1.49 c	1.61 c	3.72 bc	4.05 bc	8.24 a
10-20	3.70b c	6.29 ab	2.81 bc	3.52 bc	2.81 bc
20-30	2.97b c	2.02 c	1.47 c	1.85 c	1.92 c
30-40	1.01 c	1.49 c	1.11 c	0.84 c	1.17 c
40-50	0.85 c	1.36 c	1.32 c	0.71 c	2.14 c
50-60	0.98 c	1.29 c	0.87 c	0.57 c	1.25 c
60-70	0.83 c	1.59 c	1.62 c	0.56 c	1.40 c
70-80	1.24 c	1.63 c	1.39 c	0.77 c	1.66 c
<u>Day 91</u>					
0-10	0.75 c	0.76 c	0.51 c	0.43 c	0.33 c
10-20	0.37 c	0.38 c	0.34 c	0.37 c	0.44 c
20-30	0.62 c	0.77 c	0.75 c	0.52 c	0.67 c
30-40	0.77 c	0.71 c	0.74 c	0.76 c	0.73 c
40-50	0.76 c	0.87 c	0.68 c	0.85 c	0.76 c
50-60	0.91 c	0.80 c	0.83 c	1.41 c	0.66 c
60-70	1.27 c	1.27 c	1.08 c	0.65 c	0.98 c
70-80	1.73 c	1.65 c	1.22 c	1.17 c	0.96 c

Table 6: Average pH in the soil columns determined in a 1:1 water – soil slurry. Concentrations are averaged across days, because of the non-significant three way interaction and day*trt effect. Means followed by different letters indicate significant differences between means (n=6) at $\alpha=0.05$.

Depth (cm)	pH----- (in 1:1 slurry)				
	Alum	Control	Gypsum	Lime	Plastic
0-10	3.79 b	6.68 a	6.33 a	6.62 a	6.25 a
10-20	6.55 a	6.47 a	6.28 a	6.40 a	6.53 a
20-30	6.58 a	6.50 a	6.59 a	6.66 a	6.62 a
30-40	6.5 a	6.52a	6.57 a	6.57 a	6.59 a
40-50	6.46 a	6.43a	6.50 a	6.52 a	6.42 a
50-60	6.34 a	6.37a	6.22 a	6.39 a	6.29 a
60-70	6.21 a	6.25a	6.33 a	6.28 a	6.16 a
70-80	6.22 a	6.11a	6.24 a	6.09 a	5.99 a

Table 7: Electrical conductivity in the soil columns determined in a 1:1 water – soil slurry. Means followed by different letters indicate significant differences between means (n=3). In all cases $\alpha=0.05$.

Depth (cm)	-----Electrical conductivity----- (in 1:1 slurry dS m ⁻¹)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	3.51 b	1.11 ef	1.37 de	0.75 efg	0.16 fg
10-20	0.15 fg	0.16 fg	0.21 fg	0.13 fg	0.14 fg
20-30	0.14 fg	0.13 fg	0.13 fg	0.12 fg	0.13 fg
30-40	0.13 fg	0.12 fg	0.12 fg	0.13 fg	0.16 fg
40-50	0.12 fg	0.12 fg	0.13 fg	0.12 fg	0.12 fg
50-60	0.12 fg	0.12 fg	0.13 fg	0.11 fg	0.13 fg
60-70	0.14 fg	0.09 fg	0.12 fg	0.12 fg	0.13 fg
70-80	0.08 fg	0.14 fg	0.12 fg	0.12 fg	0.11 fg
<u>Day 91</u>					
0-10	6.44 a	2.52 bc	2.98 bc	2.40 cd	0.26 fg
10-20	0.30 fg	0.57 efg	0.61 efg	0.45 efg	0.11 fg
20-30	0.06 g	0.09 fg	0.09 fg	0.08 fg	0.05 g
30-40	0.12 fg	0.12 fg	0.12 fg	0.12 fg	0.13 fg
40-50	0.12 fg	0.12 fg	0.12 fg	0.11 fg	0.12 fg
50-60	0.12 fg	0.10 fg	0.09 fg	0.12 fg	0.11 fg
60-70	0.11 fg	0.12fg	0.11 fg	0.12 fg	0.13 fg
70-80	0.12 fg	0.12 fg	0.12 fg	0.09 fg	0.12 fg

Table 8: Average water extractable potassium concentrations in the soil columns. Means followed by different letters indicate significant differences between means (n=3). In all cases $\alpha=0.05$.

Depth (cm)	-----Water extractable K----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	167.40 efg	358.67 c	223.87 de	197.00 ef	38.10 h
10-20	26.93 h	33.35 h	37.47 h	29.30 h	27.54 h
20-30	19.17 h	21.15 h	15.13 h	17.88 h	19.12 h
30-40	11.64 h	14.54 h	10.73 h	12.87 h	13.38 h
40-50	12.66 h	14.22 h	11.13 h	9.88 h	11.35 h
50-60	8.77 h	9.68 h	8.92 h	9.77 h	11.45 h
60-70	8.11 h	9.33 h	8.70 h	6.91 h	8.21 h
70-80	6.45 h	7.98 h	8.03 h	8.50 h	7.85 h
<u>Day 91</u>					
0-10	324.67 cd	734.83 b	1125.17 a	754.00 b	54.17 gh
10-20	58.37 fgh	105.37 efgh	109.17 efgh	83.53 fgh	39.58 h
20-30	25.37 h	28.72 h	24.60 h	27.74 h	24.30 h
30-40	11.94 h	10.93 h	7.32 h	11.84 h	9.49 h
40-50	7.62 h	8.52 h	10.60 h	7.85 h	12.87 h
50-60	6.67 h	7.92 h	4.73 h	5.89 h	6.15 h
60-70	8.12 h	12.34 h	4.65 h	9.08 h	4.69 h
70-80	6.05 h	4.03 h	4.31 h	3.82 h	5.77 h

Table 9: Average water extractable sodium concentrations in the soil columns. Means followed by different letters indicate significant differences between means (n=3). In all cases $\alpha=0.05$.

Depth (cm)	-----Water extractable Na----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	105.50 de	153.30 cd	81.20 efg	85.11 ef	8.93 h
10-20	8.07 h	10.15 h	8.64 h	9.41 h	9.78 h
20-30	7.83 h	8.25 h	6.64 h	8.95 h	9.47 h
30-40	7.13 h	7.33 h	6.16 h	7.38 h	8.61 h
40-50	10.99 h	9.77 h	10.82 h	9.95 h	10.68 h
50-60	10.69 h	9.25 h	11.28 h	11.05 h	11.67 h
60-70	11.35 h	11.15 h	9.63 h	9.27 h	10.96 h
70-80	9.34 h	9.93 h	11.62 h	11.17 h	11.41 h
<u>Day 91</u>					
0-10	209.10 c	358.67 b	463.97 a	353.83 b	13.32 h
10-20	20.54 gh	46.09 efgh	45.71 efgh	34.27 fgh	11.97 h
20-30	11.57 h	11.75 h	12.67 h	11.61 h	11.21 h
30-40	5.85 h	4.67 h	5.27 h	4.35 h	4.34 h
40-50	4.20 h	6.39 h	6.66 h	5.26 h	8.90 h
50-60	4.97 h	7.74 h	5.60 h	5.70 h	4.93 h
60-70	6.96 h	11.39 h	5.60 h	10.52 h	5.34 h
70-80	5.68 h	5.32 h	6.42 h	7.15 h	7.22 h

Figures

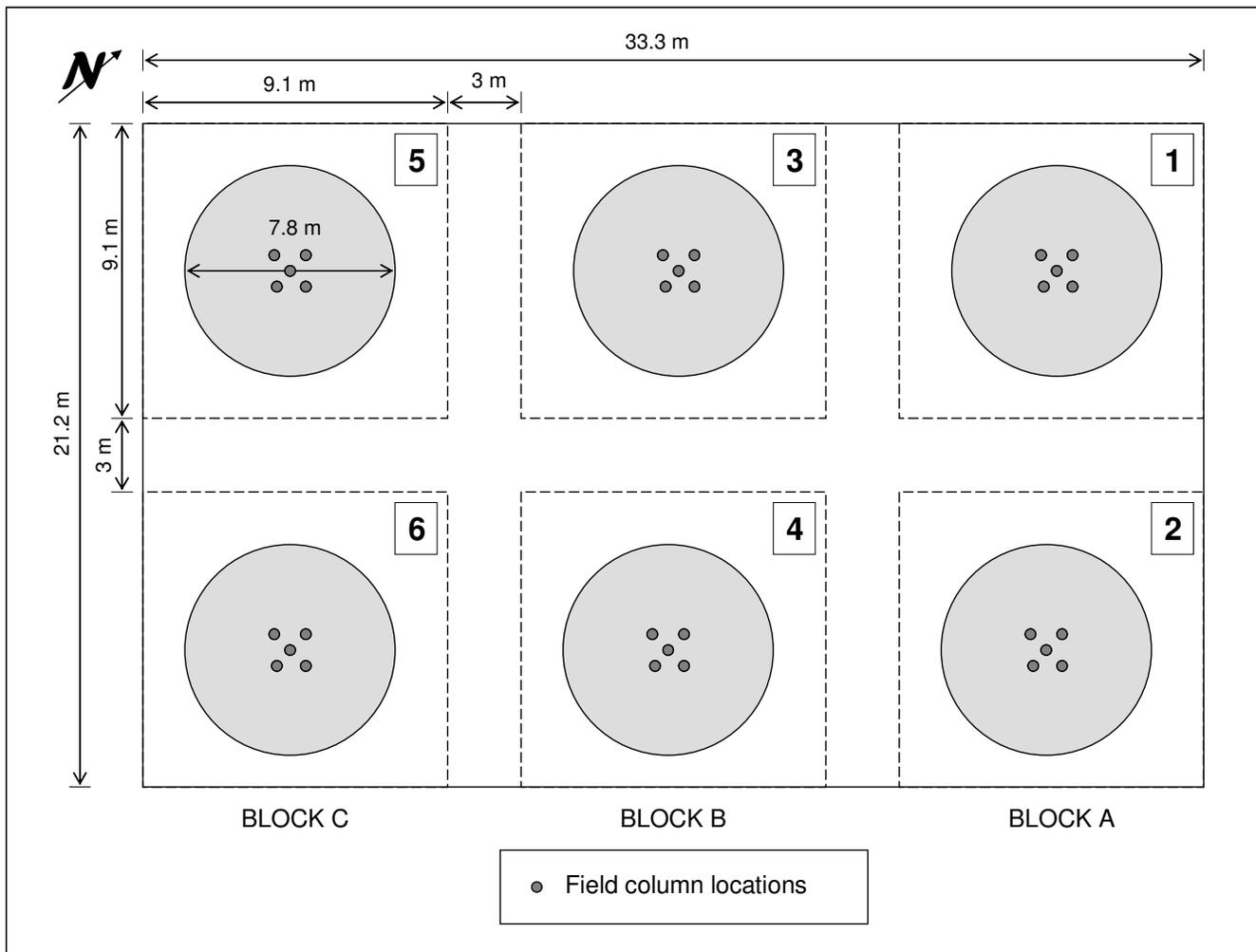


Figure 1: Research plot layout.

