FERTILIZER VALUE OF DENSIFIED BROILER LITTER

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FERTILIZER VALUE OF DENSIFIED BROILER LITTER

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THESIS ABSTRACT

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The increase in broiler (*Gallus gallus domesticus)* production across the southeastern United States and in the state of Alabama has led to locally excessive application rates of broiler litter. Because of the low fertilizer value of broiler litter, there is little economic incentive to transport litter longer distances. Densification of litter could increase the economic transport distance and decrease excessive application in high broiler production areas. Densification could affect litter nutrient concentration and nutrient uptake by forages.

The objectives of this research were to determine impacts of litter densification on: 1) litter nutrient concentration, 2) carbon (C) and nitrogen (N) mineralization of densified broiler litter, and, 3) forage yield, nutrient concentration, and nutrient uptake.

Broiler litter was collected from Talladega County, Alabama and densified. Additional moisture added to litter prior to the densification process increased pH and decreased electrical conductivity, copper (Cu) concentration, and iron concentration (Fe). Densification also increased nitrate-nitrogen (NO_3-N) concentration, total nitrogen (N), and carbon (C), but decreased concentrations of calcium (Ca), phosphorus (P), and sodium (Na). Soil potential N mineralization was negligible in raw and densified litter treated soils. While changes in nutrient concentrations upon densification were statistically significant, they are not likely to affect the agronomic use of densified litter. Thus, densified litter could be a good alternative to bulky, loose litter when transportation costs are considered.

A field study was performed to determine forage yield and nutrient uptake of densified litter, unprocessed litter and commercial fertilizer. Interactions between clover management, cultivar, and year were all found to be significant. Plots with clover had higher plant tissue nutrient concentrations than those without clover. Max Q fescue plots with clover also had significantly higher plant tissue nutrient concentrations than AU Triumph fescue. Overall, densified litter remains a viable substitute for unprocessed litter as differences between the fertilizer types were extremely small and are not likely to affect agronomic use of densified litter.

Increased litter density could enlarge the economic hauling radius of broiler litter, though more research is needed to determine cost benefits of the densification process.

Style manual or journal used Publications Handbook and Style Manual of the American Society of Agronomy

Computer software used Microsoft Word 2007, Microsoft Excel 2007, SAS v 9.1, Sigma Plot v 10.0

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I. LITERATURE REVIEW

Broiler Production

Alabama ranks third among U.S. states in broiler production with over one billion birds marketed in 2006 (AASS, 2007). In 2006, Alabama produced eleven percent of the broilers in the U.S. behind only Georgia and Arkansas (AASS, 2007). The top three broiler producing counties in Alabama, which produced thirty-one percent of the state's broilers, are Cullman, DeKalb, and Marshall Counties. These counties are all located in the northeastern part of the state (AASS, 2007).

Poultry has been beneficial to the Alabama economy. Poultry ranks number one in agricultural commodities in the state making up forty-one percent of total cash receipts (AASS, 2007). Cash receipts from broiler production amounted to $2.2 billion, decreasing slightly from the past year (AASS, 2007). Alabama exported $247 million worth of poultry products in 2006, amounting to forty-three percent of the state's total agricultural export (AASS 2007).

Waste Production

Most poultry production is located in the Sand Mountain region of northeastern Alabama (Wood et al., 1993). Economies of scale have driven the trend toward large confined animal feeding operations (CAFO) in small areas which generate large amounts of manure (Evers, 1998).

Broiler litter consists of manure, wasted feed, feathers, ash, and bedding materials (Moore et al., 1995; Mitchell and Donald, 1995). Bedding materials include wood chips, sawdust, peanut hulls, rice hulls, and wheat straw which are used to absorb the liquid part of excreta (Moore et al., 1995; Mitchell and Donald, 1995). Broiler litter production in Alabama has been estimated at over two million Mg per year (Donald et al., 1996, Adhikara et al., 2001). Between 0.2 and 0.3 kilograms of litter is produced per kilogram of broiler chicken market weight (Mitchell and Donald, 1995).

Transportation

Broiler production is usually concentrated in small areas, so litter production often exceeds crop requirements of area farms (Sharpley et al., 1993). Manure management is difficult when counties with surplus manure phosphorus (P) are clustered close together (Maguire et. al, 2007). Sims (1995) showed the disadvantages of using broiler litter over commercial fertilizer, citing high application rates requirements owing to low nutrient content. This low nutrient content makes long-distance hauling uneconomical (Sharpley et al., 1993). If solid poultry manure is to be transported long distances, drying is preferred, but mechanical drying is rarely practiced (Moore et al., 1995). Generally, poultry litter transportation is restricted to less than 10-20 km from the collection site because farmers must add five to ten times as much poultry litter as 17-17-17 fertilizer to achieve similar application rates (Moore et al., 1995). Adhikara et al. (2001), found that litter may be transported up to 262 kilometers as a substitution for commercial fertilizer when fertilized on a P basis for cotton and corn in Northern Alabama. Bukenya et al. (2000) found that transportation distance is a key determinant in the evaluation of litter substitution for ammonium nitrate commercial fertilizer. As nitrogen (N) prices continue to rise, farmers are looking for cheaper sources of N such as broiler chicken litter (Dorough and Mitchell, 2008). These other sources are increasingly scarce as N prices rise (Dorough and Mitchell, 2008). Dorough and Mitchell (2008) suggest that broiler chicken litter might be a better source of N for cattle pastures, assuming producers can find it and are willing to pay additional trucking costs.

According to Bosch and Napit (1992), per-unit litter transfer costs depend on amount of litter a farm handles and distance from the source of litter. Bosch and Napit (1992) showed that even though transporting litter to areas of low production should be economically feasible in Virginia assuming low transportation costs, regulations are needed to require growers to have a safe plan of waste removal. In Alabama, lack of a well operated market and imperfect information result in the sale of broiler litter for $11 per Mg as opposed to $40 per Mg which the litter is actually worth as fertilizer (Adhikara et al., 2001). Transporting animal wastes is also unfavorable for farmers because of logistics (Sims, 1995). Bosch and Napit (1992) concluded that government subsidies to growers who purchase poultry litter for fertilizer were needed to encourage transportation and use of manure fertilizer among producers. Acceptance of litter by producers as well as assistance by the government to make litter an acceptable alternative to commercial fertilizer are the keys to litter transportation in Alabama according to Adhikara et al. (2001).

Several agencies encourage transportation and use of manure fertilizer. The Rural Business-Cooperative Service established a program which makes grants, loan guarantees and loans to farmers to purchase renewable energy systems and make energy improvements (USDA, 2005). The Alabama NRCS Litter Distribution program gives benefits for hauling litter to litter deficient areas of the state (NRCS, 2007). States that have large poultry industries are also using markets to connect buyers and sellers of litter (Lichtenberg, 2002). Maryland's Manure Transport program provides grants of up to $22.22 per Mg to help cover costs associated with transporting manure from farms with high soil P levels to other areas of the state (MDA, 2007). The state of Maryland also provides assistance with its Manure Matching Service, which links farms with excess manure to buyers consisting of area farmers or alternative use facilities (MDA, 2007).

Litter Composition and Use as Fertilizer

Animal wastes have been used since early Greek times as fertilizer and some of the earliest agriculturalists recognized manure's varied fertilizer value (Sims, 1995). Broiler litter has a relatively low moisture content and high macronutrient content which is considered valuable as fertilizer (Moore et al., 1995). In the southeastern U. S. common $N:P_2O_5:K_2O$ ratios of broiler litter range from 3:1:2 to 5:1:4 (Evers, 1998). Sometimes the amount of waste required for fertilization exceeds 10 to 100 times the rate of inorganic fertilizer (Sims, 1995). Sims and Wolf (1994) found the nutrient level in broiler litter can vary based on feed ration, litter type, supplements, number of batches raised before cleaning, as well as handling and storage.

Litter not only provides calcium (Ca) compounds that reduce soil acidity (Wood, 1992), but also organic matter that can improve soil moisture and nutrient holding capacity (Evers, 1998; Sims, 1995). Poultry litter application can increase organic carbon (C) content of the soil which can lead to decreased bulk density (Sharpley et al., 1993; Wood, 1992). Because larger sized fractions of poultry litter are not subject to rapid microbial decomposition, litter coupled with crop residue and tillage techniques can increase soil organic matter (SOM) concentration, provide addition cover which reduces erosion, and increase pasture productivity when combined with commercial fertilizer (Nyakatawa et al., 2001).

Nitrogen

Nitrogen is vital for plant health and normally produces the most drastic growth response for forages of any element (Ball, 2002). Nitrogen deficiency symptoms include stunted growth and chlorosis of leaves (Brady and Weil, 2002). The major portion of N in soils is organic N which must be converted to inorganic forms (NO_3 and NH_4) via N pathways for plant use (Brady and Weil, 2002). Nitrogen pathways include fixation, denitrification, volatilization, immobilization, mineralization, and nitrification (Havlin et al., 2004). The majority of poultry litter N is organic with about one-third in the inorganic ammonium form (NH_4-N) (Mitchell and Donald, 1995). Gale and Gilmour, 1986, showed that poultry litter is a source of residual N fertilizer due to pools of organic N, though residual N from litter applications has been identified as a potential environmental concern (Sharpley et al., 1998).

Heavy continual manure applications can lead to nitrate (NO_3) leaching and excess NO_3 in groundwater (Bouldin and Klausner, 1998). According to the EPA, NO_3 is the most widespread agricultural contaminant in groundwater, and nearly 2% of the U.S. population (1.5 million people) is exposed to elevated NO_3 levels from drinking water wells (EPA, 2002). Nitrate poisoning can affect infants by reducing the oxygen-carrying capacity of blood which is commonly referred to as "blue baby syndrome" because the lack of oxygen can cause the skin to appear blue in color (EPA, 2002). Nitrate poisoning also causes liver disease and cancer in humans as well as fetal abortion in livestock (EPA, 2002). To protect human health, EPA has set a drinking water Maximum Contaminant Level (MCL) of 10 mg L^{-1} for NO_3-N (EPA, 2002). Nitrate contamination of groundwater is a problem that has been associated with excessive poultry litter applications to crop-land (Nyakatawa et al., 2001).

Groundwater contamination by NO_3 can occur after the nitrification of ammonium nitrogen (NH_4) present in manure and slurries applied to agricultural land (Sherlock et al., 2002). Nitrate-N was observed close to bedrock in significant amounts below fields with long-term broiler litter application which caused a potential for increased N levels in groundwater (Kingery et al., 1994). Nyakatawa et al. (2001) found that levels of NH_4 concentration in a soil depth of 30-60 cm was two to three times higher with poultry litter applications than with other fertilizers, which, when converted to NO_3, could lead to leaching problems. Though environmental concerns exist over NO_3 leaching below the root zone, no differences in NO_3-N levels could be detected below 10 cm in poultry litter applications to bermudagrass (Wood et al., 1993). Residual N remaining in soil was greater with poultry manure than with chemical fertilizers in a study done by Sims (1987). Sixty percent of N applied at an 8 ton acre^{-1} and 62% N applied at 4 ton acre^{-1} were estimated available during the first year of bermudagrass production in Texas (Evers, 1998).

In the Sand Mountain region of Alabama, soil total N and NO_3-N originating from litter applications suggest that poultry litter has been applied in excess (Kingery et al., 1994). Growing crops such as corn after years of poultry litter application to soil may help reduce residual N and environmental concerns associated with residual N (Malik and Reddy, 2002). Proper litter application practices need to be exercised to prevent seasonal buildup of soil NO_3-N, which may be leached and cause environmental problems (Nyakatawa et al., 2001; Sistani et al., 2004).

Phosphorus

Phosphorus (P) inputs from feed and fertilizer on farms have built up soil P levels that exceed crop needs (Sharpley et al., 2003). Phosphorus inputs via runoff increase biological activity in surface waters causing accelerated eutrophication (Sharpley et al., 2003; Daniels et al., 1998). Phosphorus is also a concern because phosphate levels greater than 1.0 mg L^{-1} may interfere with coagulation in drinking water treatment plants which inhibits the removal of harmful microorganisms (Bartenhagen et al., 1994).

Since poultry litter has an average N:P ratio of 3:1, N management has led to increased soil P in excess of crop requirements (Moore et al., 1995). Summaries of soil test data in the U. S. confirm that many soils dominated by animal agriculture have high or excessive P levels (Sims, 1994). Soils in the Sand Mountain region of Alabama receiving long-term litter applications have been observed with soil P concentrations more than six times that of non-litter soils (Kingery et al., 1993). Kingery et al. (1993) also found soil Mehlich P concentrations in excess of 225 mg kg^{-1}, showing that poultry litter applications can result in extreme P accumulation in soil. However, with proper management in the short term, P-uptake by cotton and winter rye crops was able to prevent P buildup in soil (Nyakatawa et al., 2001).

Evers (1998) found the major environmental problem associated with using broiler litter to fertilizer hybrid bermudagrass in Texas to be the build-up of excess P that can move into surface water through runoff and erosion. Because of large amounts of P in poultry litter, the capacity of soil to absorb more P was lower in the surface 30 cm of treated than untreated soils (Sharpley et al., 1993). Sharpley et al. (1993) found, averaged for 12 soils, an increase in P content owing to litter application on the order of Bray I P (1218%) > inorganic P (446%) > organic P (19%) with the major form in treated soils being inorganic P (IP). Inorganic P increased more than other fractions of P in soils with long-term applications of poultry litter, beef feedlot manure, and swine slurry. This suggests that a shift from mostly organic P to IP in soil provides more P for plant uptake but also can increase the potential for P loss due to runoff (Robinson et al., 1995).

Because litter contains high concentrations of water soluble P, runoff of dissolved P can occur even if best management practices are used (Moore et al., 1995). Wood (1992) concluded that using a soil test P strategy might mitigate excessive build up of P in soil as well as lower the risk of nitrate leaching. Furthermore, this strategy would eliminate much of the land area used in continual manure application and require many years to mitigate (Wood, 1992; Sharpley et al., 1993). High levels of P can require as many as 15 to 20 years of continuous crop removal with no additional P to remediate (Daniels et al., 1998).

Diet modification for birds has been suggested to reduce P in litter (Maguire et al., 2007). In the Chesapeake Bay region, researchers from Virginia Tech, USDA's Natural Resource Conservation Service and the Virginia Department of Commerce are using government grants to offer incentive payments to dairy farmers to reduce the amount of P overfed to cattle on their farms thus reducing P pollution to the Bay (Sutphin, 2008).

Livestock Systems

Potential animal health problems, such as cardiac insufficiency, reduced feed intake, and death can arise in livestock grazing on lush spring bermudagrass fertilized with broiler litter because of potassium (K) concentrations above the maximum recommended for beef cattle diets (National Research Council, 2000; Evers, 1998). An accumulation of soil N in tall fescue (*Festuca arundinacea* Schreb.) pastures fertilized with poultry litter indicate the potential for higher levels of NO_3-N in plant tissue that may be toxic to ruminants (Kingery et al., 1993). Levels of NO_3-N which can cause nitrate poisoning of farm animals were well below the critical limit for feeding in a study by Wood et al. (1993), suggesting that NO_3-N levels in bermudagrass fertilized with poultry litter should not affect the feeding quality under normal environmental conditions.

Forage Yield

Evers (1998) found that applying all broiler litter in a single spring application to hybrid bermudagrass produced 10 to 20% more forage for the season than a split application. Additional yield the second year after broiler litter application to forages was observed by Wood et al. (1993) and Evers (1998), and was attributed to additional mineralization of organic N applied the previous year, increased SOM as well as additional benefits from applying manure to acid sandy soils.

The optimal nutrient management plan suggested by Evers (1998) is moderate broiler litter rates of 2 to 4 Mg ha^{-1} $year^{-1}$ with supplemental N fertilizer. This practice would increase the economic value of broiler litter and reduce environmental problems associated with P in surface water (Evers, 1998). Increased yield of pasture grasses such as tall fescue have been shown with land application of litter (Hileman, 1965; Huneycutt et al., 1988). Corn grain yields were found higher in plots that received litter as fertilizer in previous years (Malik and Reddy, 2002). Evers (2002) increased yield and N, P, and K uptake by applying commercial N fertilizer in combination with litter to a ryegrass-bermudagrass forage system.