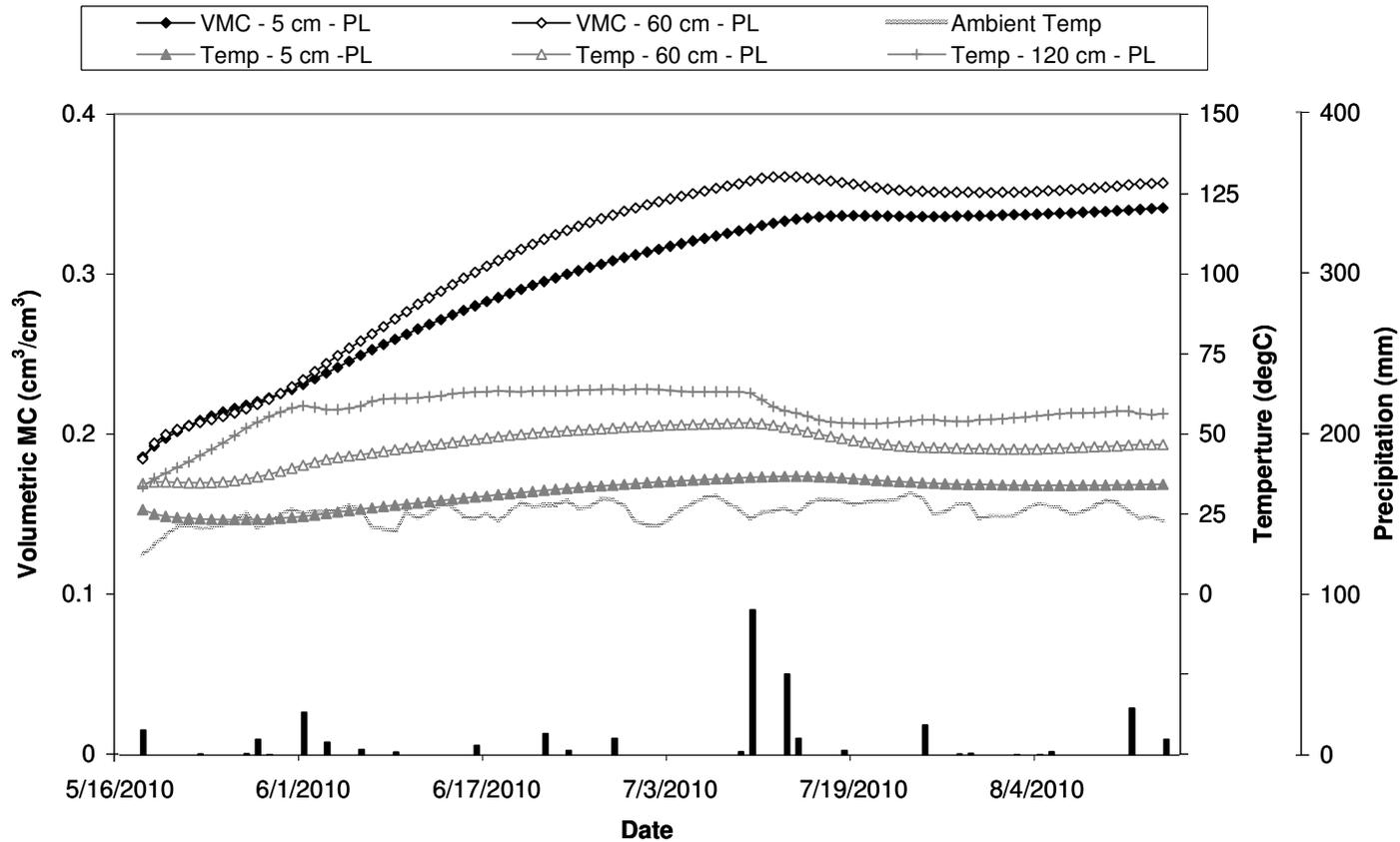


Figure 2: Volumetric moisture content and temperature monitoring data from PL piles stored for 91 days. Poultry litter moisture content monitored at 5 and 60 cm above the soil surface at the center of the pile (VMC – 5 cm – PL, VMC – 60 cm – PL) and PL temperature monitored at 5, 60 and 120 cm above the soil surface at the center of the pile (Temp – 5 cm – PL, Temp – 60 cm – PL, Temp – 120 cm – PL). Ambient temperature data (Ambient Temp) was recorded at the Wye Research and Education Center hourly at 38 91'31"N and 76.15'25"W. Precipitation data (vertical bars) was obtained from the Wye Research and Education Center weighing bucket rain gage located at 38 54' 46.15"N 76 09' 06.75"W.



Figure 3: Bisected soil column

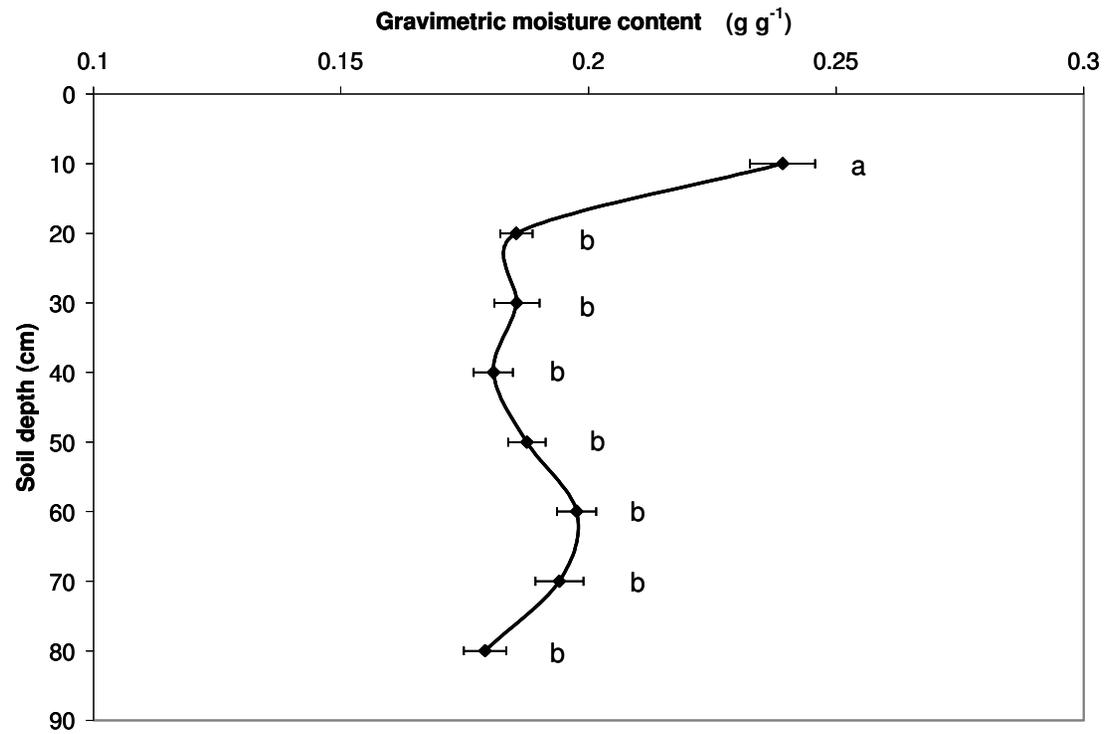


Figure 4: Gravimetric moisture content of the columns. The only significant factor was depth, therefore results are averaged over removal days and treatments (n=30). Different letters indicate significant differences between means at each depth.

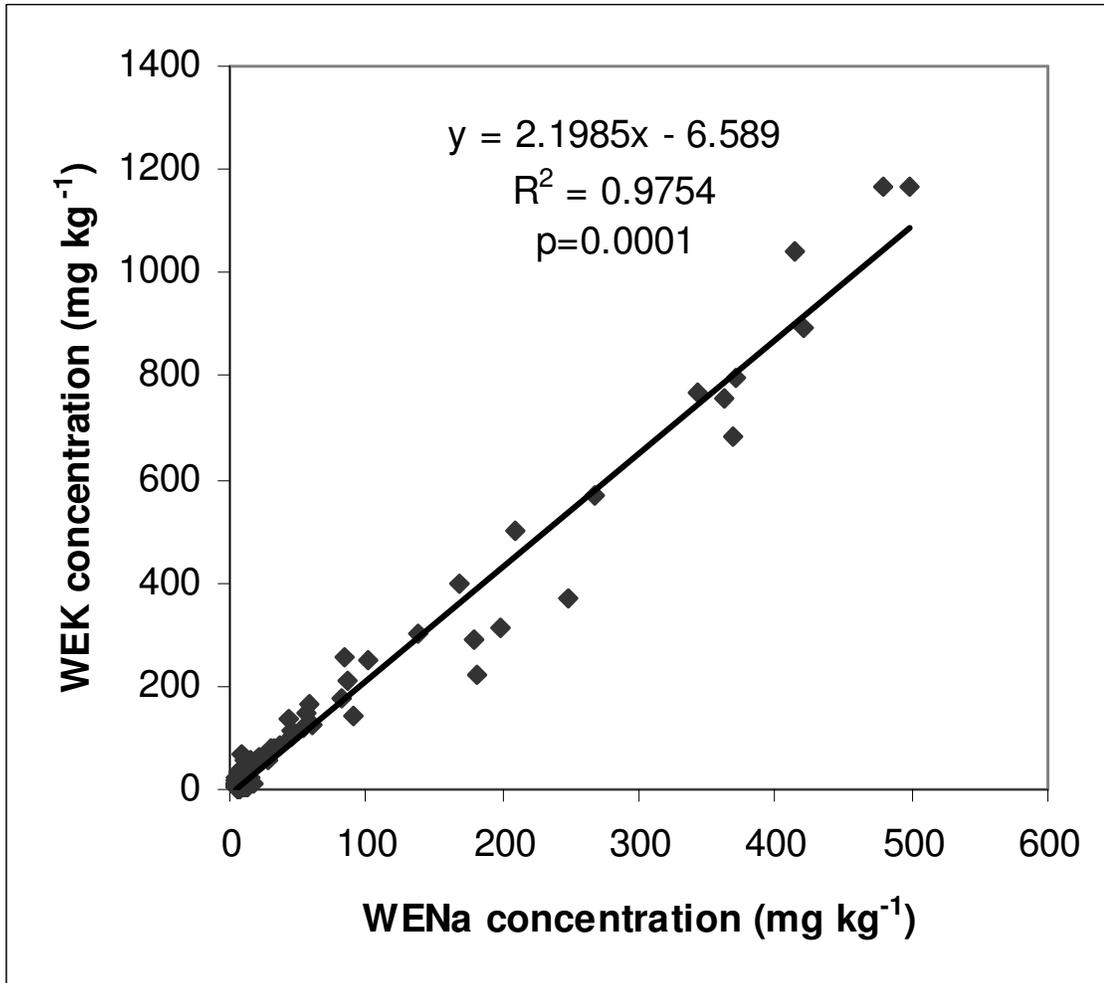


Figure 5: Water extractable Na vs. K concentration in the soil columns.