The amount of nutrient removal in kg Mg^{-1} of forage dry matter varies by crop: alfalfa 29:7:28 ($N:P_2O_5:K_20$), bermudagrass 20:6:22, clover 21:6:22, fescue 18:7:25, and ryegrass 19:8:27 (Daniels et al., 1998). In managing fields fertilized with manure, forage type is an important variable in the amount of excess nutrients left in soil.

Pelletization

Raw poultry litter is spread unevenly due to particle size variability (Wilhoit et al., 1993). Pelletization was found to improve spreading uniformity and ease transportation issues (Hammac et al., 2007). Pelletized swine lagoon solids were reported to be an excellent source of P, though they required additional N for most crops (Duffera et al., 1999). Moore et al. (1998) found the bulk density of pelletized litter higher than raw litter, allowing heavier loads to be transported. Pelletization increases total P concentration and NH_4-N concentration due to processing (Hammac et al., 2007).

Currently, several markets are available for poultry litter buyers and sellers including a joint venture between Perdue Farms and AgriRecycle in the Delaware, Maryland, and Virginia areas to produce dried litter pellets (Lichtenberg, 2002). Cargill and Harmony Products have invested in granulated litter products in Virginia (Carpenter, 2002) and the "Poultry Litter Marketing and Utilization Project" in Arkansas to link buyers and sellers (Wilson et al., 1998).

Remediation

Changing to a P based management system may result in inadequate local land area for manure application, because heavily manured soils rarely require P fertilization (Sims, 1995). Management strategies should consider the potential for N and P to accumulate at the soil surface and strategies based on P for soils susceptible to surface runoff (Sharpley et al., 1993). Removing excess P from the soil in the form of hay would curtail P buildup in soil in the long-term despite small P uptake by bermudagrass (Sims and Wolf, 1994; Brink et al., 2001). If litter is applied in the presence of actively growing temperate forages, the forage will reduce the potential for P loss by reducing sediment moving during runoff (Sharpley et al., 1993). Using temperate annual grasses or legumes in warm-season perennial grass systems with broiler litter as fertilizer gives opportunities to produce high quality forage for livestock, reduce runoff loss of nutrients, and remove nutrients added to the system through hay production (Brink et al., 2001).

II. NUTRIENT CHANGES IN DENSIFIED BROILER LITTER

Abstract

Broiler chicken (*Gallus gallus domesticus*) litter is a valuable manure fertilizer. Studies have shown that broiler litter improves soil organic matter, reduces erosion and increases pasture productivity. As broiler production continues to increase in the southeastern U.S., frequent over application of litter results in high soil phosphorus (P) concentrations. When transportation costs are considered, densified broiler litter could be transported further than raw poultry litter, alleviating over-application in close proximity to broiler production areas. This study determined temporal changes in densified broiler litter. Broiler litter was subjected to 193 MPa of pressure and compacted into 30.5 x 30.5 x 20 cm blocks. Samples were stored under an open Quonset hut for one year. Samples were collected at various times over the one year period to determine differences in mass and nutrient content. Additional moisture added to litter prior to the densification process increased pH and decreased electrical conductivity, copper (Cu) concentration, and iron concentration (Fe). Densification increased nitrate-nitrogen (NO_3-N), total nitrogen (N), and carbon (C) concentrations, but decreased concentrations of calcium (Ca), phosphorus (P), and sodium (Na). Though densification affects litter nutrient content, the changes are agronomically insignificant. Compacted litter is a good alternative to bulky, loose litter when transportation costs are considered.

Introduction

Alabama ranks third among U.S. states in broiler production in the U.S. with over one billion birds marketed in 2006 (AASS, 2007). Most poultry production is located in the Sand Mountain region of Alabama (Wood et al., 1993), where confined feeding operations generate large amounts of broiler litter in a small area (Evers, 1998). Broiler litter production in the state has been estimated at over two million Mg per year (Adhikara et al., 2001, Donald et al., 1996).

Although valuable as a fertilizer (Sims 1995), residual N from broiler litter over-application has been a potential environmental concern (Sharpley et al., 1998). Groundwater contamination by NO_3 can occur after nitrification of ammonium (NH_4)-N found in manure (Sherlock et al., 2002, Nyakatawa et al., 2001). Long-term application of broiler litter has also caused high or excessive soil P levels (Sims and Wolf, 1994, Kingery et al., 1993). Concerns exist that runoff or erosion of areas with high soil P from manure applications will accelerate eutrophication of surface waters (Sharpley et al., 2003).

Growing crops, such as corn, after years of litter application has been suggested to help reduce residual N in soils (Malik and Reddy, 2002). Proper application techniques would also help prevent buildup of NO_3 in the soil surface (Sistani et al., 2004, Nyakatawa et al., 2001). Strategies to mitigate excessive soil P include halting additional P inputs to soils (Daniels et al., 1998), using a soil test P strategy (Sharpley et al., 1993, Wood 1992), modifying broiler diets to reduce P in litter (Maguire et al., 2007), and giving incentive payments for farmers to reduce the amount of P overfed to animals (Sutphin, 2008).

Since broiler production is usually concentrated in relatively small areas, litter production often exceeds crop requirements of area farms (Sharpley et al., 1993). Generally, poultry litter transport is restricted to less than 10-20 km from the collection site because of transportation costs (Sharpley et al., 1993). When these costs are considered, densified poultry litter could be cost effectively transported further than raw poultry litter, alleviating over-application of manure around production sites. Little information exists on the value of densified poultry litter. This study was performed to determine whether densification of broiler litter alters litter nutrient value.

Materials and Methods

Densification

Broiler chicken litter was collected from a producer in Talladega County, Alabama and transported to Auburn, Alabama. Prior to densification, initial moisture content of litter was determined using a Model IR-200 moisture analyzer (Denver Instruments, Arvada, CO). Water was then added and mixed with litter using a concrete mixer to bring moisture content to 400 g kg^{-1} for densification. This moisture content was found in initial trials to be optimal for densification. Litter was subjected to approximately 193 MPa of pressure in one minute increments until four layers of litter were compacted into a block approximately 30.5 x 30.5 x 20 centimeters. The press was designed by Auburn University's Biosystems Engineering department. Densified litter blocks were immediately placed on plywood boards lined with plastic and weighed. Initial density of the blocks was determined from dimension and mass measurements. Samples were placed in an open Quonset hut in completely random order for storage until sampling.

External ambient and internal broiler litter block temperatures were determined with Model SM-325 two probe temperature dataloggers placed in two blocks (Dickson Co., Addison, IL). Density differences were determined using mass and block dimensions upon initial densification and sampling.

Broiler litter blocks (r = 3) were sampled on days 0, 1, 2, 4, 7, 14, 28, 98, 128, and 365 using a 10 cm diameter hydraulic soil probe (Giddings Machine Co., Fort Collins, CO). Prior to sampling, blocks were weighed and measured for final density at that sampling time. Samples were analyzed for pH (1 g sample to 3 g water) and electrical conductivity (EC) (1 g sample to 10 g water). Samples were ground to pass a 1-mm mesh screen using a Wiley Mill prior to analysis for carbon (C), N, P, potassium (K), Ca, magnesium (Mg), Fe, Cu, and zinc (Zn).

Nutrient Concentration

Nutrient concentration of poultry litter as affected by moisture and densification was determined. Unprocessed dry, unprocessed wet (40% moisture), and densified litter were analyzed in triplicate. Total C and N were determined via dry combustion on a LECO TruSpec CN analyzer (St. Joseph, MI). Inorganic N ($NH_4$and NO_3) was extracted with 2*M* KCl and measured by colorimetric procedures (Sims et al., 1995). For elemental determination, samples were dry-ashed, evaporated with 10 mL 1*N* HNO_3, then dissolved with 10 mL 1*N* HCl (Hue and Evans, 1986). Samples were filtered using Whatman # 42 filter paper before analysis. Total P, K, Ca, Mg, Fe, Cu, and Zn were measured using inductively coupled plasma (ICP) spectroscopy (Spectro Ciros CCD, Germany).

<u>Incubation</u>

A laboratory study to determine C and N mineralization from broiler litter as impacted by densification followed the general methodology detailed by Anderson (1982). Litter treatments of 1) densified poultry litter, 2) unprocessed litter, and 3) soil only, replicated three times, were mixed into a Lucedale loam (fine loamy, siliceous, subactive, thermic Rhodic Paleudult) (0 to 15 cm depth) from the Monroeville, AL area. Soil was sieved to pass a 2 mm diameter screen and weighed (50 g dry weight basis) into plastic containers. Unprocessed and densified litter were added and mixed with soil at a rate of 18 Mg ha^{-1}. Water was added to maintain soil and waste mixtures at -12 kPa. An 8 mL vial of 1*N* NaOH was added to each container to trap respired carbon dioxide (CO_2-C). Treatments were incubated for 30 days in the dark at 25^oC. Potential C mineralization was calculated as the difference between the incubation base trap and the mean of four blanks. Carbon turnover and relative N mineralization were calculated as the fraction of C or N mineralized (Burke et al., 1989).

Total C, total N, and inorganic N ((NH_4 and NO_3) were measured in the soil and litter prior to incubation. Respired carbon dioxide (CO_2-C), NH_4-N and NO_3-N were measured after 30 days. Carbon dioxide in NaOH traps was determined by back-titrating excess base with 1*N* hydrochloric acid (HCl) in the presence of $BaCl_2$. Inorganic N was extracted with 2*M* KCl and measured by colorimetric procedures (Sims et al., 1995).

Statistical Analysis

Statistical analysis for nutrient concentrations of unprocessed and densified litter was performed using the ProcMixed procedure at $\alpha = 0.10$ significance level (SAS Institute, 2003). Nutrient concentration models were formulated using the dynamic curve feature of SigmaPlot version 10 (Systat Corporation, San Jose, CA). Nutrient concentrations over a one year period were modeled using exponential (double exponential decay, Weibull, Sigmoidal, Gaussian, and Polynomial) equations which model non-negative response variables.

Statistical analysis for cumulative C and N mineralization was performed using ProcMixed procedure at $\alpha = 0.05$ significance (SAS Institute, 2003).

Results and Discussion

Densification process

During the densification process, water was added to litter to aid compaction. Some effects of added water were evident (Table 1). Copper, Fe, and EC decreased slightly, while pH increased with addition of water. No other differences in nutrient concentrations were detected (Table 1). Samples were also tested to determine the effect of densification on broiler litter (unprocessed and densified litter) nutrient concentrations (Table 2). Calcium concentration was lower in densified samples than in unprocessed samples with similar results for Na and P. Total N increased after densification, though the actual increase was only 1 g kg^{-1} and not considered biologically significant (Table 2).

Large changes in nutrient concentration upon densification were not expected, though similar studies (Hammac et al., 2007; Hadas et al., 1983) found increases in total N due to processing. A study by Delaune et al. (2004) found decreases of initial manure N of up to 47% during composting even when chemical amendments were used. While changes in nutrient concentrations upon densification were statistically significant, compaction will not likely affect the agronomic use of densified litter.

Change Over Time

Analyses were conducted on samples collected over the course of one year. Double exponential decay models with four parameters were used for total N, NH_4-N and NO_3-N (Figs. 1 and 2). Ammonium-N and NO_3-N accounted for almost half of N lost over the time period (Figs. 1 and 2). Over the study period, total N losses were approximately 5 g kg^{-1} while NH_4-N + NO_3-N losses totaled approximately 3.5 g kg^{-1}.

Magnesium, pH, Ca, K, Cu, and Fe were modeled using single exponential equations (Figs. 3-8). Magnesium and pH concentrations initially increased and then decreased over time to concentrations lower than initial sampling. Flynn (1995) found similar results in compost piles where pH decreased to approximately 6.9 indicating compost maturity. Calcium concentration initially increased then decreased over time to similar levels of initial sampling. Tiquia et al. (2002) found similar decreases in Ca concentration during composting when windrow piles were unturned; losses were unexplained. Potassium, Cu, and Fe increased initially and decreased to concentrations above those of the initial sampling time (Figs. 6- 8). These increases suggest composting of bedding material could have added quantities of these nutrients to the litter mixture as reported by Warman and Cooper (2000).

Phosphorus and Na concentrations appear to level out over time (Figs. 9 and 10). Losses of these nutrients were not expected since the available forms of these elements are not volatile.

Carbon concentration in densified broiler litter blocks decreased slightly over time (Fig. 11). This decrease was not as large as those reported by Flynn (1995), probably due to lack of aeration and aerobic microbial C decomposition. Bedding type could also affect the small amount of C loss (Flynn, 1995).

Figure 12 shows Zn concentration in broiler litter blocks over a one year period. Zinc concentration increase over time was consistent with findings by Warman and Cooper (2000) where reported Zn levels in chicken manure compost were higher than in initial manure.

A decrease in nutrient concentration over time was expected to occur because of chemical loss pathways, microbial activity, and climatic factors. Wood and Hall (1991) observed differences in nutrient concentrations of broiler litter. They found the greatest reduction among nutrients occurred with N. However, observed differences were considered inconsequential agronomically and environmentally (Wood and Hall, 1991). In a study of NO_3 and NH_4 losses from surface applied fertilizer, King and Torbert (2007) found NO_3-N losses from composted dairy manure and poultry litter to be consistently less than commercial fertilizers. Flynn et al. (1995) found nutrient changes from litter compost negligible over a two year period due to the recalcitrant nature of compost materials and shelter under which compost was stored. Similarly, nutrient losses from densified litter are not expected to affect the agronomic use of densified litter as a manure fertilizer.

Density

Density changes were measured using block weight and dimensions upon initial densification and sampling. Initial density of densified litter was almost double that of raw poultry litter (Fig. 13). McMullen et al. (2005) found similar results when comparing pelleted and raw poultry litter. Figures 14 and 15 show changes in density of litter blocks over a one year period. Differences were not significant.

Temperature

Ambient and internal block temperatures were measured using data loggers during the sample period. Data for the first 98 days suggests internal block litter temperature reaches ambient air temperature within two weeks of densification (Fig. 16. The maximum temperature reached by densified litter was about 50^{o} C. Flynn (1995) found similar results though temperature patterns were unique to each C source co-composted with litter.

The possibility of fire caused by heat generated within a stored litter pile has long been a danger associated with poultry litter storage (Donald et al., 1996; Donald and Blake, 1995). Known factors that affect storage fires include moisture (over 40%), pile size, and amount of litter compaction (Donald et al., 1996). Since the maximum block temperature was well below wood's flash point (300 C), individual densified litter blocks are unlikely to cause spontaneous fires. In a study quantifying the microbial properties of densified poultry litter made by the same process as described previously, Feng (2007) noted the negligible amount of fecal coliforms and *Salmonella* detected may be attributed to the heating of litter during storage and varying numbers of fecal coliforms depending on storage time and conditions.

Incubation

Cumulative soil inorganic N and respired CO_2-C were measured after thirty days of incubation. Soil potential N mineralization was negligible in raw and densified litter treated soils (Table 3). Carbon turnover was the only variable affected (p=0.05) when comparing raw and densified litter, with raw litter having higher C turnover (Table 3).

No net N mineralization suggests that N in densified and raw litter samples could have been lost via ammonia volatilization, immobilization or denitrification. The most probable pathways were loss by volatilization and denitrification, the last mostly likely from high moisture. Other studies detailed by Sharpley et al. (2003) show that gaseous losses of N can occur with manure applications, partly due to the large amount of C added to soil with manure. Hammac et al. (2007) showed a similar loss of inorganic N during an incubation study with pelletized poultry litter.

Conclusions

Minor alterations in nutrient concentrations subject to densification of broiler litter are not expected to affect its use as a manure fertilizer. The almost doubling of density from unprocessed to densified litter appears to create a viable method to promote transportation of litter to areas further from broiler production. Government programs and subsidies, manure markets, and other incentives along with densification could alleviate environmental concerns in production areas. While temperatures reached in individual densified litter blocks are well below wood's flash point and cause no concern for fire hazards, additional research on stacked densified litter blocks is needed to further assess fire concerns. Costs associated with densification should be evaluated with benefits to further determine the economical hauling distance.

Table 1. Comparison of unprocessed litter with (wet) and without (dry) additional moisture.