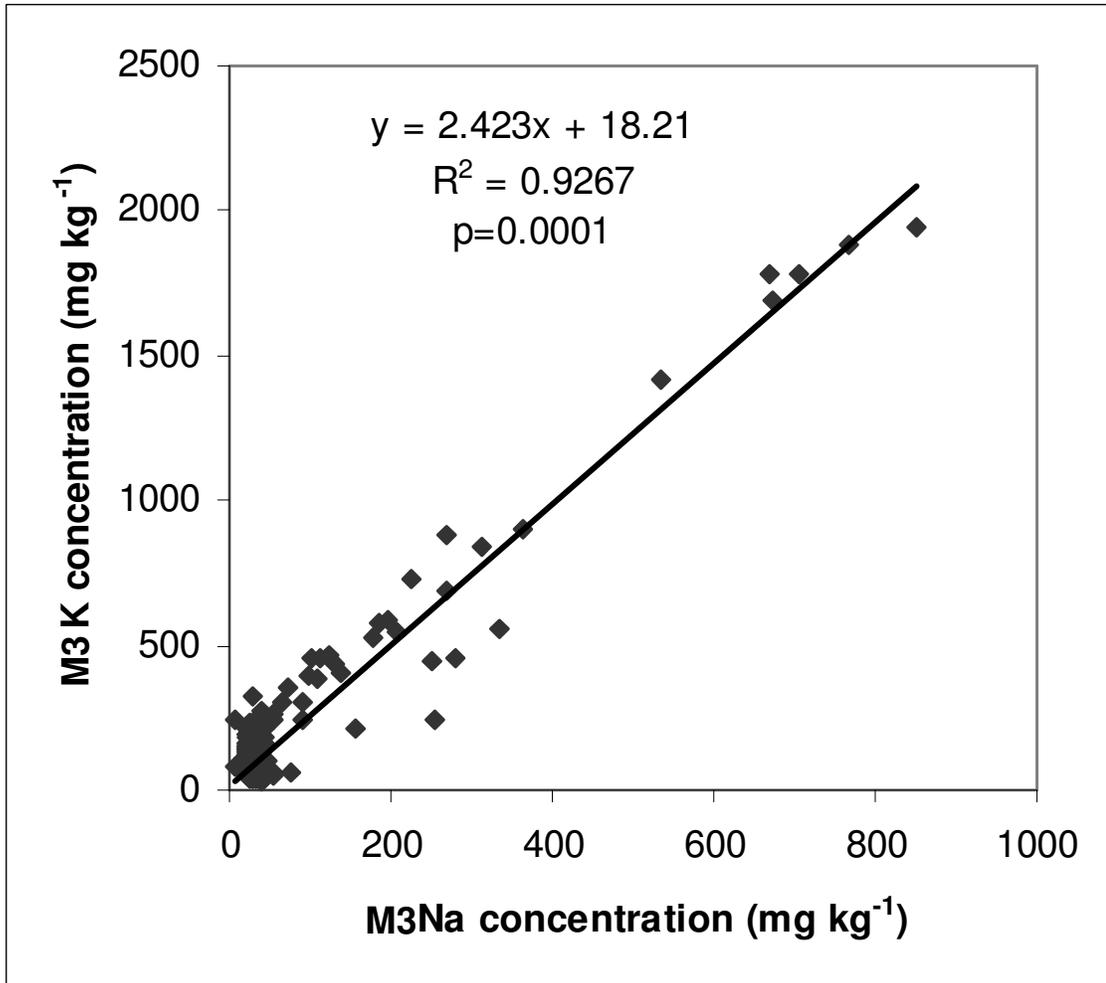


Figure 6: Mehlich-3 extractable Na vs. K concentration in the entire soil profile.

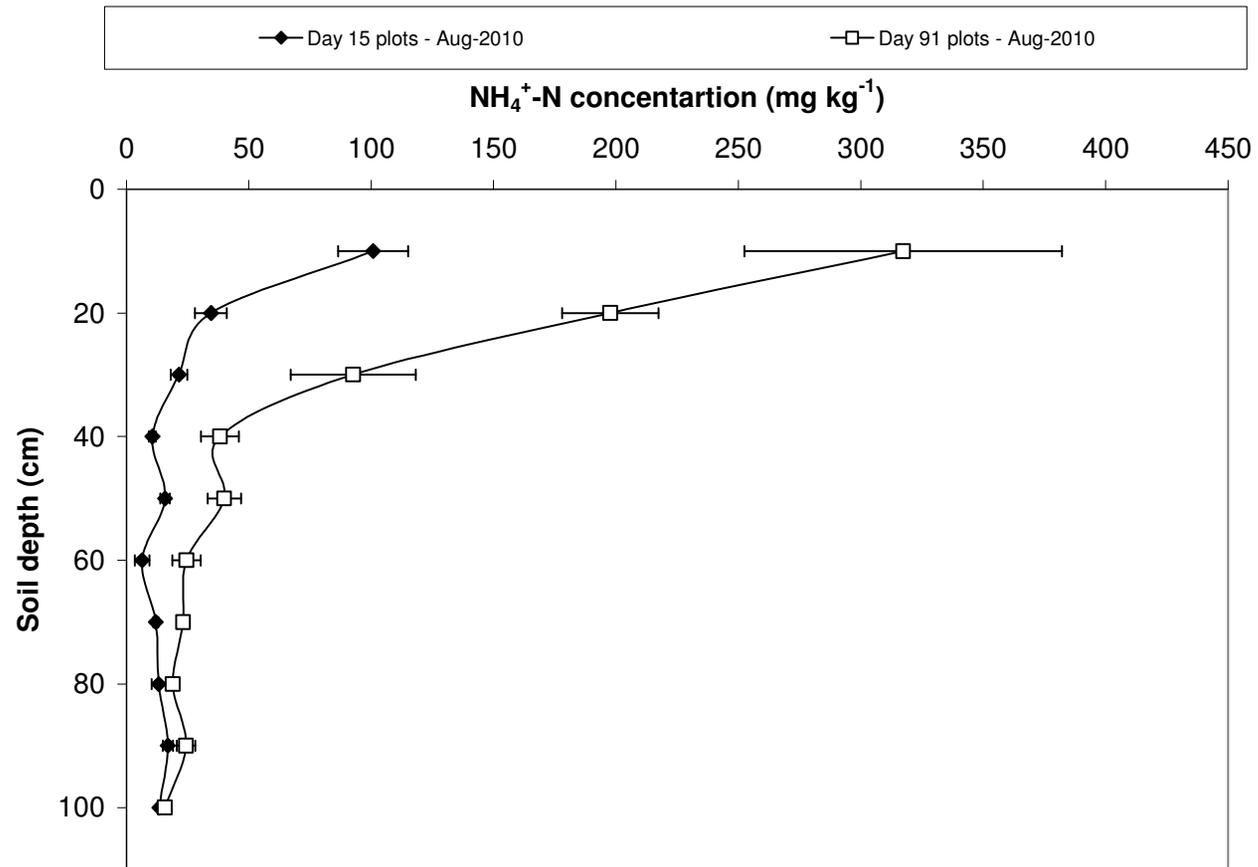


Figure 7: Soil $\text{NH}_4^+\text{-N}$ concentration in August 2010 after all PL was removed from the site. Samples were taken from each plot separately. The means of concentrations are shown separately from the Day 15 and Day 91 plots. Error bars show the standard error of the mean ($n=3$). Before the PL piles were placed on the plots soil $\text{NH}_4^+\text{-N}$ concentration was 6.4 mg kg^{-1} in the 0 – 30 cm layer and 4.4 mg kg^{-1} in the 30 – 60 cm layer (not shown).

Appendix A: Sample SAS codes

```
title 'column analysis';
title2 'complete randomized split plot repeated measures';
options ls=124 ps=45 pageno=1;

proc mixed data=column80;
class day trt depth blk;
model NH4=day|trt|depth /ddfm=satterth;
random blk blk*trt;
repeated depth/ subject=blk*day*trt type=ar(1);
lsmeans day*trt*depth/ adj=tukey;
run;

/*only depth is significant in case of WetGMC at alpha=0.05*/
proc mixed data=column80;
class depth;
model wetgmc=depth /ddfm=satterth;
lsmeans depth/ cl adj=tukey;
run;
```

Appendix B: Water extractable salt concentrations in the soil columns

TableB-1: Average water extractable aluminum concentrations in the soil columns. Means followed by different letters indicate significant differences between treatments at a given depth and day of removal. At Day 91 “*” indicates significantly different concentration from Day 15 at a given treatment and depth. In all cases $\alpha=0.05$.

Depth (cm)	-----Water extractable Al----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	1206.67b	6.01a	5.25a	6.78a	7.65a
10-20	8.31a	8.42a	7.31a	10.04a	8.07a
20-30	10.27a	8.74a	7.58a	7.19a	11.41a
30-40	9.98ab	8.57ab	17.79b	6.22a	6.29a
40-50	6.67a	6.86a	10.61a	6.39a	7.03a
50-60	5.26a	7.65a	5.48a	6.33a	5.38a
60-70	4.75a	5.54a	35.73a	4.68a	5.16a
70-80	3.34a	6.45a	5.09a	4.95a	5.31a
80-90	5.79a	4.95a	4.53a	5.55a	4.30a
90-100	4.09a	4.94a	4.52a	5.20a	4.94a
<u>Day 91</u>					
0-10	2248.67b*	27.19a	23.92a	23.28a	9.98a
10-20	7.92a	7.75a	6.94a	8.48a	8.73a
20-30	8.31a	7.77a	8.43a	8.44a	7.64a
30-40	5.06a	4.40a	3.72a*	5.41a	5.17a
40-50	3.00a	4.01a	4.32a	3.63a	6.19a
50-60	2.47a	3.19a	2.60a	2.75a	3.02a
60-70	3.31a	5.34a	2.08a	4.16a	1.77a
70-80	2.55a	1.54a*	2.72a	2.18a	3.13a
80-90	3.70a	3.42a	3.40a	3.17a	1.94a
90-100	2.76a	2.89a	3.05a	2.31a	2.28a

Table B-2: Average water extractable sulfur concentrations in the soil columns. Means followed by different letters indicate significant differences between treatments at a given depth and day of removal. At Day 91 “*” indicates significantly different concentration from Day 15 at a given treatment and depth. In all cases $\alpha=0.05$.

Depth (cm)	-----Water extractable S----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	2252.67b	134.80a	361.03a	60.29a	7.50a
10-20	9.84a	8.46a	40.42a	6.09a	6.08a
20-30	7.75a	5.72a	6.49a	4.94a	5.08a
30-40	3.79a	4.66a	4.15a	7.82a	4.97a
40-50	6.40a	6.24a	7.65a	6.52a	6.44a
50-60	10.01a	7.57a	10.42a	8.64a	9.44a
60-70	11.01a	9.24a	10.03a	8.23a	10.33a
70-80	9.28a	10.00a	9.48a	9.00a	9.68a
80-90	9.86a	8.38a	8.76a	8.78a	8.13a
90-100	9.92a	10.35a	10.55a	11.20a	9.27a
<u>Day 91</u>					
0-10	2284.00c	64.30a	1053.50b*	55.88a	25.69a
10-20	60.76a*	10.16a	16.79ab	9.85a	9.99a
20-30	11.05a	5.60a	8.16a	5.25a	5.72a
30-40	4.07a	4.10a	5.03a	3.34a	3.07a
40-50	4.46a	6.93a	7.19a	4.76a	7.73a
50-60	6.22a	11.02b	7.65ab	7.62ab	7.47ab
60-70	7.39a	10.38b	7.54a	14.20b	9.35b
70-80	8.03a	8.43a	8.63a	11.09a	9.27a
80-90	6.95a	7.92a	8.89a	10.69a	8.32a
90-100	6.61a	8.63a	9.11a	9.38a	7.20a

Table B-3: Average water extractable calcium concentrations in the soil columns. Means followed by different letters indicate significant differences between treatments at a given depth and day of removal. At Day 91 “*” indicates significantly different concentration from Day 15 at a given treatment and depth. In all cases $\alpha=0.05$.

Depth (cm)	-----Water extractable Ca----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	785.00a	40.14a	316.37a	28.17a	16.99a
10-20	17.22a	20.33a	48.36a	14.52a	15.78a
20-30	20.55a	15.57a	15.54a	15.06a	14.16a
30-40	13.92a	11.30a	12.49a	17.16a	12.50a
40-50	13.18a	12.91a	15.19a	12.21a	13.26a
50-60	15.55a	14.29a	17.56a	15.73a	18.74a
60-70	16.16a	16.08a	17.44a	20.49a	16.35a
70-80	14.82a	16.78a	15.66a	15.40a	14.57a
80-90	14.07a	13.23a	14.09a	14.18a	14.04a
90-100	13.11a	17.48a	16.34a	17.11a	17.19a
<u>Day 91</u>					
0-10	721.33ab	61.02a	1228.50b	118.03a	21.60a
10-20	40.34a	30.45a	50.29a	28.02a	18.11a
20-30	21.92a	24.91a	26.97a	22.59a	20.64a
30-40	10.63a	10.90a	13.54a	10.71a	12.28a
40-50	9.16a	11.22a	12.81a	11.61a	14.18a
50-60	12.12a	20.42a	12.46a	13.33a	12.89a
60-70	13.71a	15.94a	13.39a	21.94a	15.05a
70-80	12.87a	14.90a	15.29a	17.95a	13.05a
80-90	11.88a	13.79a	15.01a	14.23a	11.95a
90-100	12.42a	13.50a	13.02a	12.60a	11.36a

TableB-4: Average water extractable magnesium concentrations in the soil columns. Means followed by different letters indicate significant differences between treatments at a given depth and day of removal. At Day 91 “*” indicates significantly different concentration from Day 15 at a given treatment and depth. In all cases $\alpha=0.05$.

Depth (cm)	-----Water extractable Mg----- (mg kg ⁻¹ in air dried soil)				
	Alum	Control	Gypsum	Lime	Plastic
<u>Day 15</u>					
0-10	118.93b	13.59a	33.64a	7.34a	4.30a
10-20	3.34a	3.73a	7.23a	3.03a	2.66a
20-30	3.73a	2.47a	2.74a	2.52a	2.53a
30-40	2.61ab	1.96a	3.05b	2.80ab	2.01ab
40-50	2.28a	2.09a	2.68a	1.94a	2.22a
50-60	2.62a	2.48a	2.71a	2.46a	2.51a
60-70	2.36a	2.52a	4.42a	2.07a	2.46a
70-80	2.21a	2.65a	2.22a	2.17a	2.12a
80-90	1.89a	1.89a	2.04a	2.15a	1.97a
90-100	2.03a	2.46a	2.54a	2.44a	2.51a
<u>Day 91</u>					
0-10	110.07b	13.92a	104.37b*	31.55a	4.84a
10-20	8.03a	5.71a	9.91a	6.10a	2.99a
20-30	3.45a	3.96a	4.44a	3.96a	3.42a
30-40	2.02a	2.32a	2.57a	2.23a	2.39a
40-50	1.84a	2.26a	2.50a	2.25a	2.50a
50-60	2.33a	3.16a	2.53a	2.52a	2.55a
60-70	2.37a	2.74a	2.48a	3.74a	2.78a
70-80	2.33a	2.62a	2.60a	3.17a	2.26a
80-90	2.31a	2.50a	2.47a	2.67a	2.13a
90-100	2.30a	2.41a	2.23a	2.54a	2.06a

Appendix C: Moisture and Temperature Monitoring in the PL stockpiles and the underlying soil

Materials and Methods

Temporary poultry litter storage study was conducted using 6 conically shaped piles on bare soil. The study was located at the Wye Research and Education Center, Queenstown, Maryland, USA (Latitude: 38°54'34", Longitude: 76°08'51"). The study site is dominated by Mattapex – Butlertown silt loam soil with 0 to 2 % slopes, moderately well drained and typically has 46 – 122 cm water table. The soils of Mattapex series are fine-silty, mixed, active, mesic Aquic Hapludults. The Butlertown series is characterized as fine-silty, mixed, mesic Typic Fragidults. Butlertown is similar to Mattapex soil, but has a fragipan starting at depth of 76 to 96 cm (USDA-SCS, 2010).

Six tractor trailer loads (approx. 120 Mg) of poultry litter were obtained from multiple local growers on the Eastern Shore during October 2009. The litter was stored in a 2 m tall pile with a 7.6 m x 11 m footprint, covered with 6 mil black poly plastic sheets and secured in place with tires until May 2010. Since the litter was sourced from multiple different growers, large variation in its properties was expected. The density of the litter was determined on 10 replications on the day the study piles were created following the guidelines of the Mid-Atlantic Regional Water Program on compost bulk density estimation (Evanlo and Felton, 2008). The bulk density of the PL was 0.66 g cm^{-3} on an “as is” basis. Subsamples were oven dried at 105°C and gravimetric moisture content was determined: 0.6 g g^{-1} .

Study set up

The study plot had 0% slope and was a rectangle measuring 33.3 m × 21.2 m. Six square shaped, 9.1 m × 9.1 m plots with 3 m wide buffer zones were laid out with flags. The site contained three rows with two plots in each row. On May 17, 2010 six approximately 19 Mg conical poultry litter piles were established on each plot. Using a front-end loader the plots received 24 loads of PL which was built in an “A” shape. The piles were 2 m tall and had a circular base with a radius of 3.9 m.

The experimental design was a completely randomized block design with three blocks established based on differences in soil properties. Each block contained two randomly assigned piles – one of those was removed after 15 days and one after 91 days of simulated storage.

The plots containing the 91 day piles were instrumented with monitoring sensors. Temperature and moisture content were continually measured and logged at 9 locations in the soil underneath the piles (3 depths: 0.05 m, 0.3 m, and 0.6 m below the soil surface, and at 3 horizontal locations: underneath the center of the piles, under the circumference of the pile footprint and 1.8 m in from the circumference of the piles). Sensors were placed at 2 vertical and 2 horizontal locations into the litter piles (0.05 m and 0.60 m above the soil surface, at the center and 1.8 m in from the circumference of the pile footprint.). Additional temperature probes were placed at 1.20 m in the center of the PL piles. Temperature probes were built from TT-T-24-1000 Thermocouple Wire (Omega Engineering, Inc., Stamford, CT). For moisture content monitoring EC5 capacitance probes (Decagon Devices, Inc., Pullman, WA) were used at all locations in the PL and in the soil at depths of 0.05 m and 0.3 m. These probes were custom coated with epoxy to

tolerate the higher temperatures induced by the decomposing poultry litter. For data acquisition two Campbell Scientific 21X(L) data loggers with CSI AM416 multiplexers (Campbell Scientific, Inc., Logan, UT) were used to log data from EC5 moisture and the thermocouple temperature sensors. Moisture readings were taken every hour using 2500 mV excitation voltage. Differential temperature readings were taken every 60 seconds and automatically averaged over each hour. Power was supplied by a deep cycle marine battery that was recharged by a Sunsei SolarCharger 1200 (ICP Solar Technologies, Inc., Montreal, Canada). At 0.6 m depth in the soil, ECH₂O sensors were used with Em50 data loggers (Decagon Devices, Pullman, WA). All sensor wires were buried into a 15-cm deep trench to protect the cables from temperature fluctuations due to solar radiation. Two additional temperature sensors were left in the open air near the data loggers to record ambient air temperature.

Decagon Devices (Logan, UT) prepared custom calibrations on the epoxy coated EC5 sensors for higher precision and prepared a moisture release curve for both the soil and poultry litter.

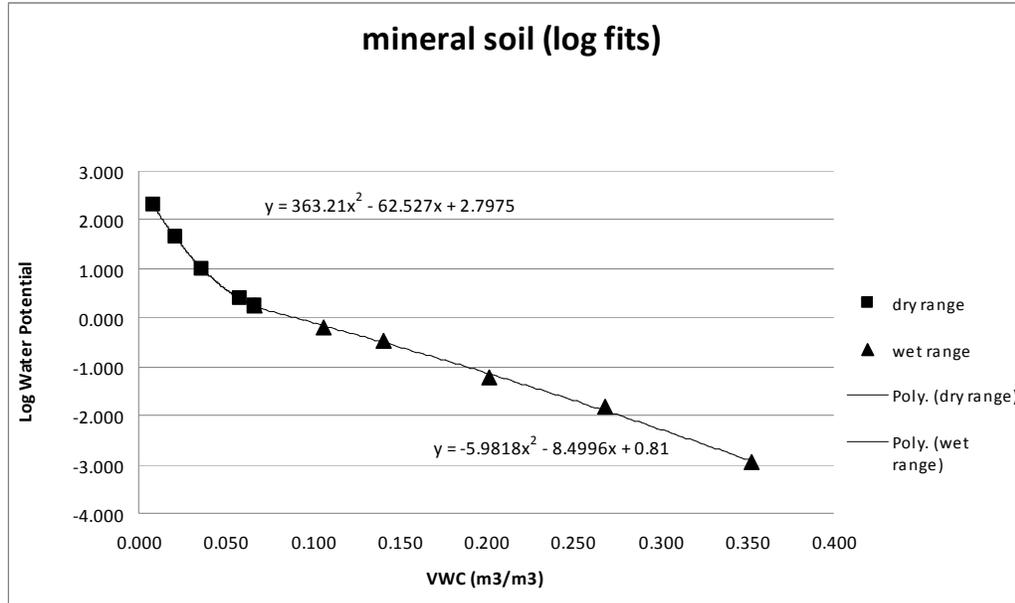


Figure C-1: Moisture release curve for a representative soil sample from the study site. Measurements prepared by Decagon Devices using an epoxy coated EC5 moisture monitoring sensor.

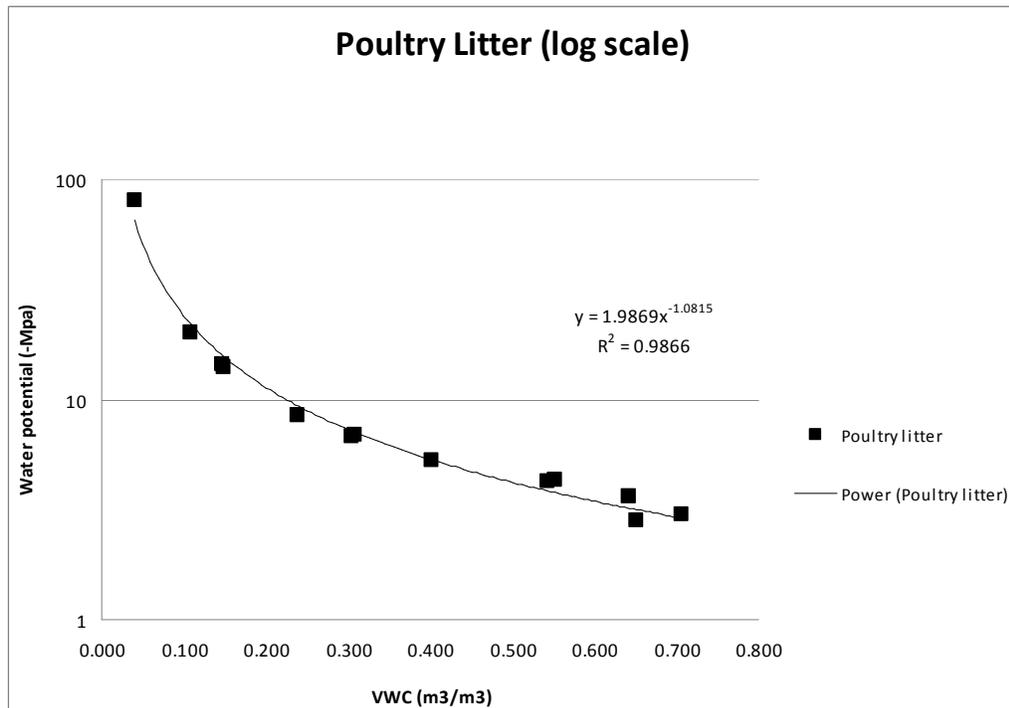


Figure C-2: Moisture release curve for PL. Sample was taken on Day 0 from every load of PL hauled to the research plots. Measurements prepared by Decagon Devices using an epoxy coated EC5 moisture monitoring sensor.