	Unprocessed Dry†		Unprocessed Wet†		
Variable	Mean	SE	Mean	SE	P-difference
C (g kg^{-1})	342	6	355	4	0.127
N (g kg^{-1})	38	0.00	38	0.00	0.558
NH_4-N (g kg^{-1})	4	0.2	4	0.09	0.114
NO_3-N (g kg^{-1})	0	0.5	0.6	0.2	0.301
P (g kg^{-1})	15	0.2	15	0.1	0.956
K (g kg^{-1})	37	0.5	37	0.4	0.833
Ca (g kg^{-1})	19	0.4	19	0.3	0.644
Mg (g kg^{-1})	7	0.5	7	0.03	0.747
Cu (mg kg^{-1})	461	21	405	15	0.070
Fe (mg kg^{-1})	695	87	527	61	0.156
Na (mg kg^{-1})	9597	122	9440	87	0.331
Zn (mg kg^{-1})	633	8	644	5	0.265
EC (dS m^{-1}) (1:10)	7.3	0.1	7.0	0.1	0.048
pH (1:3)	7.5	0.1	7.6	0	0.080

† All means on dry-weight basis

Table 2. Differences between unprocessed litter and densified litter samples upon initial densification of samples (Time Zero).

	Unprocessed		Densified		
Variable	Mean	SE	Mean	SE	P-difference
C (g kg^{-1})	343	4	367	0	0.000
N (g kg^{-1})	38	0.1	39	0.1	0.003
NH_4-N (g kg^{-1})	4	0.2	4	0.1	0.343
NO_3-N (g kg^{-1})	0	0.1	0.8	0.1	0.012
P (g kg^{-1})	15	0.07	14	0.1	0.030
K (g kg^{-1})	37	0.4	38	0.5	0.347
Ca (g kg^{-1})	19	0.2	18	0.3	0.048
Mg (g kg^{-1})	7	0.03	7	0.05	0.848
Cu (mg kg^{-1})	452	5	366	6	0.000
Fe (mg kg^{-1})	691	10	366	14	0.000
Na (mg kg^{-1})	9583	72	9311	101	0.064
Zn (mg kg^{-1})	645	5	631.7	7.2	0.176
EC (dS m^{-1}) (1:10)	7.2	0.1	7.1	0.1	0.563
pH (1:3)	7.6	0.1	7.5	0.1	0.665

Table 3. Potential C and N mineralization, C turnover, and C:N mineralized as affected by litter additions to soil.

	C mineralization (mg kg^{-1})		C turnover (%)		N mineralization† (mg kg^{-1})		C:N mineralized	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Soil + densified litter	28.7	1.7	0.010	<0.001	0	0.14	0	<0.001
Soil + raw litter	34.7	1.7	0.012	<0.001	0	0.14	0	<0.001
Control	4.8	1.7	0.003	<0.001	3.3	0.14	0.001	<0.001
P-difference[‡]	0.219		0.041		NS[#]		NS	
P-difference[§]	0.00		<0.001		<0.001		0.007	
P-difference[¶]	0.00		<0.001		<0.001		0.007	

†No Net N mineralization for litter
[‡]P-difference for comparison of two parameter means (densified and raw)
[§]P-difference for comparison of two parameter means (densified and soil)
[¶]P-difference for comparison of two parameter means (raw and soil)
[#]NS, not significant for α=0.05

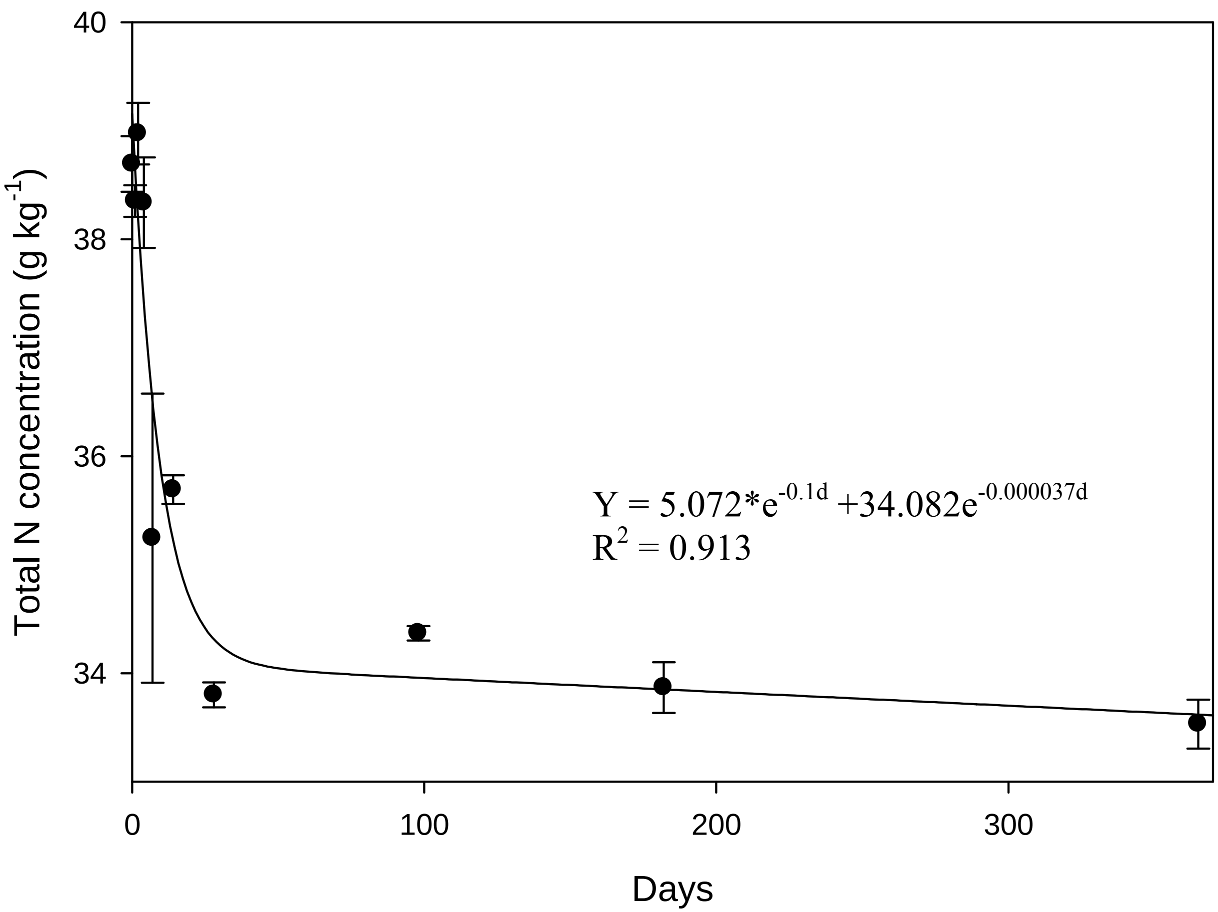

Figure 1. Change in densified litter total nitrogen concentration over a one year period.

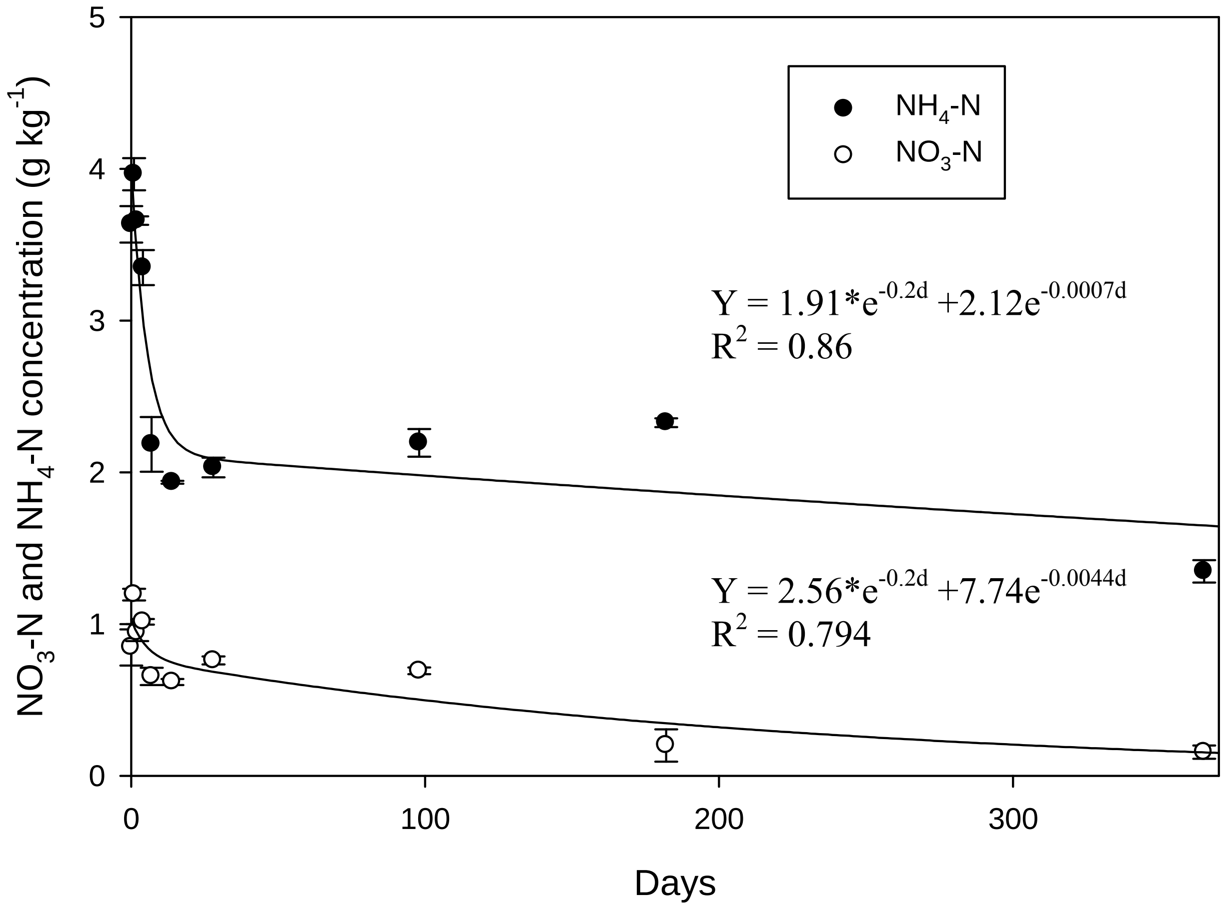

Figure 2. Change in densified litter ammonium and nitrate-nitrogen concentration over a one year period.

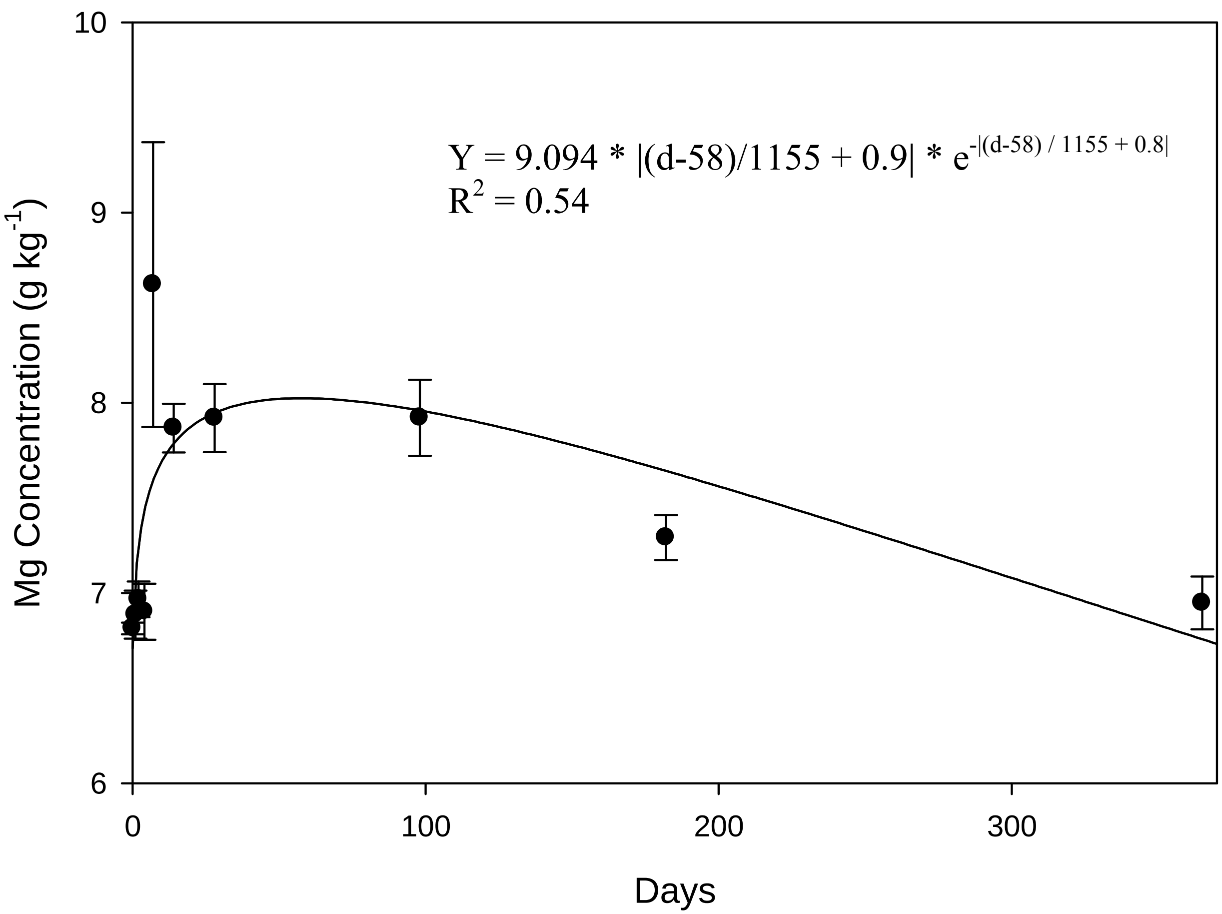

Figure 3. Change in densified litter magnesium concentration over a one year period.

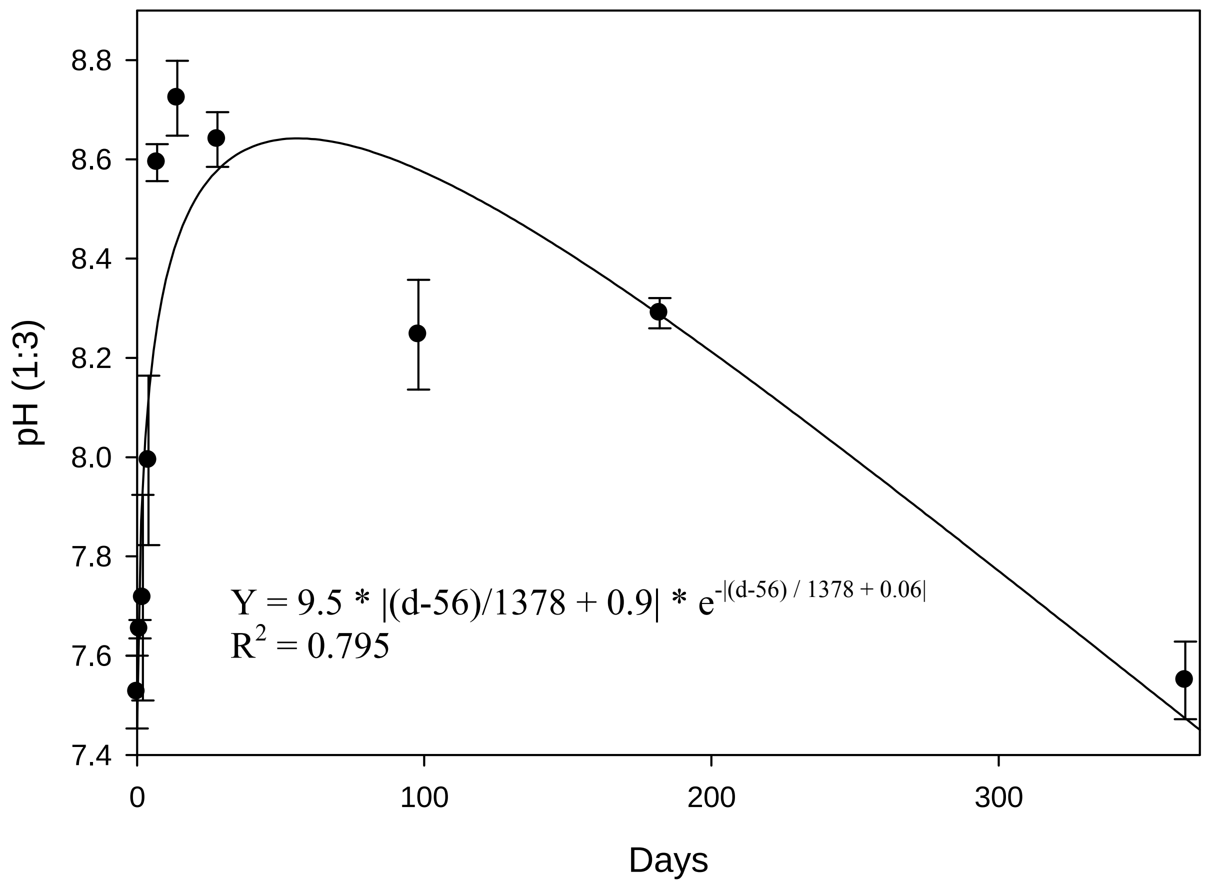

Figure 4. Change in densified litter pH over a one year period.