Before the establishment of the poultry litter piles, soil samples were taken from each plot at depths of 0.025, 0.075, 0.15, 0.3, 0.6 m. Five cores were composited from each plot and each depth, except in case of the shallow depth samples where more cores were required to obtain at least 100 grams of soil. The soil removed by sampling was replaced with a 1:1 mix of sand and bentonite. Immediately after PL removal soil samples were taken again from each plot from the same depths, but these times from four different horizontal locations along concentric circles. The locations were under the center of the pile (C), 1.8 m in from the circumference of PL pile footprint (E), along the circumference of the pile footprint (A) and outside of the piles (O). Upon arrival to the lab, all soil samples were air dried at room temperature, crushed and passed through a 2 mm sieve.

In order to avoid changes in nitrogen composition, soil and litter samples were first extracted with 2M KCl and NO₃-N and NH₄-N concentrations were determined by an automated ascorbic acid colorimetric method (Keeney and Nelson, 1982) using Lachat QuikChem 8500 Flow Injection Analysis System (Hach Company, Loveland, CO). The pH and EC were determined on 1:1 water slurry (Combs et al., 2003) with Mettler Toledo InLab® Expert Pro pH and Mettler Toledo InLab® 731 EC meter. Mehlich 3 K, Na, Ca, P, K, Al, Fe, S were determined by shaking 2.5 g sample with 25 mL of Mehlich 3 solution (0.2 M CH₃COOH, 0.25 M NH₄NO₃, 0.015 M HNO₃, and 0.001 M EDTA) for five minutes on a reciprocating shaker (Mehlich, 1984). Water extractions of the samples were carried out by shaking 2.5 g of soil samples with 25 ml of deionized water and 0.4 g PL samples in 40 ml deionized water then filtered through 0.45 µm filters using the Millipore filtration apparatus. The M3 and water extracts were analyzed by inductively

coupled plasma atomic emission spectroscopy (ICP-AES, "Spectro-flame Modula E" from Spectro GMBH, Kleve, Germany) for K, Na, Ca, P, K, Al, Fe and S. After drying for 24 h at 105°C, all samples were analyzed for total C, H and N using a LECO® Corporation 2000 Elemental Analyzer by the method of Nelson and Sommers (1996).

The results from the moisture and temperature monitoring and the analysis of the bulk soil samples are presented in the attached CD ROM. Moisture and temperature changes in the PL and soil are graphically presented in the following pages.

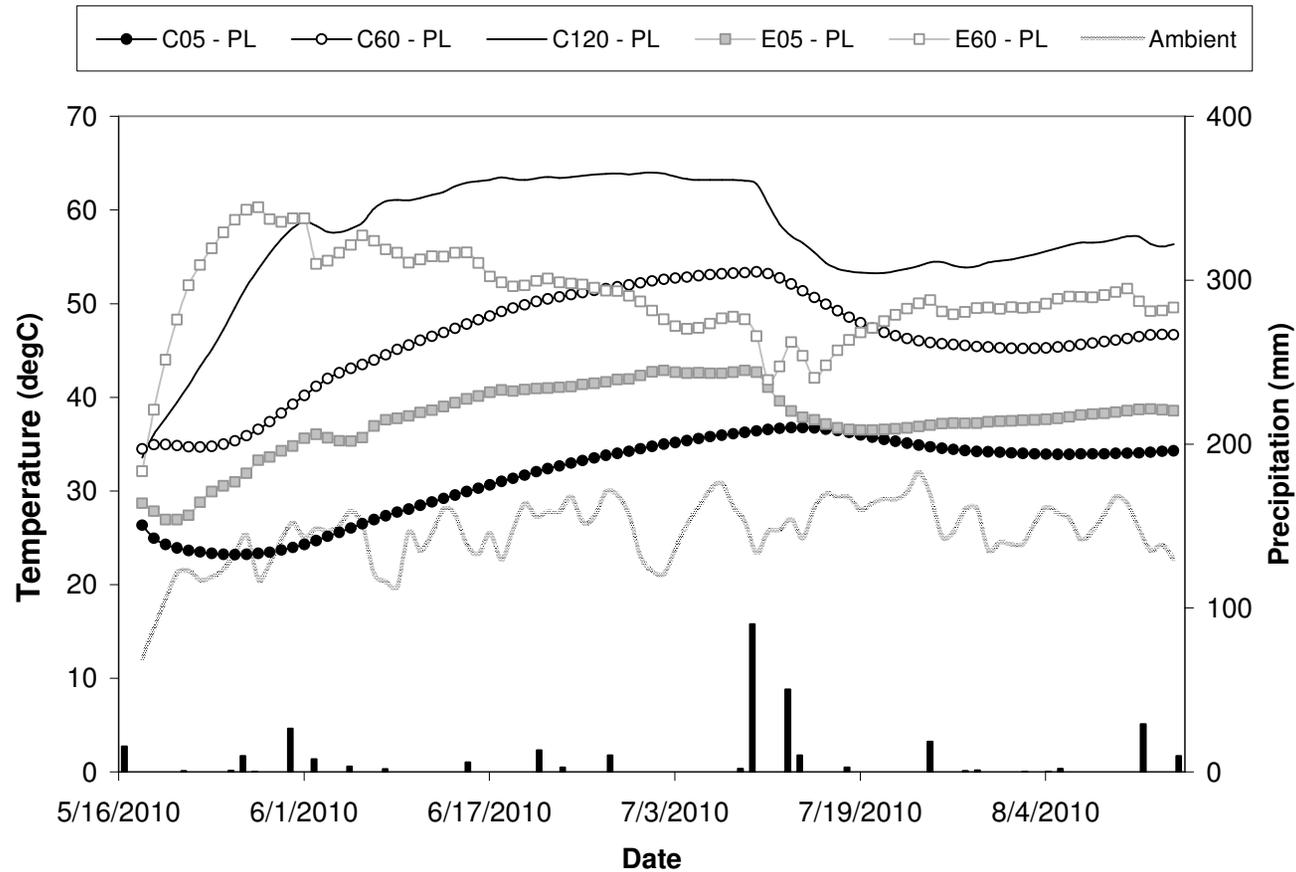


Figure C-3: PL temperature readings were taken over the course of the study at five different locations: 5, 60 and 120 cm above the soil surface at the center of the pile (C05 – PL, C60 – PL, C120 – PL respectively) and 5 and 60 cm above the soil surface and 1.8 m in from the circumference of the PL pile footprint (E05 – PL and E60 – PL respectively). The data points represent three replications. Ambient temperature data was recorded at the Wye Research and Education Center hourly at 38 91'31"N and 76.15'25"W. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage located at 38 54' 46.15"N 76 09' 06.75"W.

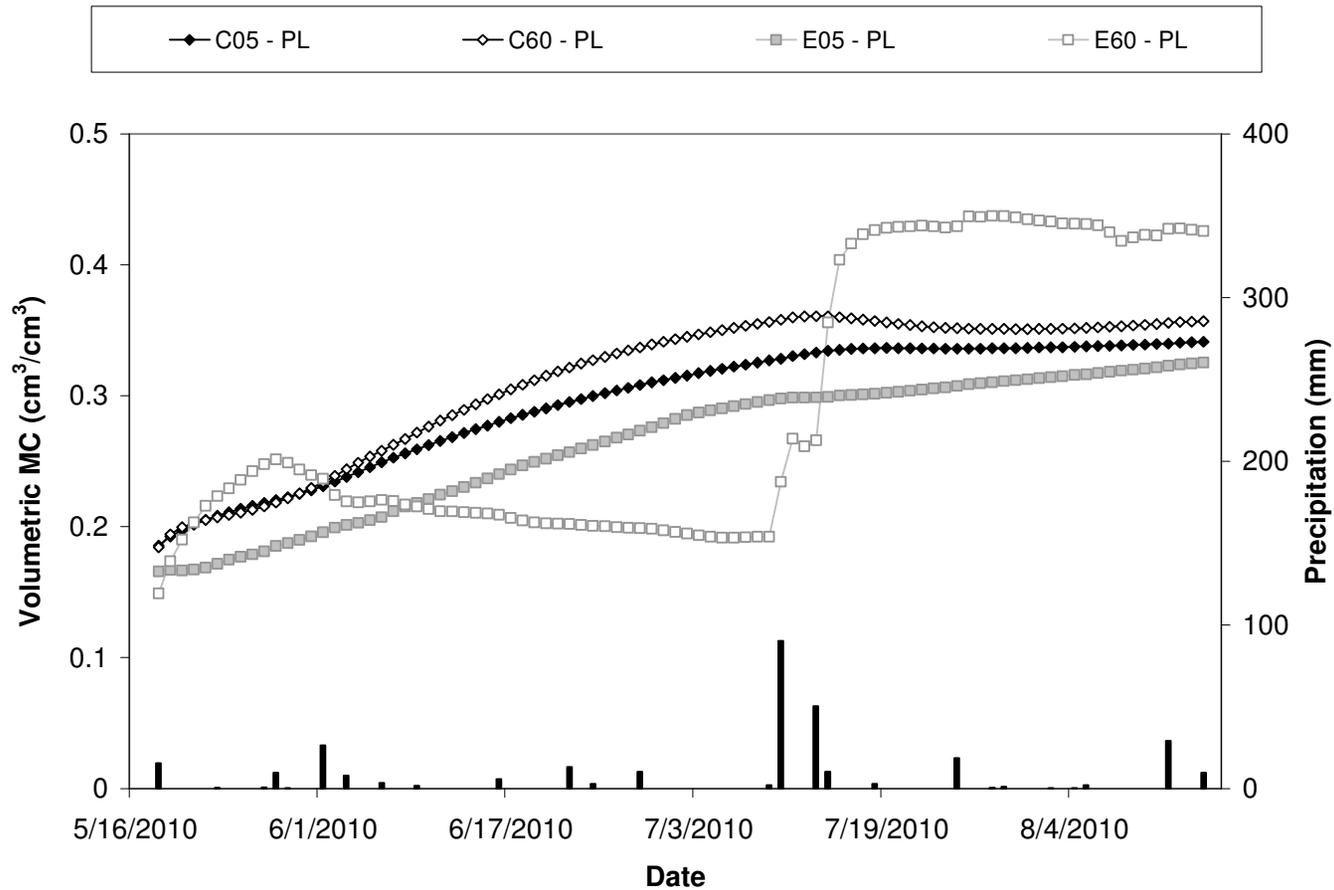


Figure C-4: PL volumetric moisture content readings were taken over the course of the study at four different locations: 5 cm and 60 cm above the soil surface at the center of the pile (C05 – PL, C60 – PL respectively) and 5 and 60 cm above the soil surface and 1.8 m in from the circumference of the PL pile footprint (E05 – PL and E60 – PL respectively). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage located at 38 54' 46.15"N 76 09' 06.75"W.