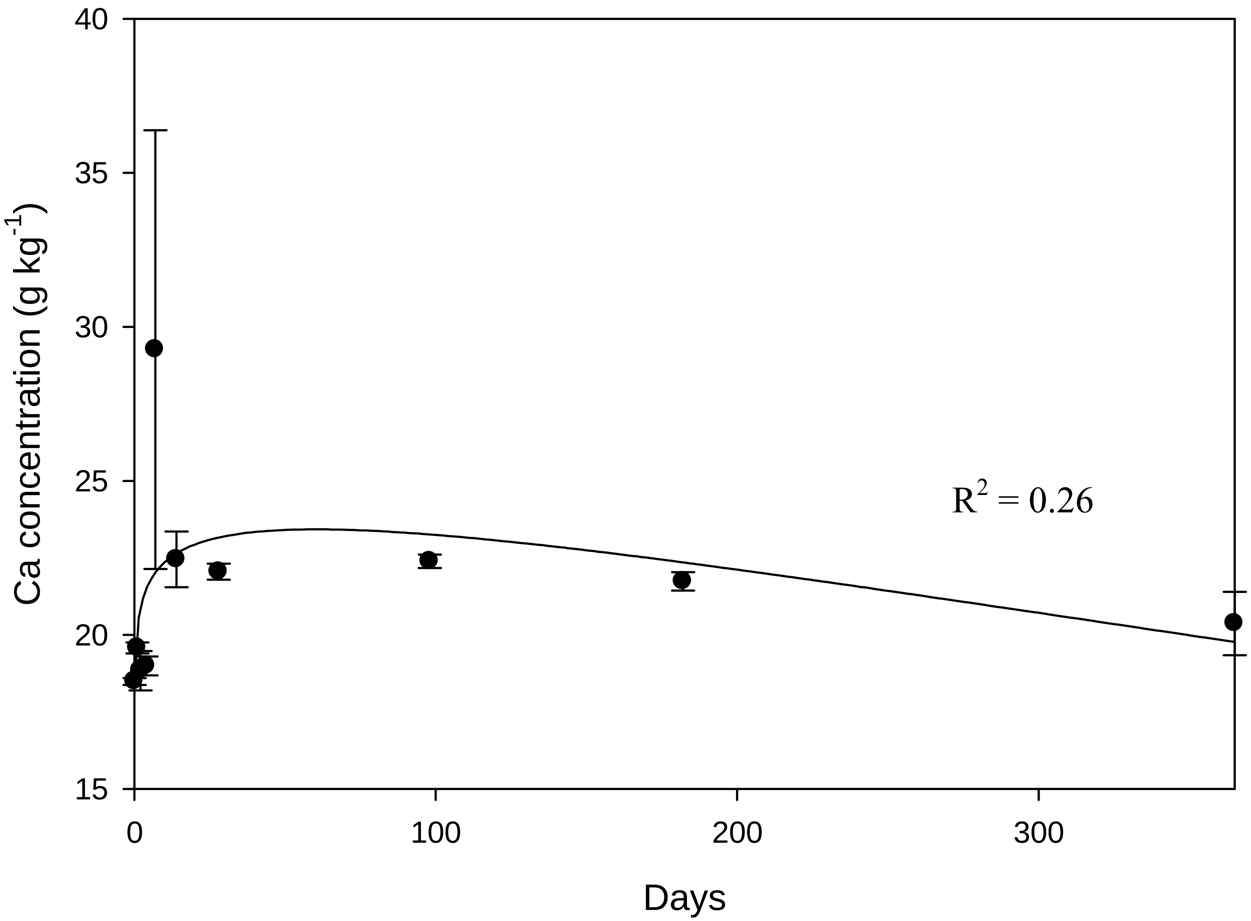

Figure 5. Change in densified litter calcium concentration over a one year period.

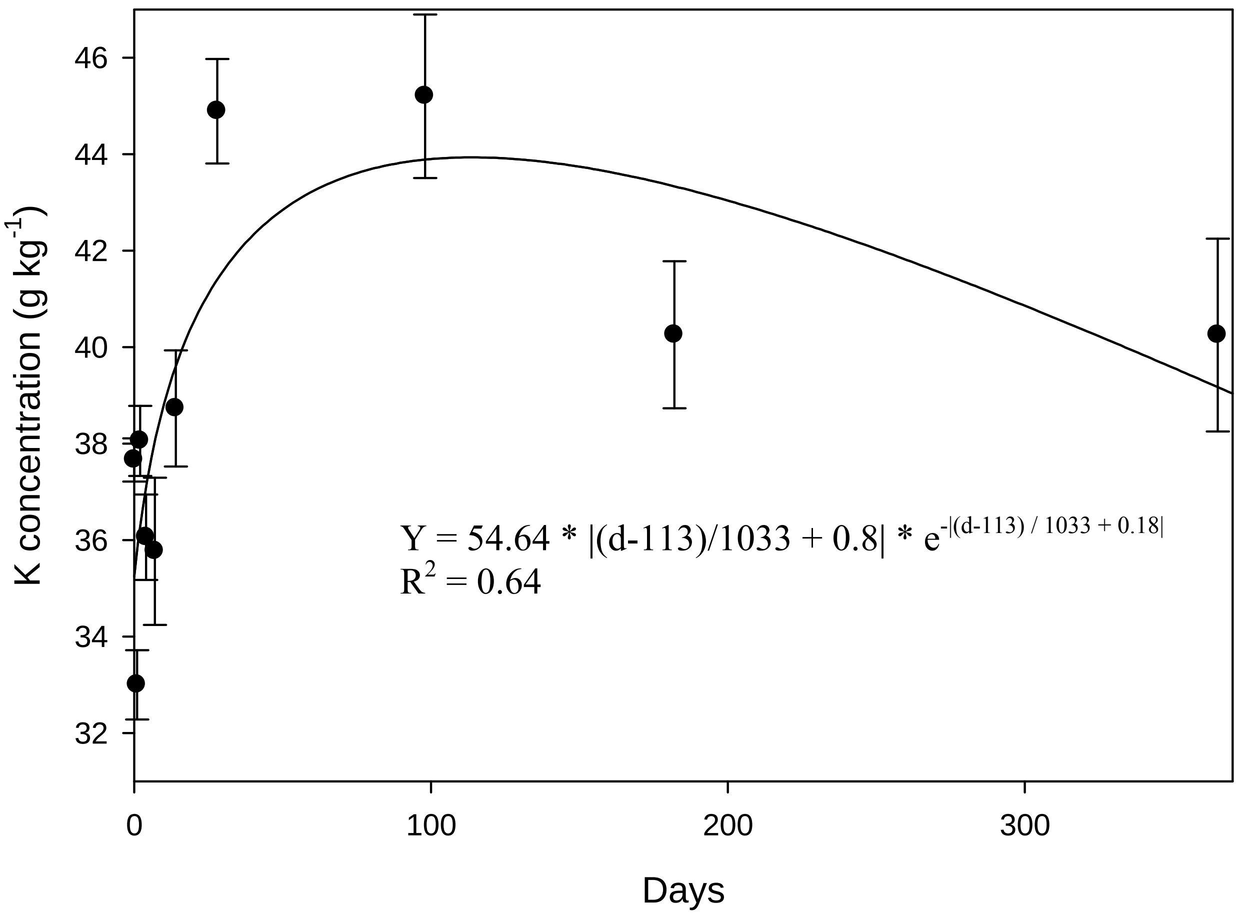

Figure 6. Change in densified litter potassium concentration over a one year period.

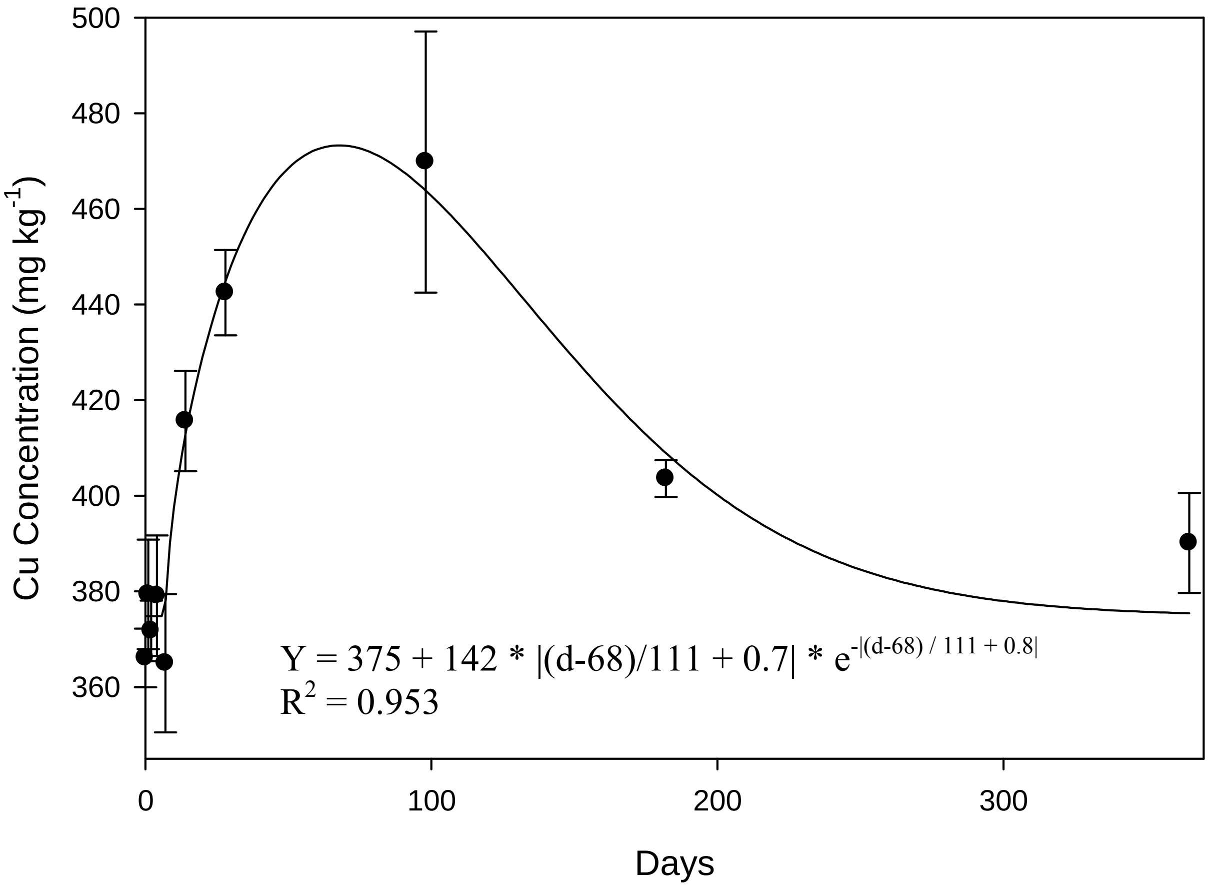

Figure 7. Change in densified litter copper concentration over a one year period.

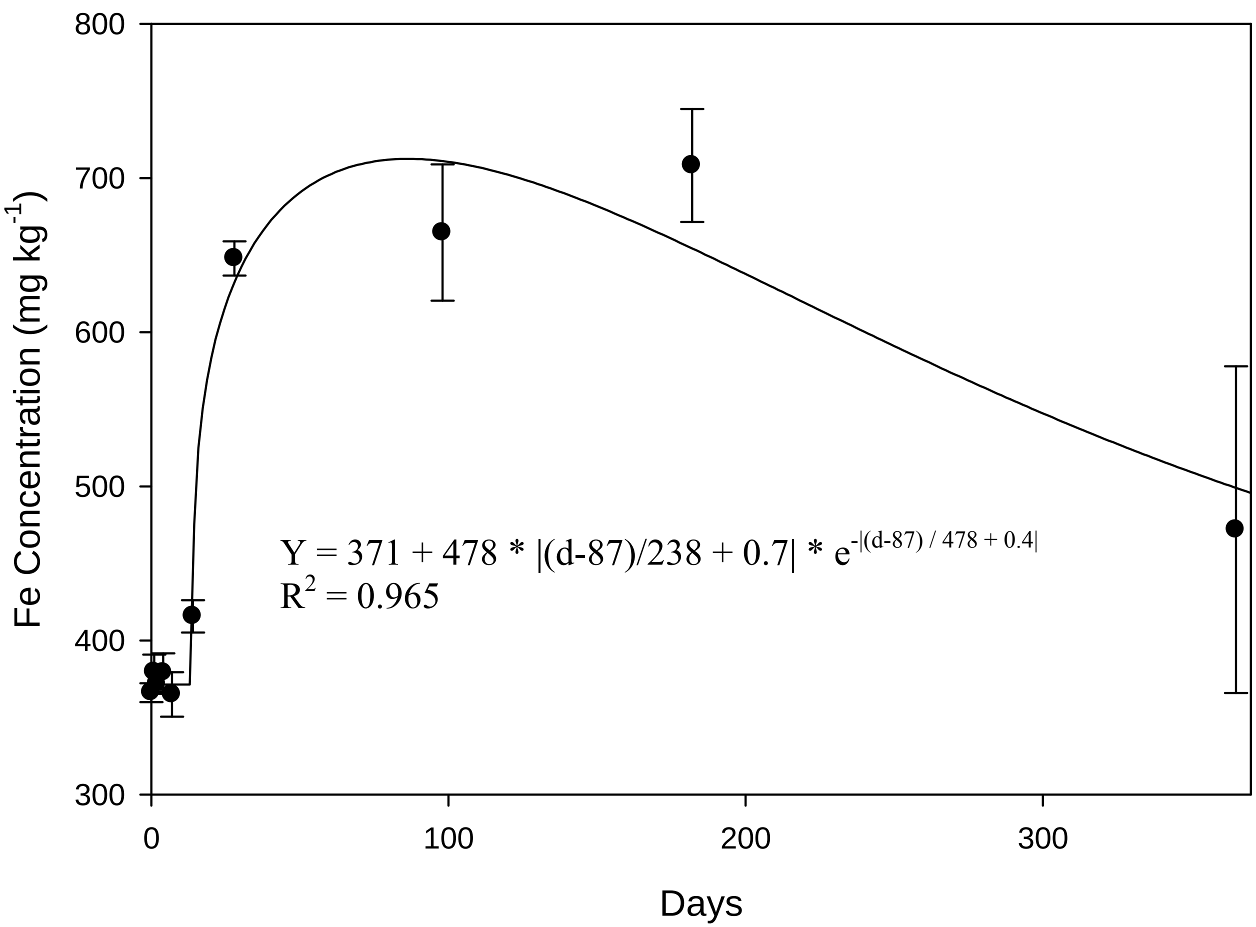

Figure 8. Change in densified litter iron concentration over a one year period.