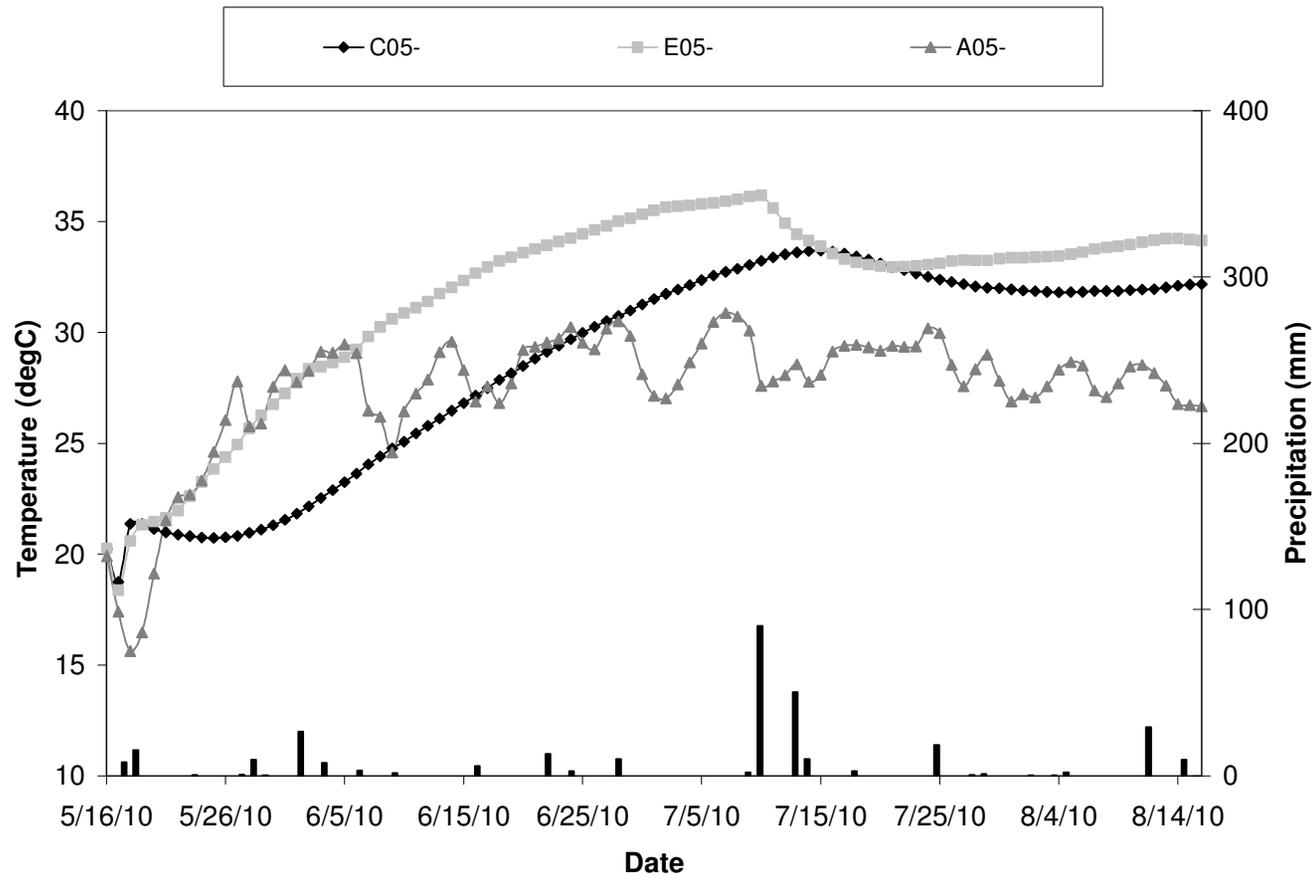


Figure C-5: Soil temperature readings were taken over the course of the study 5 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C05 – S), 1.8 m in from the circumference of the piles (E05 – S) and under the circumference of the pile footprint (A05 – S). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

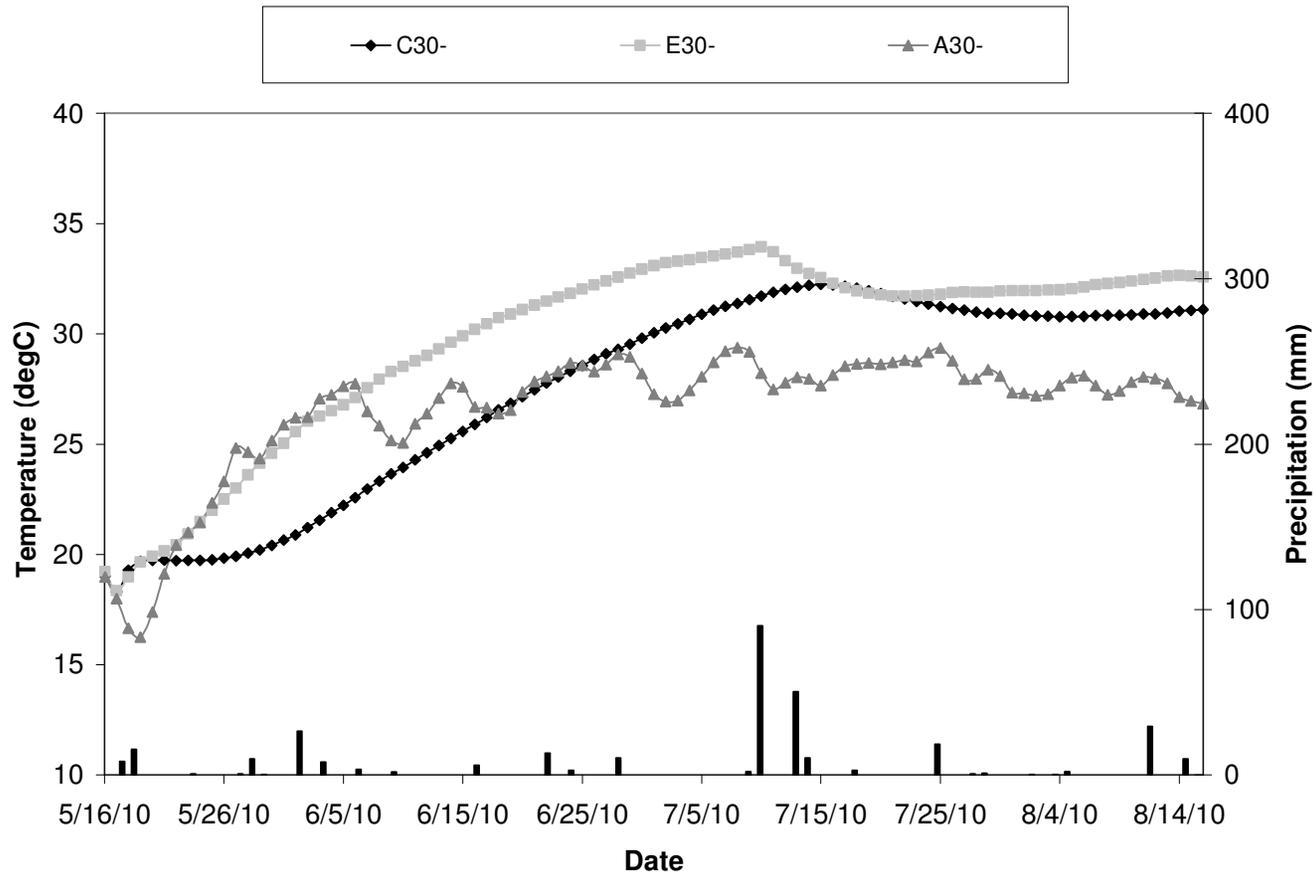


Figure C-6: Soil temperature readings were taken over the course of the study 30 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C30 – S), 1.8 m in from the circumference of the piles (E30 – S) and under the circumference of the pile footprint (A30 – S). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

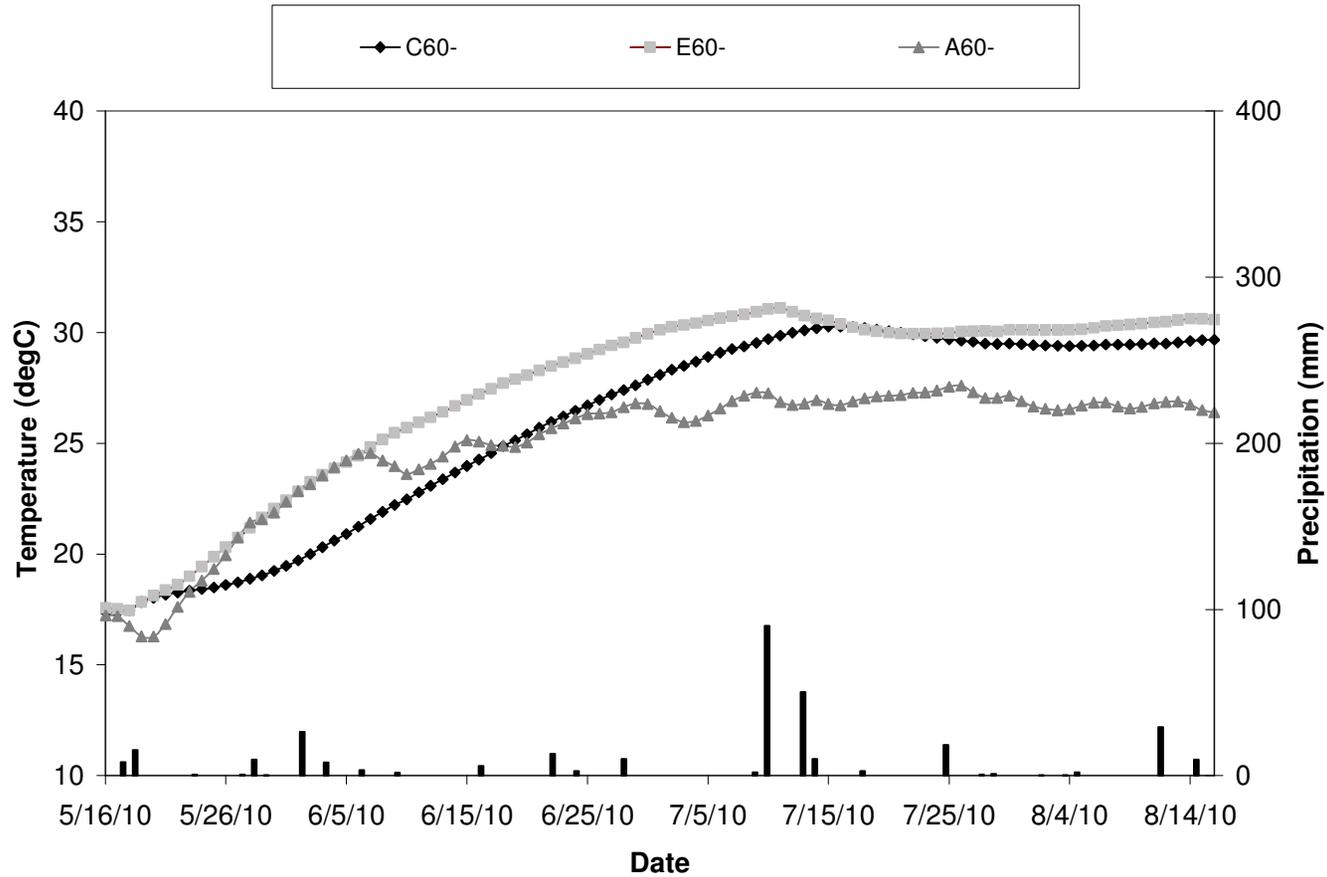


Figure C-7: Soil temperature readings were taken over the course of the study 5 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C60 – S), 1.8 m in from the circumference of the piles (E60 – S) and under the circumference of the pile footprint (A60 – S). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