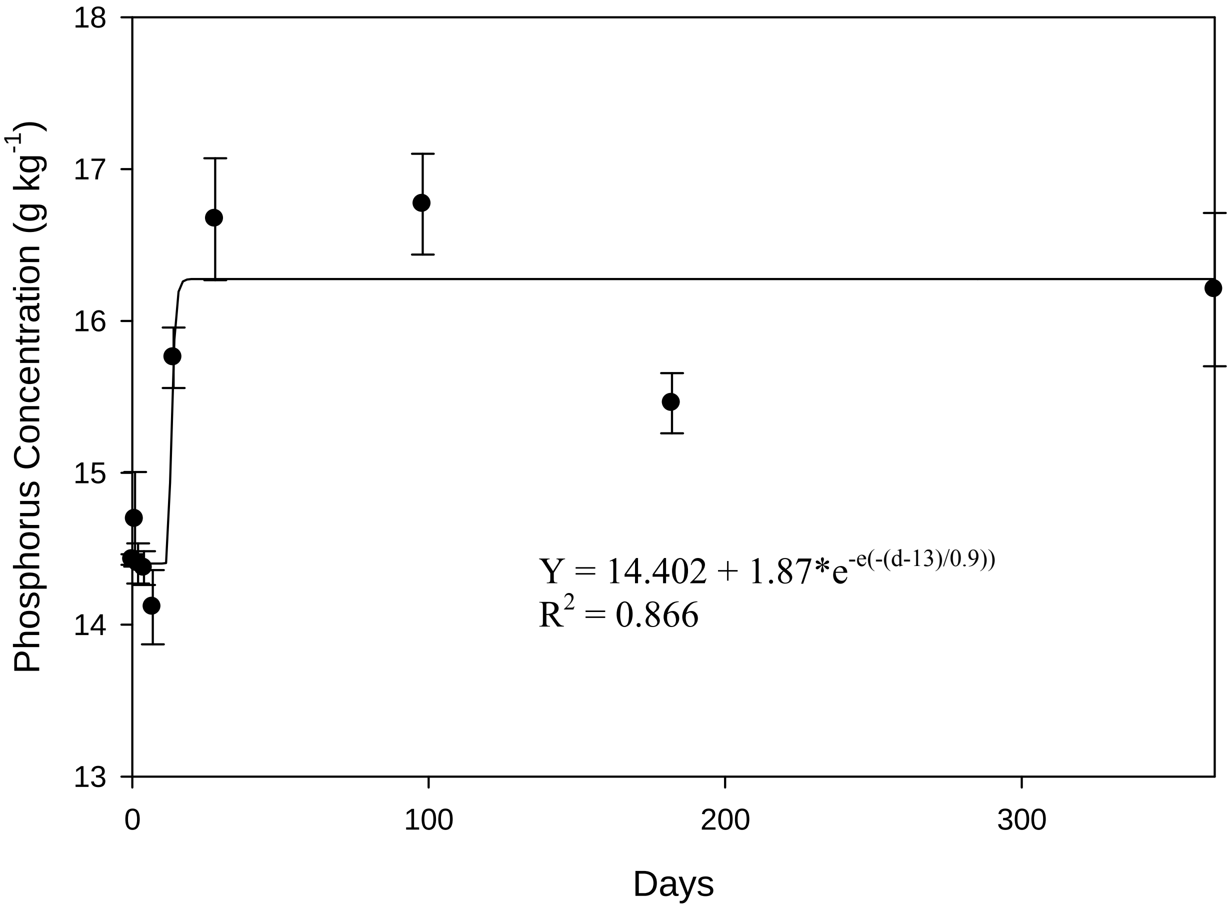

Figure 9. Change in densified litter phosphorus concentration over a one year period.

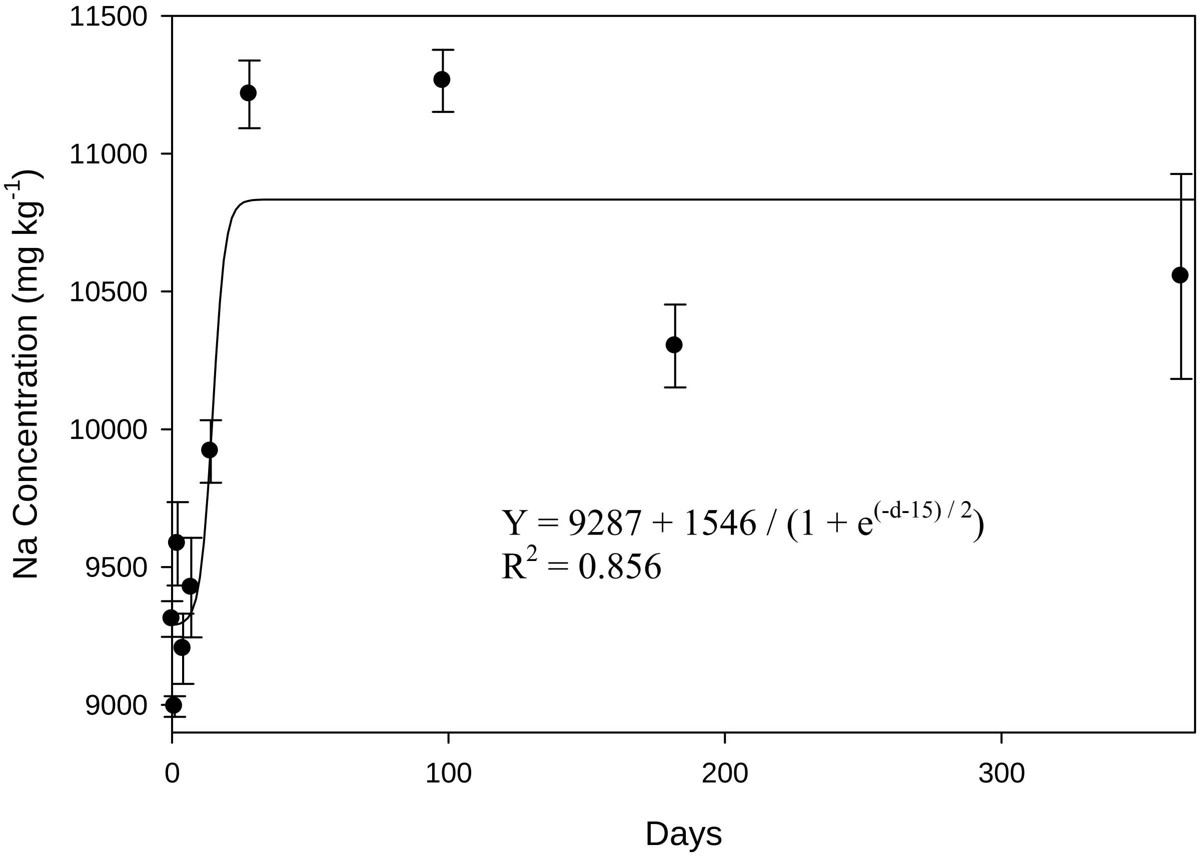

Figure 10. Change in densified litter sodium concentration over a one year period.

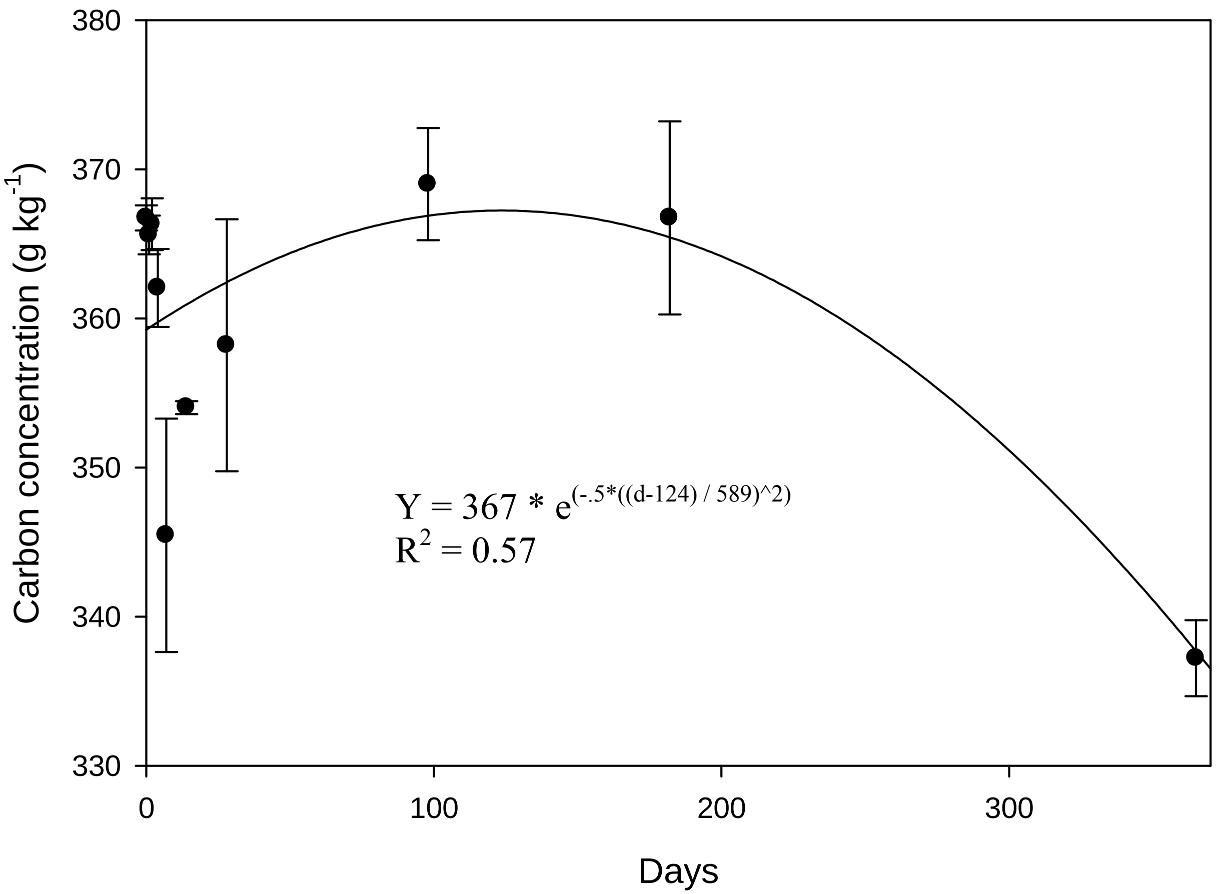

Figure 11. Change in densified litter carbon concentration over a one year period.

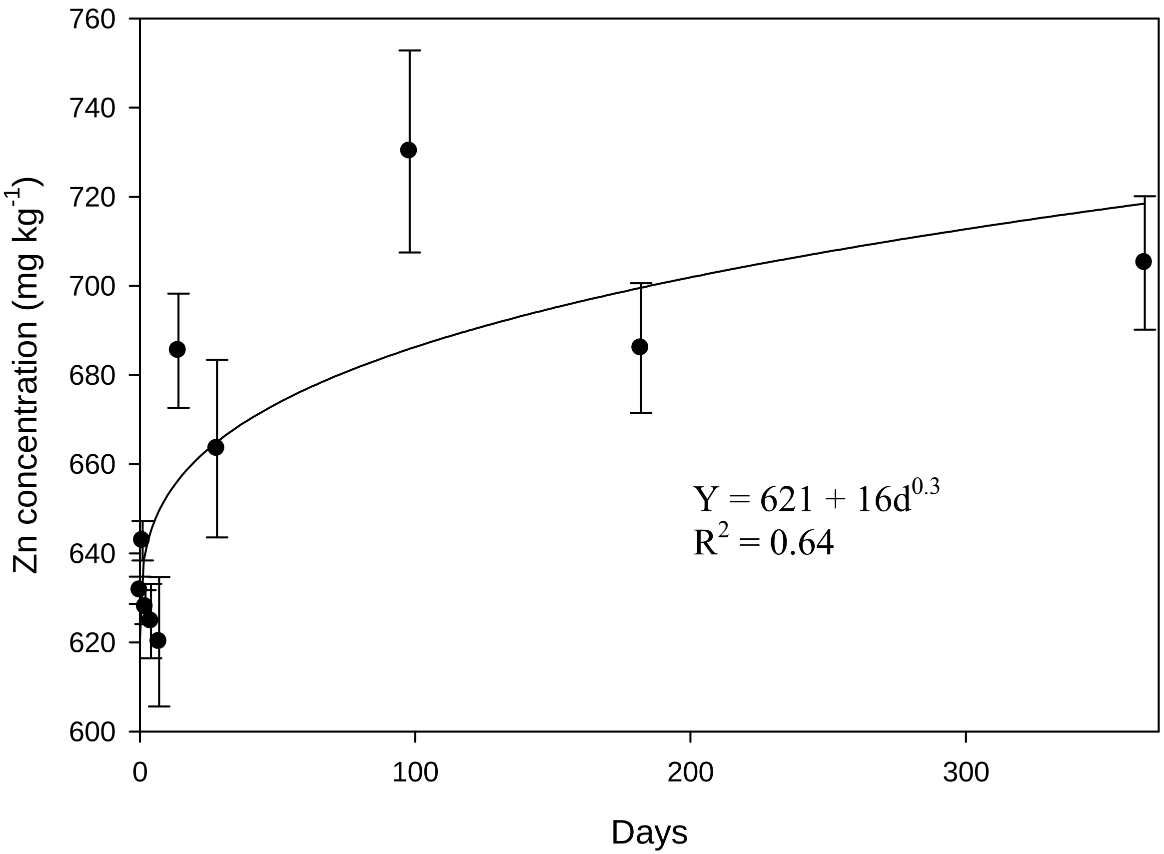

Figure 12. Change in densified litter zinc concentration over a one year period.

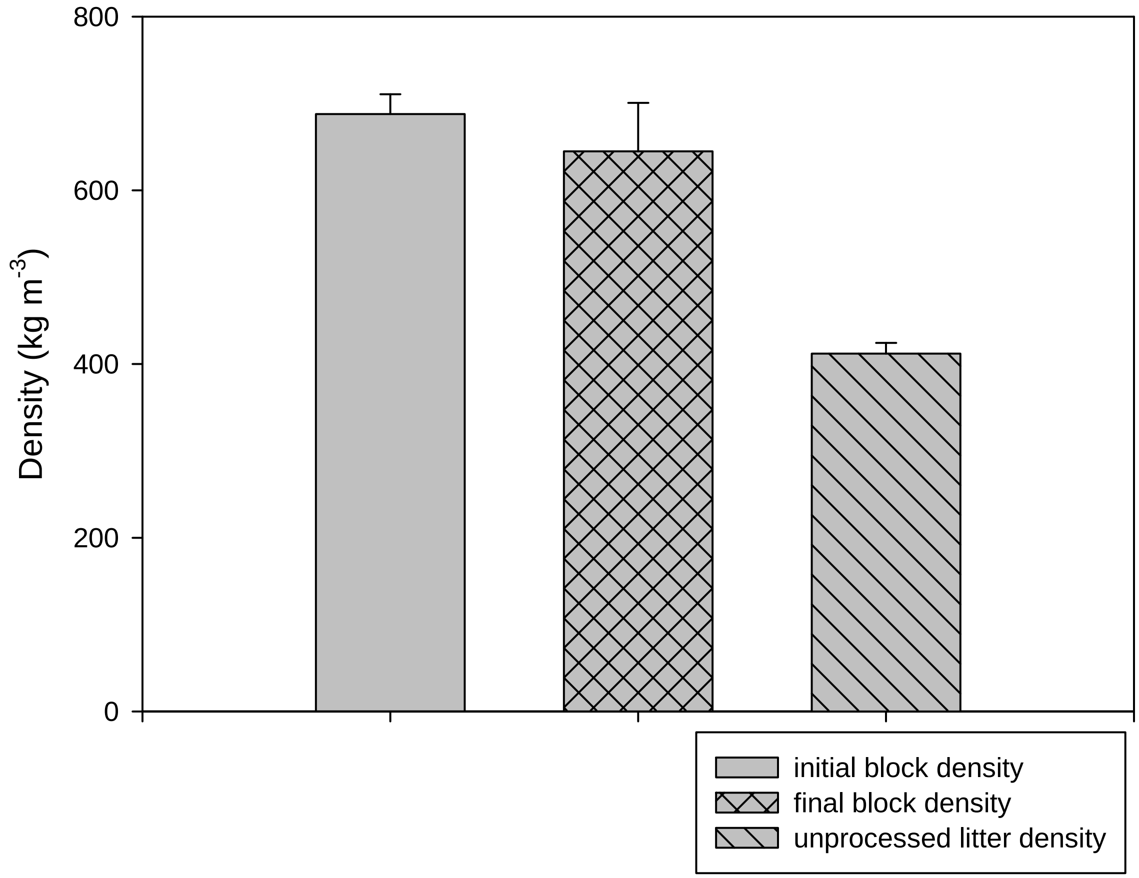

Figure 13. Average broiler litter density before compaction (unprocessed), after initial compaction and at sampling (final).