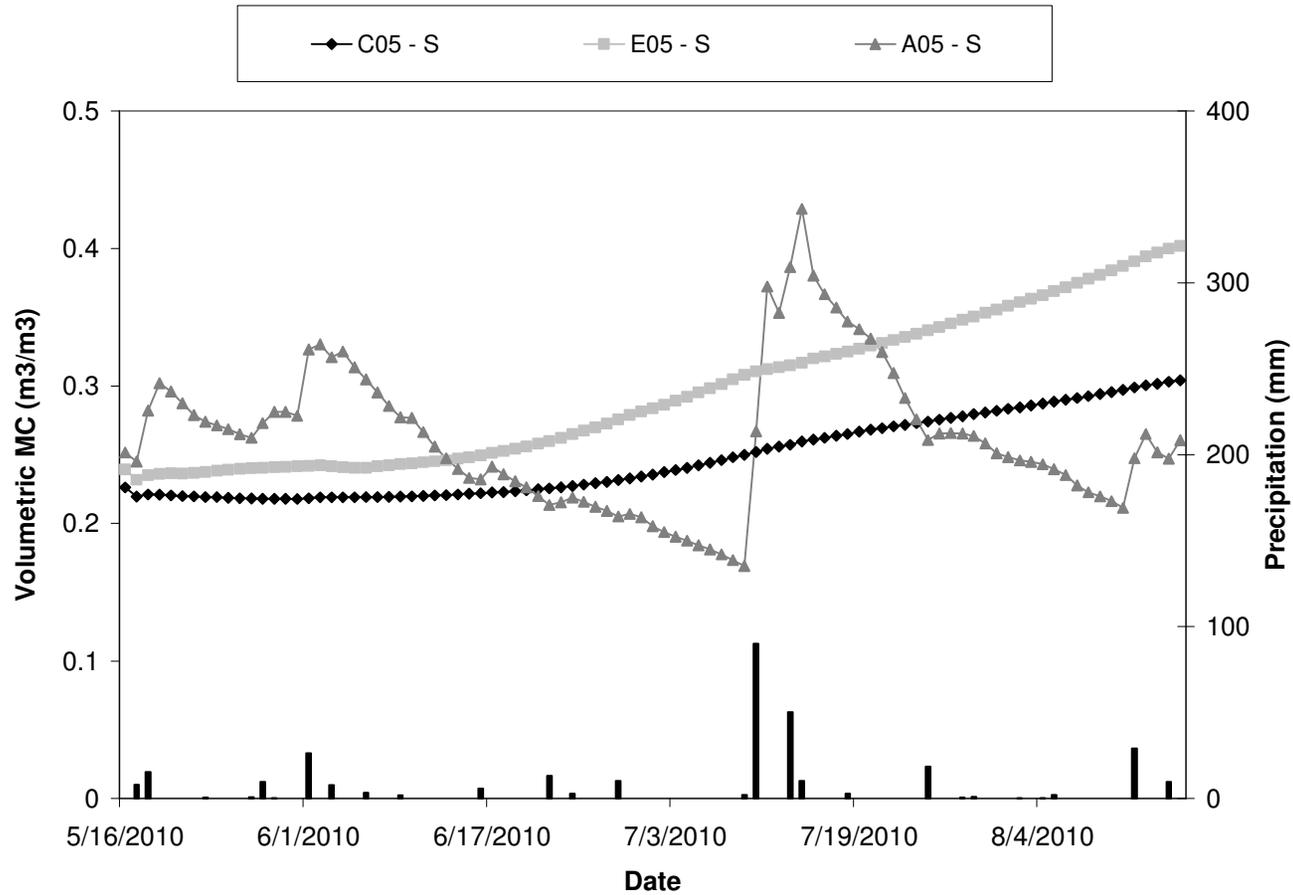


Figure C-8: Soil volumetric moisture content readings were taken over the course of the study 5 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C05 – S), 1.8 m in from the circumference of the piles (E05 – S) and under the circumference of the pile footprint (A05 – S). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

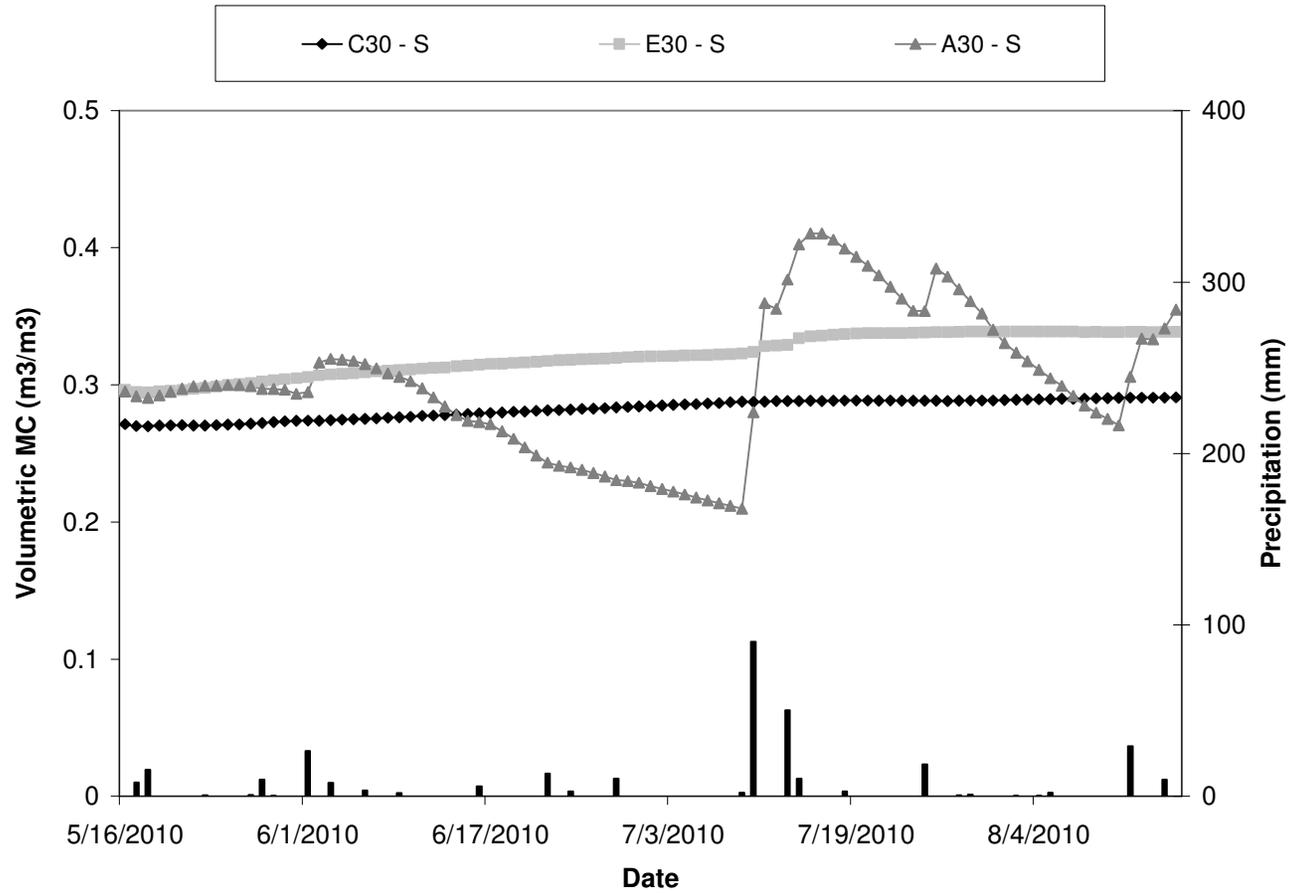


Figure C-9: Soil temperature readings were taken over the course of the study 30 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C30 – S), 1.8 m in from the circumference of the piles (E30 – S) and under the circumference of the pile footprint (A30 – S). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

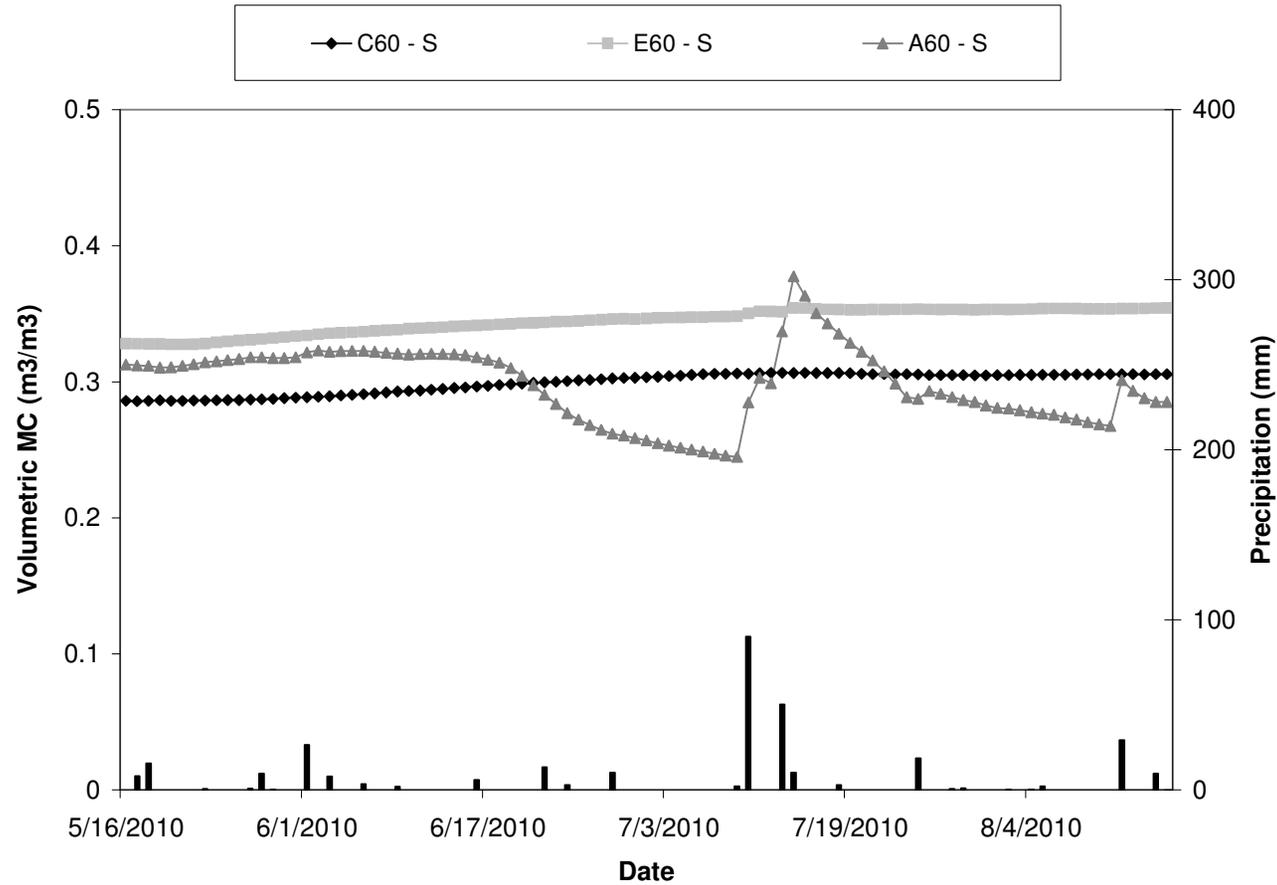


Figure C-10: Soil temperature readings were taken over the course of the study 60 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C05 – S), 1.8 m in from the circumference of the piles (E60 – S) and under the circumference of the pile footprint (A60 – S). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