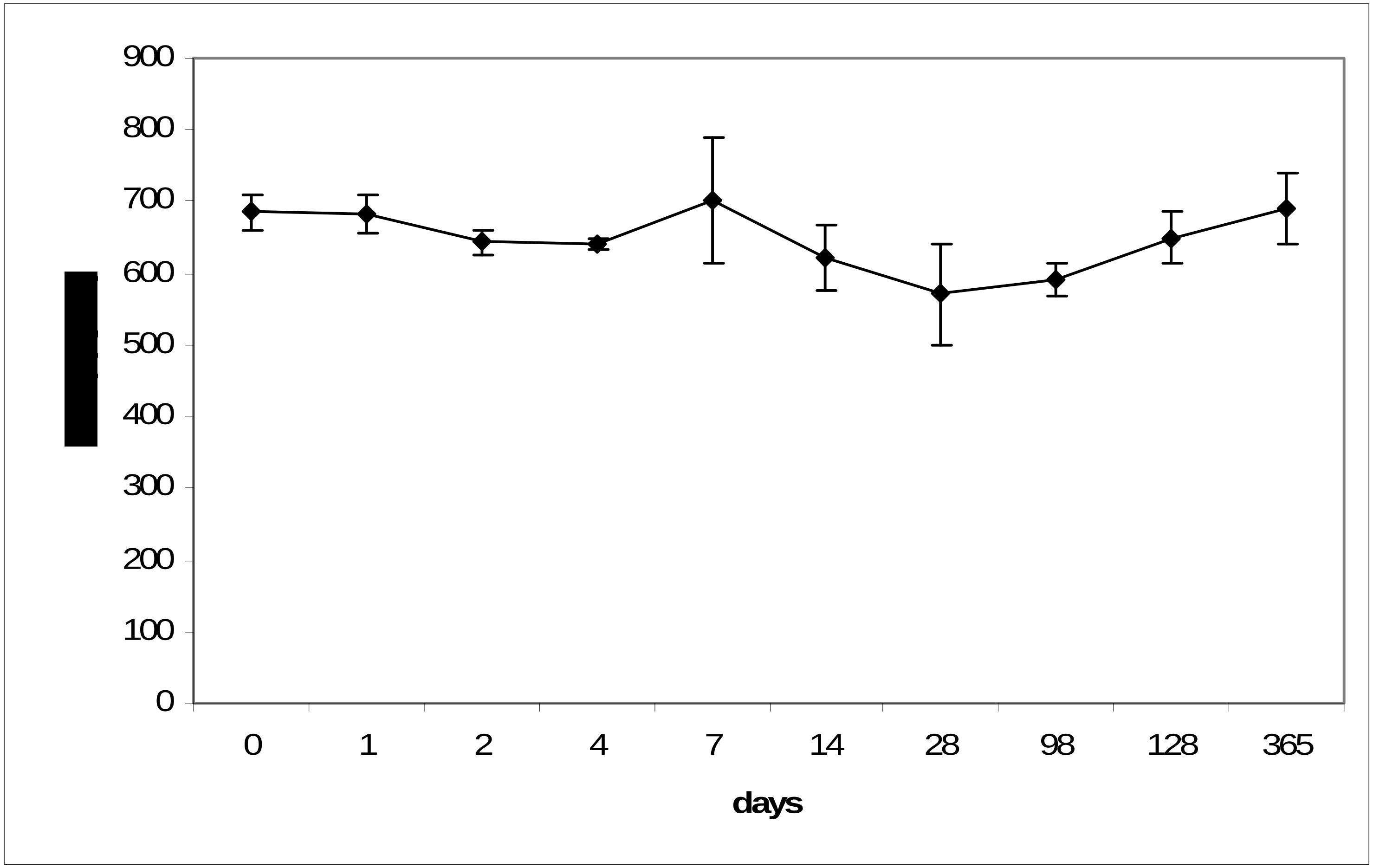

Figure 14. Change in densified litter density over a one year period.

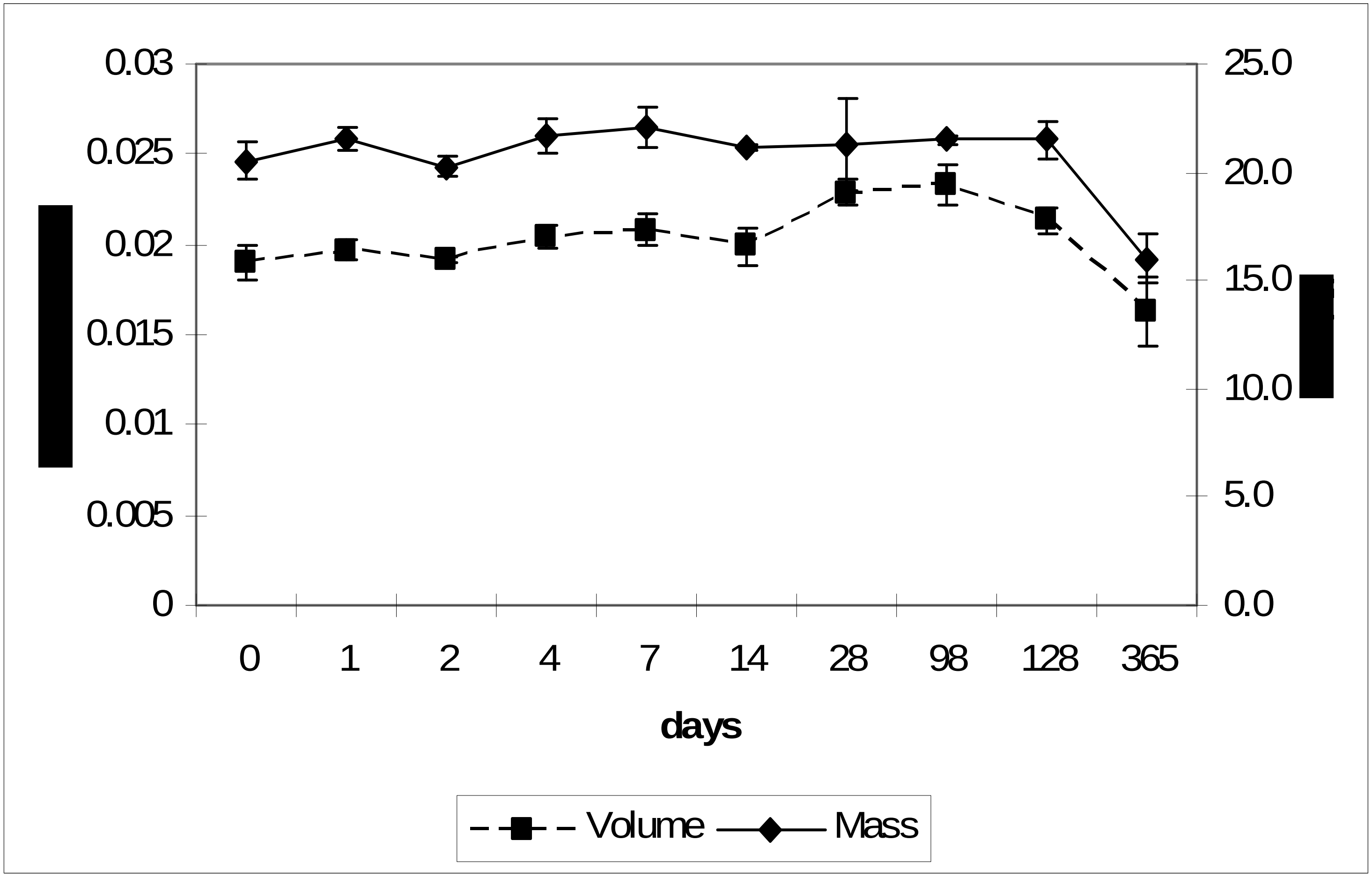

Figure 15. Change in densified litter mass and volume by sampling day over a one year period.

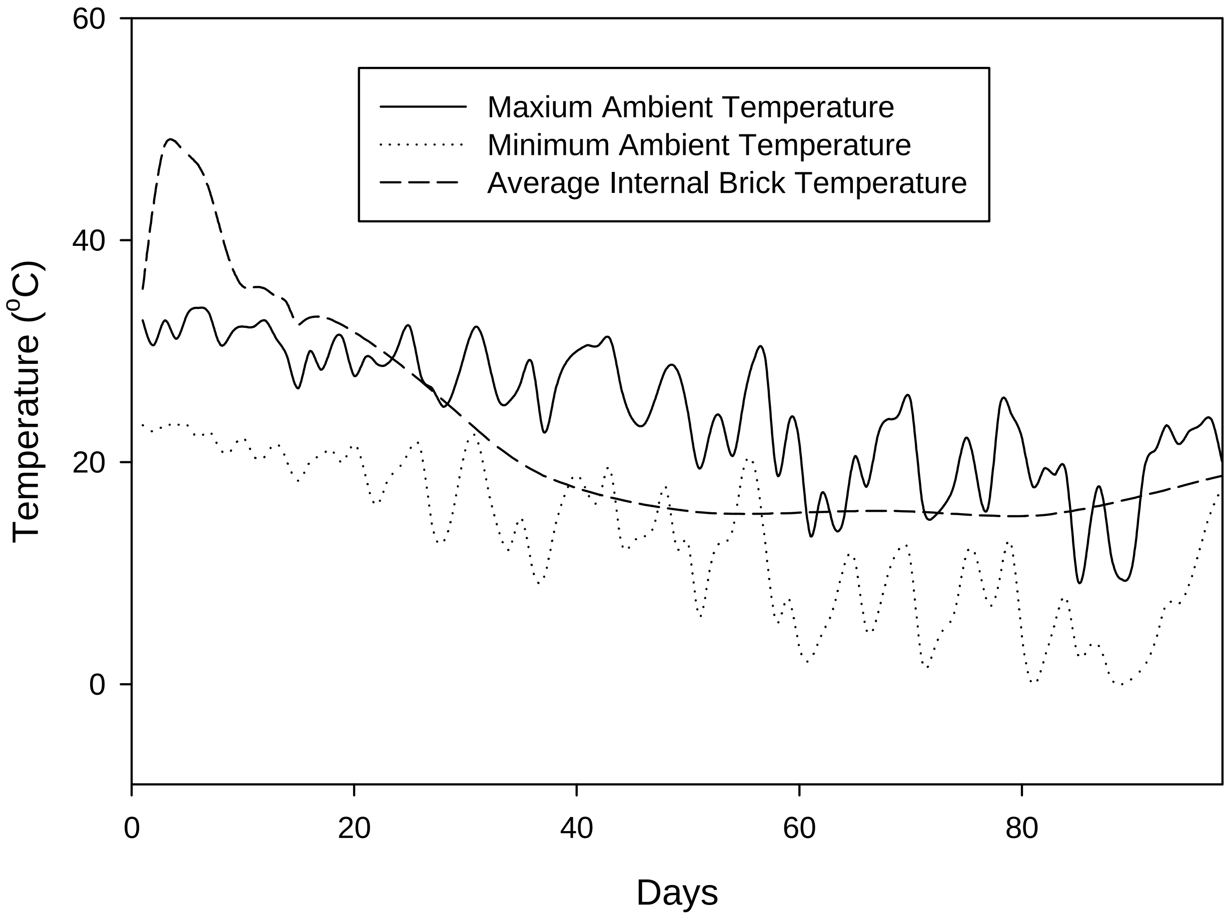

Figure 16. Ambient air temperature and internal densified litter temperature over 98 days

III. EFFECT OF DENSIFIED BROILER LITTER ON YIELD AND NUTRIENT UPTAKE OF TALL FESCUE IN THE BLACK BELT

Abstract

Broiler chicken (*Gallus gallus domesticus*) litter has long been shown to improve soil quality by reducing soil acidity and erosion, increasing soil moisture holding capacity, soil cation exchange capacity, and increasing pasture productivity. However, environmental problems associated with over-application have been noted in areas with high broiler production. Improved economics in litter transport to areas of low broiler production are possible with densification. This study was conducted to determine the effects of densified litter on tall fescue (*Festuca arundinacea* Schreb.) pastures in the Black Belt region of Alabama. Broiler litter was subjected to 193 MPa of pressure and compacted into 30.5 x 30.5 x 20 cm blocks. After five days, blocks were mulched to facilitate application on field plots. Two fescue cultivars, AU Triumph and Max Q, were fertilized with densified litter, unprocessed litter, or commercial fertilizer on plots that included clover or not. All litter fertilizer was applied based on soil test phosphorus (P) recommendations and nutrients lacking in the soil amendments (e.g., nitrogen (N)) were applied as commercial fertilizer to soil test recommendations. Interactions between clover management, cultivar, and year were significant. Plots with clover had higher plant tissue nutrient concentrations and uptake than those without clover. Max Q fescue

plots with clover had higher plant tissue nutrient concentrations and uptake than AU Triumph fescue. Dry matter yield was greater in 2007 than 2008, owing to harsh climatic conditions with high temperatures and little rainfall in 2008. Overall, densified litter remains a viable substitute for unprocessed litter as differences between the fertilizer types were small and unlikely to affect the agronomic use of broiler litter.

Introduction

The Alabama poultry industry ranks third nationally in broiler production with over one billion birds marketed in 2006 (AASS, 2007). The top three counties in the state, producing thirty-one percent of the state's broilers, are located in the Sand Mountain region of Alabama (AASS, 2007). Broiler litter production in the state has been estimated at over two million Mg per year (Adhikara et al., 2001; Donald et al., 1996).

Animal waste has long been used as fertilizer (Sims, 1995). Broiler litter is considered a valuable manure fertilizer because of its low moisture content and high macronutrient content (Moore et al., 1995). Litter also reduces soil acidity (Wood, 1992), adds organic matter that can improve soil moisture and nutrient holding capacity (Evers, 1998; Sims, 1995), and increases organic carbon (C) content of soil which can decrease bulk density (Sharpley et al., 1993, Wood, 1992). Broiler litter application has been found to be beneficial for crops, increasing yield of several crops including corn (*Zea mays* L.), bermudagrass (*Cynolon dactylon* L. Pers.), and tall fescue (Evers, 1998; Hileman, 1965; Honeycutt et al., 1988). Additional yield the year after broiler litter application has been observed by Wood et al. (1993) and Evers (1998) and was attributed to increased soil organic matter, decreased soil acidity and additional mineralization of organic nitrogen (N). Under normal conditions, Wood et al. (1993) found that levels of nitrate in forage, which can cause nitrate poisoning in farm animals, was well below the critical limit.

Because it is uneconomical to transport broiler litter more than 10-20 km from broiler production sites, excessive application on cropland has caused environmental concerns including nitrate contamination of groundwater and accumulation of P in soil (Moore et al., 1995; Nayakatawa et al., 2001; Sharpley et al., 2003; Daniels et al., 1998). Densification could allow transport further from production sites to soils with low soil test P, alleviating environmental concerns. This study was performed to determine differences in yield and plant uptake among densified broiler litter, unprocessed broiler litter and commercial fertilizer treatments in the Black Belt region of Alabama.

Materials and Methods

A field experiment was conducted over two growing seasons at the Black Belt Research and Extension Center in Marion Junction, Alabama (32°28'50.29"N, 87°15'26.61"W, 57 m above MSL). The experimental design was a randomized complete block with a split-split plot restriction on randomization. Grass cultivars were main plots, clover or no clover were subplots, and soil amendments were sub-subplots. Tall fescue cultivars included Max Q (Lot # L29-6-172 200612420148 677 and Lot # L29-6-172 200612420148 583) and AU Triumph (LA5-6-3). The clover cultivar was Regal Graze Ladino Clover (*Trifolium repens* L., Lot # 9714 27C0005557) and soil amendments included unprocessed broiler litter, densified block broiler litter, and commercial fertilizer. Each treatment was replicated four times for a total of 144 sub-subplots with an individual plot size of 3 m x 6 m.

Litter Densification

Broiler chicken (*Gallus gallus domesticus*) litter was collected from a producer in Talladega County, Alabama and transported to Auburn, Alabama. Prior to densification, initial moisture content of litter was determined using a Model IR-200 moisture analyzer (Denver Instruments, Arvada, CO). Water was then added and mixed with litter using a concrete mixer to bring the moisture content to 400 g kg^{-1}. This moisture content was found in initial trials to be optimal for densification. Litter was subjected to approximately 193 MPa of pressure for one minute increments until four layers of litter were compacted into a cube approximately 30.5 x 30.5 x 20 cm. Blocks were stored for five days before they were chipped, transported to Marion Junction, and applied.

Fertilization

Fertilizer requirements for the study (commercial fertilizer, unprocessed litter, and block litter) were determined using soil test recommendations (Tables 4 and 5). Litter and fertilizer were weighed and labeled prior to transport to the Black Belt region. Prior to initial fertilization and planting, existing grasses and weeds were killed with glyphosate. All plots were seeded according to recommended rates. Plots were fertilized with densified litter, unprocessed litter, or commercial fertilizer. All litter fertilizer was applied based on soil test P recommendations and nutrients lacking in the soil amendments (e.g. N) were applied as commercial fertilizer to soil test recommendations. Commercial fertilizer used included ammonium nitrate and diammonium phosphate (Table 5). Table 6 shows selected characteristics of broiler litter by year collected as applied. All fertilizer was applied by hand and incorporated before initial planting. Consecutive year fertilizer applications were broadcast by hand onto the soil surface.

Harvest

Plots were harvested using a flail-chopping mower cut to a simulated grazing management height of approximately 10 cm. Grasses were harvested at early heading both years. Freshly cut forage was immediately weighed on a portable scale for yield and subsamples were placed in tared brown paper bags and weighed for fresh weight. Samples were dried at 60^{o} C for 48 hr for dry weight determination. Dry matter (DM) yield was then calculated for each sub-subplot.

Nutrient Uptake

Nutrient concentration in plant tissue was determined by grinding dried plant samples to pass a 1 mm mesh screen using a Wiley Mill. Total C and N were determined via dry combustion on a LECO TruSpec CN analyzer (St. Joseph, MI). For P, potassium (K), calcium (Ca), copper (Cu), and zinc (Zn) determination, samples were dry-ashed, evaporated with 10 mL 1*N* HNO_3, then dissolved with 10 mL 1*N* HCl (Hue and Evans, 1986). Total P, K, Ca, Cu, and Zn were measured using inductively coupled plasma (ICP) spectroscopy (Spectro Ciros CCD, Germany). Nutrient uptake was calculated as the product of forage nutrient concentration and DM yield.

Statistical Analysis

Statistical analyses for nutrient concentration, uptake, and DM yield were performed using the ProcGlimmix procedure (SAS Institute, 2003) for a split-split plot design for all sub-subplots in each growing season and all years combined. Sources of variation included cultivar, fertilizer, clover management, year, and their interactions. All variables were analyzed and non-significant interactions were eliminated consecutively from the model. All statistical analyses were performed at $\alpha = 0.10$ significance level. Where interactions were significant, main effects were not discussed.

Results and Discussion

Tables 7 and 8 present *P* values for DM yield, and selected nutrient concentrations and uptake, considering main effects and interactions among sources of variation. Most nutrient concentrations were affected by two way interactions between cultivar, clover management, fertilization and year. Fewer interactions affected nutrient uptake than nutrient concentration (Table 8).

Dry Matter Yield

Forage production was limited in 2007 and 2008 due to below average rainfall at the study location during the past three years (Fig. 19). Rainfall totals for the growing seasons (80 cm and 74 cm, respectively) were well below 76-year rainfall averages of 134 cm. Dry matter yield was higher in 2007 than 2008 (Figs.17 and 18). High summer temperatures and drought conditions resulted in poor growth during the fall of 2007 and lower yields in 2008. Dry matter yield was not affected by fescue cultivar, presence of clover or fertilizer type (Table 7). Evers (2002) found similar results for ryegrass and bermudagrass when forage was limited by rainfall. Interactions among N fertilizer and broiler litter treatments did not affect yield of either grass in that study (Evers, 2002).

Nutrient Uptake

Nitrogen Concentration and Uptake

Nitrogen concentration and uptake were greater in plots seeded with clover than without clover (Table 9). Clover (*Trifolium* repens) is commonly inter-seeded with grass species to obtain higher yields without the use of N fertilizer (Ball, 2002).

Nitrogen concentration and uptake were affected by the interaction of cultivar, fertilization, and year (Tables 7 and 8). In 2007 and 2008, Max Q plots had greater N concentration than AU Triumph plots among all fertilizer types (Table 10). In 2008, there was no significant difference in N concentration for densified litter and unprocessed litter applied on Max Q plots. Table 11 shows N uptake by cultivar, fertilization, and year. In 2007, Max Q plots had higher N uptake across all fertilizer types. In 2008, there were no significant differences in N uptake among fertilizer types (Table 11). A similar study by Brye et al. (2006) found that N release and uptake by rice was unaffected by litter type, fresh or pelletized.

Phosphorus Concentration and Uptake

Table 12 presents P concentrations as affected by clover management and year. In 2008, plots with clover had significantly greater concentrations of P. The Brink et al. (2001) findings show typical results of legume P concentrations exceeding that of temperate grasses. Phosphorus uptake was also affected by clover management and year as plots in 2008 had greater P uptake than in 2007 (Table 13). Since P is essential for animal growth, mixed grass pastures of tall fescue-clover could increase P available for animal digestion (Ball, 2002).

Potassium Concentration and Uptake

Potassium concentrations were affected by interactions between clover management and year (Table 14). Fertilization by year interaction was significant for K concentration in plant tissue. Comparisons within years show differences between unprocessed litter and commercial fertilizer in 2007 and between both litter types and commercial fertilizer in 2008, with commercial fertilizer having the greatest nutrient uptake in both years (Table 16). Plant tissue K concentration was greater for plots receiving broiler litter than those receiving commercial fertilizer for both years. Differences were not found for comparisons of unprocessed broiler litter between years, though plots receiving densified broiler litter in 2008 had higher K concentrations than densified broiler litter plots in 2007. Potassium concentrations of densified broiler litter were lower than unprocessed broiler litter for both years with unprocessed broiler litter > densified broiler litter > commercial fertilizer. A four way interaction of fertilizer, cultivar, clover management and yield was found for K uptake. Table 16 shows K uptake estimates by year, cultivar, fertilizer, and clover management. In 2008, plots fertilized with densified and unprocessed broiler litter had significantly higher K uptake than those applied with commercial fertilizer. In both years, plots fertilized with unprocessed broiler litter had slightly greater K uptake than those fertilized with densified broiler litter or commercial fertilizer. Warman and Cooper (2000) found similar results in a study of the effects of fresh and composted chicken manure on plant uptake, where K content in plant tissue increased linearly with compost and manure applications rates while decreasing linearly with commercial fertilizer application rates. Though high K levels in forages can inhibit Ca and Mg uptake, causing grass tetany in ruminants, Tewolde et al. (2005) found that plant reproductive parts do not accumulate K beyond what is necessary for plant growth, regardless of litter application rate. Densified broiler litter could, however, help reduce the risk of grass tetany in livestock by reducing the amount of K concentration and uptake in plants.

Calcium Concentration and Uptake

Interactions between clover management and year were significant for Ca concentration and uptake. Table 17 shows Ca concentrations by clover management and year. Significant differences were found between years with 2007 plots having higher Ca concentrations. In both years, plots with clover had higher Ca concentrations, and findings were similar for Ca uptake (Table 18). Plots with clover had significantly higher Ca uptake than those without clover, though no differences were found between years. Warman and Cooper (2000) found that plots fertilized with organic amendments tended to have higher legume cover than those fertilized with commercial fertilizer in mixed crop plots. Because legumes generally have higher tissue Ca than grasses, higher Ca concentration and uptake were found in plots with clover.

In comparisons between cultivar and year, both cultivars had greater Ca uptake in 2007 than 2008, while no differences were found between cultivars within years (Table 15). Because rainfall was limited during the study period, Ca uptake differences between years could be due to inadequate rainfall during growth.

Copper Concentration and Uptake

Interactions between cultivar, clover management and year were significant for Cu concentrations in plant tissue (Table 20). Plots with clover had significantly higher Cu concentrations than those without clover. Both cultivars had greater Cu concentrations in 2008 than 2007. In 2007, AU Triumph plots that contained clover had significantly greater Cu concentrations than those without clover. Max Q plots had similar results for 2008. Clover has been found to have greater Cu concentrations than grasses such as ryegrass, which may explain the increased Cu concentration in plots where clover was planted (Brink et al., 2001).

Similarly, Cu uptake was significant for the three-way interaction of cultivar, clover management and year. Plots with clover had higher Cu uptake than those without clover (Table 21). Though, actual differences in Cu uptake among clover management, cultivars, and years were extremely small. Though levels of Cu were higher plots with clover, concentrations do not exceed tolerable levels for cattle of 115 ppm (National Research Council, 2000).

Broiler litter and densified broiler litter did not increase tissue Cu concentration and uptake. While Cu is added to broiler chicken feed to enhance growth (Arias and Koutsos, 2006), Cu concentration and uptake in this study was not different among fertilizer types.

Zinc Concentration and Uptake

Cultivar and year interactions affected Zn concentrations in plant tissue. Zinc concentrations in plant tissue were higher for both AU Triumph and Max Q fescue cultivars in 2008 than 2007 (Table 22). In 2008, Zn concentrations and uptake in AU Triumph were significantly greater than Max Q yields.

Differences were found among interactions of cultivar, clover management and fertilization for Zn uptake (Table 23). Max Q plots with clover which were fertilized with unprocessed litter had higher Zn uptake than those same plots applied with densified litter. Densified litter and commercial fertilizer plots had lower Zn uptake than plots fertilized with unprocessed litter for AU Triumph plots with no clover. There were no differences between Zn concentrations and uptake of littered and non-littered plots which is consistent with findings from Kingery et al. (1993), Warman and Cooper (2000), and Whittington et al. (2007). While Zn is added to broiler chicken feed to enhance weight gain, it did not increase Zn concentration and uptake to a harmful level for livestock (National Research Council, 2000). Though significant differences exist, they are extremely small and unlikely to impact the agronomic use of densified or unprocessed litter as a substitute for commercial fertilizer.

Conclusions

This study measured nutrient concentrations, uptake, and dry matter yield from plots fertilized with unprocessed broiler litter, densified broiler litter, and commercial fertilizer. Poor moisture conditions in both years could have contributed to differences in yield, nutrient concentrations, and uptake as Max Q fescue is more drought tolerant than AU Triumph. Interactions among fertilization, clover management, and cultivar should be considered when choosing proper pasture management. However, any differences in yield, nutrient concentration, or nutrient uptake owing to the treatment variables in this study were small and are not expected to have environmental, biological, or agronomic implications. Densified broiler litter is a good alternative to commercial fertilizer and, combined with clover management, could increase nutrient uptake of nutrients

Table 4. Soil Test Results and Recommendations for tall fescue at the study site.†

Soil Test Results					Recommendations			
pH	P‡	K‡	Mg‡	Ca‡	Limestone	N	P_2O_5	K_2O
	kg ha^{-1}				Mg ha^{-1}	kg ha^{-1}		
5.5	M 56	H 263	H 1769	8115	5.5	67	45	0

†Adapted from Auburn University Soil Testing Laboratory report

‡Extractable nutrients in kilograms per hectare

Table 5. Fertilization dates and application rates.

Date Fertilized	Fertilizer Type	N†	P‡	Manure Application Rate§
		--------------------------------kg ha^{-1}	-------------------------	
27 Nov 2006	Commercial Fertilizer	69	39	
	Densified Broiler Litter	15		1441
	Broiler Litter	15		1441
30 Oct 2007	Commercial Fertilizer	67	39	
	Densified Broiler Litter	25		1359
	Broiler Litter	25		1359

†N applied as 34-0-0

‡P applied as 18-36-0

§Manure rate on dry weight basis

Table 6. Selected characteristics of broiler litter by year as applied on P content and dry matter basis.

								Moisture Content	
	N	P	K	C	Ca	Cu	Zn	Unprocessed	Densified
	------------------g kg^{-1}------------------								
2006	37.7	14.7	37.3	352	18.3	0.37	0.63	240	410
2007	36.9	16.2	16.2	337	19.1	0.44	0.65	230	390

Table 7. Analysis of variance for tall fescue dry matter yield and tissue nutrient concentrations as affected by cultivar, fertilization, clover management, and year.

	DM Yield†	N	P	K	Ca	Cu	Zn
	P value						
Cultivar	0.682	0.055	0.117	0.361	0.044	0.247	0.100
Clover	0.951	0.031	0.497	0.883	0.001	0.019	0.021
Fertilizer	0.359	0.002	0.654	<0.001	0.305	0.423	0.386
Year	0.002	<0.001	<0.000	0.877	0.001	0.150	0.001
Cultivar x Fertilizer	0.804	0.977	0.706	0.372	0.248	0.404	0.978
Cultivar x Year	0.192	0.020	0.540	0.969	0.159	0.336	0.017
Clover x Year	0.622	0.159	0.054	0.050	0.000	0.310	0.508
Fertilizer x Year	0.144	0.109	0.395	<0.001	0.943	0.405	0.746
Cultivar x Fertilizer x Year	0.609	0.074	0.776	0.377	0.482	0.382	0.170
Cultivar x Clover x Year	0.917	0.295	0.506	0.704	0.217	0.017	0.483
Cultivar x Clover x Fertilizer	0.320	0.406	0.525	0.144	0.694	0.441	0.158
Cultivar x Fertilizer x Clover x Year	0.149	0.903	0.864	0.684	0.363	0.978	0.255

† Dry matter yield

Table 8. Analysis of variance for tall fescue nutrient uptake as affected by cultivar, fertilization, clover management, and year.

	N	P	K	Ca	Cu	Zn
			P value			
Cultivar	0.036	0.181	0.199	0.070	0.265	0.229
Clover	0.034	0.718	0.756	0.002	0.013	0.036
Fertilizer	0.242	0.361	<0.001	0.461	0.324	0.370
Year	0.048	0.010	0.002	0.001	0.648	0.420
Cultivar x Fertilizer	0.767	0.792	0.379	0.318	0.481	0.999
Cultivar x Year	<0.001	0.495	0.234	0.017	0.589	0.065
Clover x Year	0.154	0.052	0.065	<0.001	0.789	0.477
Fertilizer x Year	0.603	0.222	0.011	0.311	0.210	0.570
Cultivar x Fertilizer x Year	0.057	0.639	0.152	0.251	0.313	0.501
Cultivar x Clover x Year	0.374	0.277	0.941	0.502	0.025	0.600
Cultivar x Fertilizer x Clover	0.817	0.816	0.446	0.403	0.529	0.069
Cultivar x Fertilizer x Clover x Year	0.233	0.293	0.063	0.665	0.751	0.130

Table 9. Tall fescue N concentration and uptake for plots with and without clover at Marion Junction during 2007 and 2008.

	N (g kg^{-1})	N uptake (kg ha^{-1})
	Mean	Mean
Clover	19.0	2.5
No Clover	18.0	2.3
SE	3.1	0.08

Table 10. Tall fescue tissue N concentrations by cultivar, fertilization, and year at Marion Junction during 2007 and 2008.

	2007		2008	
Fertilizer	AU Triumph	Max Q	AU Triumph	Max Q
	------------------------------g kg^{-1}------------------------------			
Unprocessed Litter	15.0	17.0	20.6	21.0
Densified Litter	14.8	16.0	19.6	21.1
Commercial Fertilizer	14.9	17.3	22.1	22.1
$LSD_{0.1}$ †	0.1		0.1	

†LSD based on fertilizer by cultivar interaction

Table 11. Tall fescue N uptake by cultivar, fertilization, and year at Marion Junction during 2007 and 2008.

	2007		2008	
Fertilizer	AU Triumph	Max Q	AU Triumph	Max Q
	----------------------------kg ha^{-1}	------------------------------		
Unprocessed Litter	2.4	2.7	2.2	2.1
Densified Litter	2.5	2.7	2.0	2.2
Commercial Fertilizer	2.4	3.0	2.2	2.1
$LSD_{0.1}$†	0.2		0.2	

†LSD based on fertilizer by cultivar interaction

Table 12. Tall fescue tissue P concentrations by clover management and year at Marion Junction during 2007 and 2008.