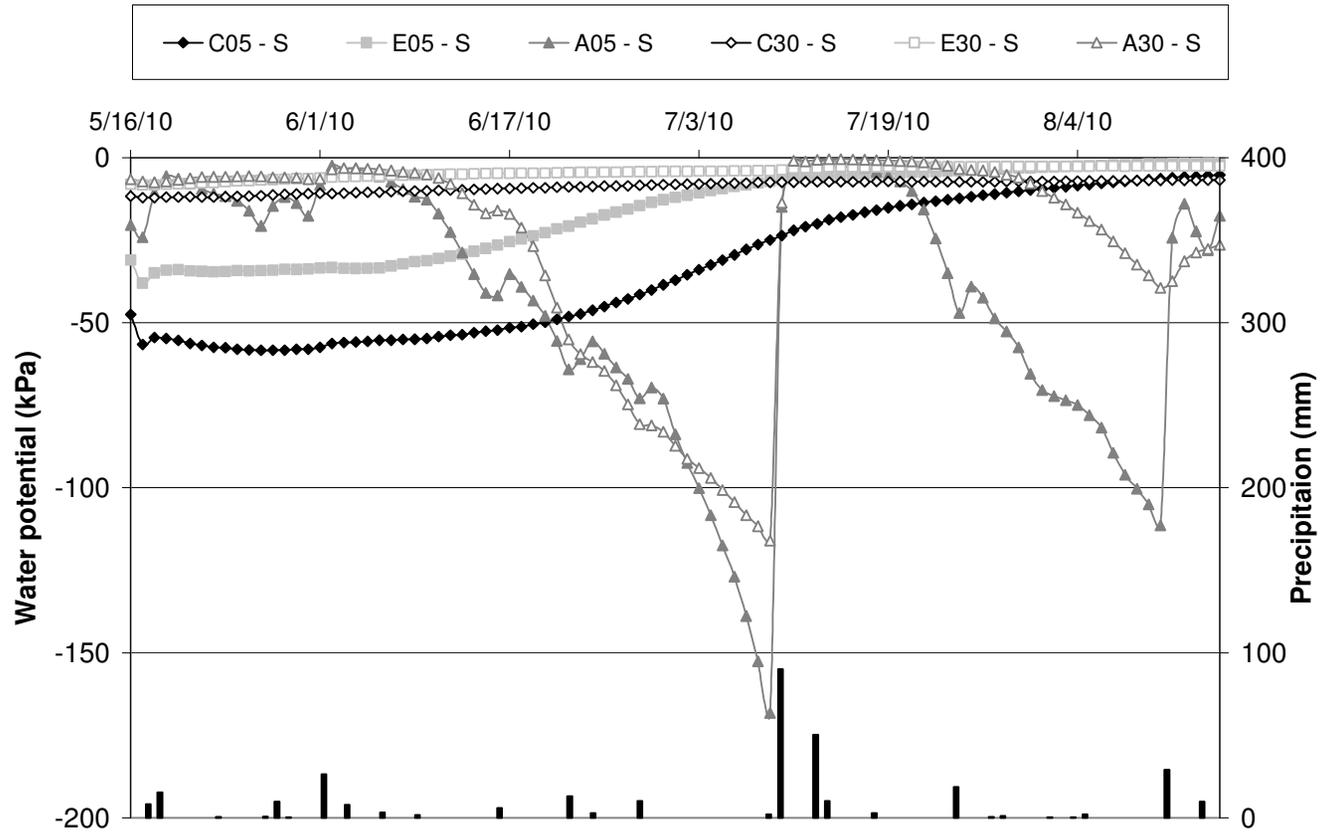


Figure C-11: Water potential in the soil at the moisture sensor locations: 5 and 30 cm below the ground surface at three different vertical locations: under the center of the PL footprint (C05 – S, C30 – S), 1.8 m in from the circumference of the piles (E05 – S, E30 – S) and under the circumference of the pile footprint (A05 – S, A30 – S). Calculations were based on the moisture release curve, prepared by Decagon Inc. (Logan, UT). The data points represent three replications. Precipitation data was obtained from the Wye Research and Education Center weighing bucket rain gage at 38 54' 46.15"N 76 09' 06.75"W.

Appendix D: Initial and final inorganic N and salt concentrations on the research plots

Table D-1: Water extractable salt concentrations, electrical conductivity and pH in the research site before the study. Samples were taken in October 2009 with a tractor mounted auger to a depth of 1 m. Five soil cores were taken from each plot randomly and split to 10 cm segments. Data shown are averages of six plots that were analyzed separately in the laboratory.

Depth (cm)	-----Initial concentration of water extractable salts----- (mg kg ⁻¹ in air dried soil)						EC (1:1) (dS m ⁻¹)	pH (1:1)
	WEK	WENa	WEAl	WES	WECa	WEMg		
0-10	74.26	20.11	9.46	29.13	40.26	10.75	0.34	5.99
10-20	44.84	20.48	12.80	18.97	29.61	6.10	0.25	6.08
20-30	30.98	18.50	8.49	17.16	23.70	4.01	0.20	6.36
30-40	26.71	18.49	8.63	15.07	21.20	3.61	0.17	6.48
40-50	23.52	19.08	7.43	13.75	18.06	3.04	0.17	6.53
50-60	21.92	18.13	6.25	18.84	21.69	3.73	0.18	6.63
60-70	21.56	18.86	5.78	21.17	24.41	3.84	0.18	6.50
70-80	20.29	18.23	5.71	23.30	27.09	3.83	0.18	6.57
80-90	20.76	17.72	5.20	21.34	27.91	3.88	0.15	6.42
90-100	19.42	19.25	5.65	20.47	24.17	3.20	0.13	6.37

Table D-2: Inorganic-N and water extractable salt concentrations, electrical conductivity and pH in the soil where poultry litter was stored for 15 days. Samples were taken in August 2010 with a tractor mounted auger to a depth of 1 m. Five soil cores were taken from each of the three plots randomly and split to 10 cm segments. Data shown are averages of three plots that were analyzed separately in the laboratory.

Depth (cm)	-----Concentration of inorganic N and water extractable salts in Day 15 plots----- (mg kg ⁻¹ in air dried soil)								EC (1:1) dS m ⁻¹	pH (1:1)
	NH ₄ ⁺ -N	NO ₃ ⁻ -N	WEK	WENa	WEAl	WES	WECa	WEMg		
0-10	100.80	103.30	593.43	278.40	24.40	233.37	99.73	51.44	1.92	6.23
10-20	34.53	58.27	238.57	131.55	24.76	129.95	118.45	25.01	1.03	5.40
20-30	21.50	38.97	118.78	79.10	30.33	73.90	101.58	19.63	0.66	5.60
30-40	10.58	21.53	39.15	35.11	5.83	30.20	70.26	12.65	0.33	5.91
40-50	15.80	8.82	24.15	18.70	15.17	13.41	38.14	6.83	0.22	6.13
50-60	6.40	5.39	26.03	18.47	12.66	15.53	27.59	5.50	0.19	6.20
60-70	12.03	4.12	20.29	15.29	9.37	13.23	25.19	4.47	0.17	6.16
70-80	13.25	2.85	18.41	15.17	5.63	12.96	20.37	3.33	0.14	6.05
80-90	16.93	2.52	35.44	28.41	12.84	16.86	50.74	4.22	0.14	6.18
90-100	13.40	3.27	19.28	17.19	8.03	14.85	24.85	4.24	0.16	6.11

Table D-3: Inorganic-N and water extractable salt concentrations, electrical conductivity and pH in the soil where poultry litter was stored for 91 days. Samples were taken in August 2010 with a tractor mounted auger to a depth of 1 m. Five soil cores were taken from each of the three plots randomly and split to 10 cm segments. Data shown are averages of three plots that were analyzed separately in the laboratory.

Depth (cm)	-----Concentration of inorganic N and water extractable salts in Day 15 plots----- (mg kg ⁻¹ in air dried soil)								EC (1:1) dS m ⁻¹	pH
	NH ₄ ⁺ -N	NO ₃ ⁻ -N	WEK	WENa	WEAl	WES	WECa	WEMg		
0-10	317.33	46.73	2746.83	1239.67	48.08	768.67	136.17	97.70	6.23	7.23
10-20	197.67	29.00	611.00	332.50	69.43	227.57	58.75	14.94	2.08	6.54
20-30	92.67	19.10	326.78	205.03	46.32	179.12	80.82	17.35	1.30	6.17
30-40	38.20	16.67	155.98	129.83	32.47	98.62	99.80	16.97	0.67	6.06
40-50	39.97	19.27	165.27	139.27	38.51	111.50	96.45	17.27	0.76	5.98
50-60	24.53	11.10	67.82	80.68	13.22	68.90	106.30	15.93	0.34	6.03
60-70	23.10	8.35	37.47	53.54	5.77	52.55	67.27	11.61	0.30	5.89
70-80	18.97	4.63	42.61	49.36	12.50	38.50	58.17	8.46	0.18	5.84
80-90	24.33	10.75	34.70	46.28	5.59	46.44	59.96	10.56	0.36	5.72
90-100	15.70	5.88	28.42	42.95	5.75	49.54	62.90	10.10	0.32	5.72

Appendix E: Contents of the enclosed CD-ROM

Poultry litter

1_PL study_PL discrete data_17 May-16 Aug 2010

2_PL study_PL Temp and MC monitoring_17 May 2010-16 Aug 2010

Soil column samples

3_PL study_SOIL COLUMN discrete data_17 May 2010_16 Aug 2010

Initial and final bulk soil samples from each research plot

4_PL Study_INITIAL-Oct 2009 and FINAL-Aug 2010 Soil samples from whole plots

Soil observational data

5_PL study_BULK SOIL discrete data_17 May-16 Aug 2010

6_PL study_SOIL Temp and MC monitoring_17 May 2010-16 Aug 2010

Raw sensor data

7_PL Study_Output from 21X Campbell Datalogers_Temp and VMC_PL and soil_17
May-16 Aug 2010

8_PL Study_Decagon sensor output_MC_TEMP_EC_May 16-Aug16_at 60 cm soil
depth

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