	2007	2008
	------------g kg^{-1}------------	
Clover	1.2	2.8
No Clover	1.3	2.7
$LSD_{0.1}$†	0.1	

†LSD based on clover management by year interaction.

Table 13. Tall fescue P uptake by clover management and year at Marion Junction during 2007 and 2008.

	2007	2008
	----------------kg ha^{-1}---------------	
Clover	0.2	0.3
No Clover	0.2	0.3
$LSD_{0.1}$ [†]	0.01	

[†] LSD based on clover management by year interaction.

Table 14. Tall fescue tissue K concentrations by clover management and year at Marion Junction during 2007 and 2008.

	2007	2008
	----------------g kg^{-1}----------------	
Clover	14.8	15.4
No Clover	15.3	14.8
$LSD_{0.1}$†	0.9	

†LSD based on fertilizer by cultivar interactio

Table 15. Tall fescue tissue K concentrations by fertilization and year at Marion Junction during 2007 and 2008.

Fertilizer	2007	2008
	---------------------------g kg^{-1}---------------------------	
Unprocessed Litter	16.3	17.0
Densified Litter	15.0	16.5
Commercial Fertilizer	13.7	11.8
$LSD_{0.1}$ †	0.8	

†LSD based on fertilizer by year interaction.

Table 16. Tall fescue K uptake as affected by cultivar, fertilization, clover management, and year at Marion Junction during 2007 and 2008.

	2007					
	AU Triumph			Max Q		
	Unprocessed Litter	Densified Litter	Commercial Fertilizer	Unprocessed Litter	Densified Litter	Commercial Fertilizer
	--kg ha^{-1}--					
Clover	2.5	2.3	2.2	2.7	2.5	2.3
No Clover	2.6	2.7	2	2.7	2.5	2.6
$LSD_{0.1}$ †	0.29					
	2008					
	AU Triumph			Max Q		
	Unprocessed Litter	Densified Litter	Commercial Fertilizer	Unprocessed Litter	Densified Litter	Commercial Fertilizer
	--kg ha^{-1}--					
Clover	1.8	1.8	1.1	1.9	1.7	1.2
No Clover	1.7	1.6	1.2	1.7	1.7	1.1
$LSD_{0.1}$ †	0.29					

†LSD based on clover management by cultivar by year interaction.

Table 17. Tall fescue tissue Ca concentrations by clover management and year at Marion Junction during 2007 and 2008.

	2007	2008
	-----------------g kg^{-1}-----------------	
Clover	7.0	4.0
No Clover	5.4	3.8
$LSD_{0.1}$†	0.3	

†LSD based on clover management by year interaction.

Table 18. Tall fescue Ca uptake by clover management and year at Marion Junction during 2007 and 2008.

	2007	2008
	----------------kg ha^{-1}------------	
Clover	1.2	0.4
No Clover	0.9	0.4
$LSD_{0.1}$†	0.06	

†LSD based on clover management by year interaction.

Table 19. Tall fescue Ca uptake by cultivar and year at Marion Junction during 2007 and 2008.

	2007	2008
	---------kg ha^{-1}-------	
AU Triumph	1.0	0.4
Max Q	1.1	0.4
$LSD_{0.1}$ †	0.06	

†LSD based on cultivar by year interaction

Table 20. Tall fescue tissue Cu concentrations by cultivar, clover management, and year at Marion Junction during 2007 and 2008.

	2007		2008	
	AU Triumph	Max Q	AU Triumph	Max Q
	-------------------------mg kg^{-1}------------------------			
Clover	4.4	4.1	6.2	9.4
No Clover	2.5	3.7	5.7	5.4
$LSD_{0.1}$†	1.7		1.7	

†LSD based on clover management by cultivar interaction.

Table 21. Tall fescue Cu uptake by cultivar, clover management, and year at Marion Junction during 2007 and 2008.

	2007		2008	
	AU Triumph	Max Q	AU Triumph	Max Q
	-------------------------g ha^{-1}	------------------------		
Clover	0.7	0.7	0.6	1.0
No Clover	0.4	0.6	0.6	0.6
$LSD_{0.1}$ †	0.2		0.2	

†LSD based on clover management by cultivar interaction.

Table 22. Tall fescue tissue Zn concentrations by cultivar and year at Marion Junction during 2007 and 2008.

	2007	2008
	---------------mg kg^{-1}-------------	
AU Triumph	16.0	26.0
Max Q	15.8	23.0
$LSD_{0.1}$[†]	1.4	

[†]LSD based on cultivar by year interaction

Table 23. Tall fescue Zn uptake by cultivar, clover management and fertilization at Marion Junction during 2007 and 2008.

	Clover		No Clover	
Fertilizer	AU Triumph	Max Q	AU Triumph	Max Q
	---------------------------g ha^{-1}------------------------			
Unprocessed Litter	3.0	3.0	3.0	2.0
Densified Litter	3.0	2.0	2.0	3.0
Commercial Fertilizer	3.0	3.0	2.0	2.0
$LSD_{0.1}$ †		0.4		

†LSD based on fertilizer by clover management interaction.

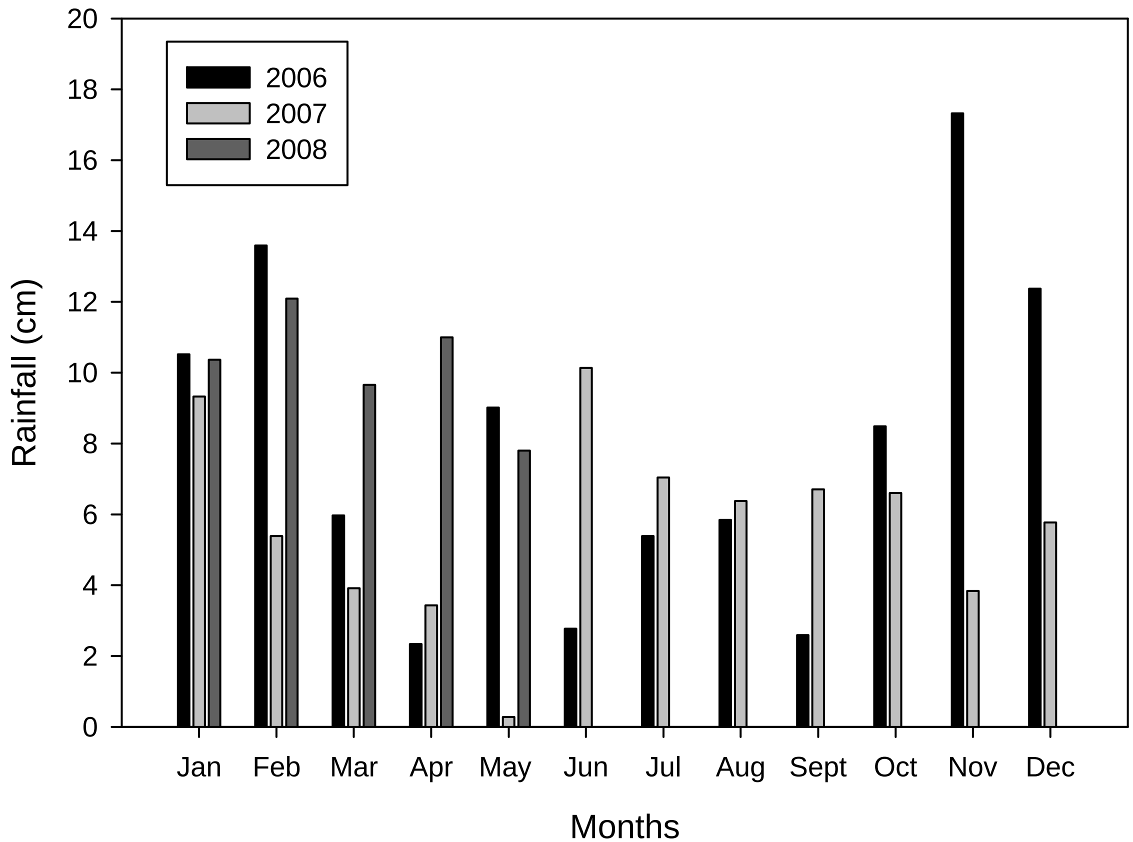

Figure 17. Marion Junction rainfall by month and year.

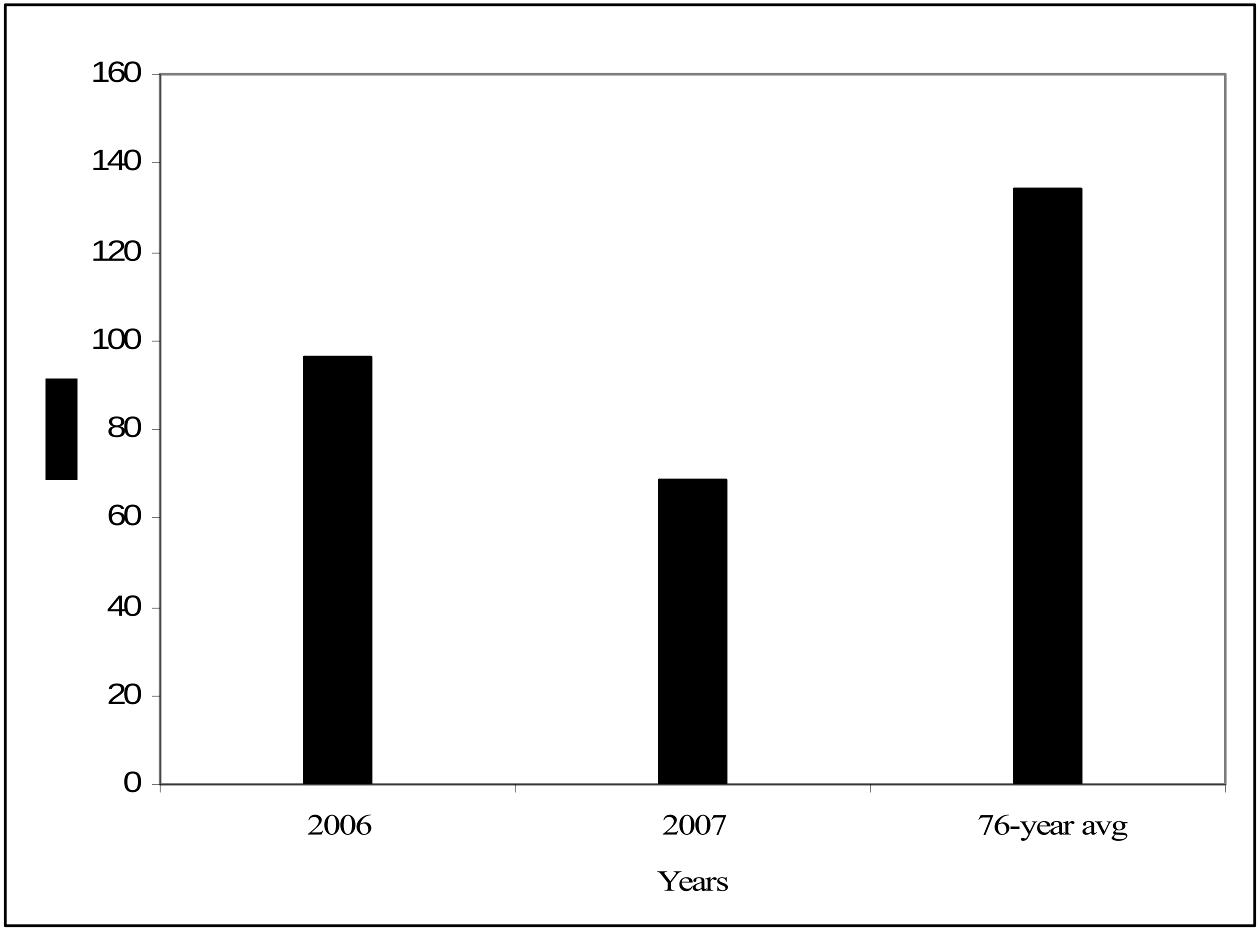

Figure 18. Marion Juction rainfall by year.

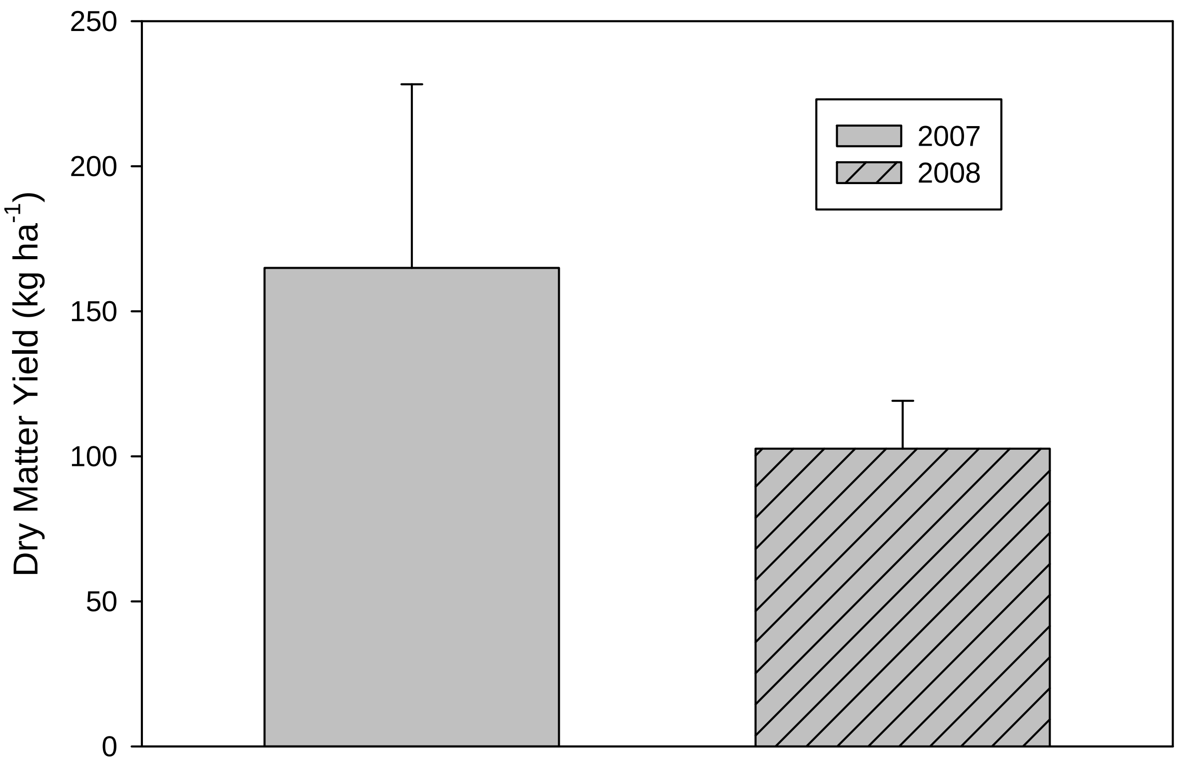

Figure 19. Tall fescue dry matter yield by year

IV. SUMMARY AND CONCLUSIONS

Many studies have been conducted to illustrate the problems associated with broiler litter application to agricultural land. Most of these problems stem from the uneconomical hauling distance of litter, namely over-application of litter on land close to broiler production which may cause pollution. This study showed that:

1. Densification doubles the density of unprocessed broiler litter.
2. Though statistically significant, changes in litter from densification would not affect the practical use of densified litter as a substitute for unprocessed litter.
3. Changes in densified litter over a one year period are inconsequential in regard to the agronomic use of densified broiler litter as a manure fertilizer.
4. Densified litter significantly increased the nutrient uptake of several macro and micro-nutrients, though concentrations did not exceed tolerable livestock levels.
5. Nitrogen uptake was similar among all fertilizer types suggesting densified litter may be an alternative to unprocessed broiler litter and commercial fertilizer.

In conclusion, densification appears to increase the transportation distance of broiler litter by allowing great loads to be carried. As a fertilizer, densified litter serves as a good alternative to unprocessed broiler litter and commercial fertilizer for forage systems.

More research is needed to determine the benefit of densified broiler litter on a larger scale.

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