COMPARISON OF BROILER LITTER, BROILER LITTER ASH WITH REAGENT GRADE MATERIALS AS SOURCES OF PLANT NUTRIENTS.

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COMPARISON OF BROILER LITTER, BROILER LITTER ASH WITH REAGENT GRADE MATERIALS AS SOURCES OF PLANT NUTRIENTS.

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COMPARISON OF BROILER LITTER, BROILER LITTER ASH WITH REAGENT

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Zachry Clay Adams, son of Terry and Sara Jo Adams, was born September 9, 1979 in Dothan, Alabama. He graduated from Wicksburg High School in the top ten of his class in May of 1997. In August 1997, he entered Enterprise State Junior College in Enterprise, Alabama and transferred to Auburn University in September 2000. In May 2002, he graduated with a Bachelor of Science degree in Forestry. After graduation he began Graduate School at Auburn University in June of 2002. He received a Master of Science degree in Agronomy and Soils in December 2005.

THESIS ABSTRACT

COMPARISON OF BROILER LITTER, BROILER LITTER ASH WITH REAGENT GRADE MATERIALS AS SOURCES OF PLANT NUTRIENTS.

Zachry Clay Adams

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Broiler chicken production is a major agricultural industry in the southeastern United States that produces large amounts of waste in the form of broiler litter (manure and bedding). Broiler litter is often used as a fertilizer for forages and row crops. The use of broiler litter as a fuel to produce electricity creates a byproduct of broiler litter ash which has the potential to be a fertilizer with a relatively high concentration of P and K. The objectives of this study were to (1) summarize a broiler litter survey conducted in Sand Mountain, Alabama and report nutrient content of litter and litter produced per bird, (2) determine nutrient loss in broiler litter upon ignition, and determine the effectiveness of broiler litter ash versus broiler litter and reagent grade materials as a source of plant nutrients in a ryegrass (*Lolium multiflorum* Lam.) and sorghum-sudangrass (*Sorghum*

bicolor L.) greenhouse study, and (3) determine P adsorption rates for a sandy soil amended with reagent grade materials, broiler litter, and broiler litter ash.

The Sand Mountain surveys were collected and litter was analyzed for nutrient concentrations and the results summarized and reported. Broiler litter was incinerated in a muffle furnace several different temperatures and analyzed for nutrient concentrations. Ryegrass and sorghum-sudangrass seeds were planted in pots containing a Lucedale very fine sandy loam and amended with reagent grade, broiler litter, or broiler ash materials then placed in greenhouse. Plant yields, heights, and nutrient uptake of P and K were determined. A Lucedale very fine sandy loam was amended with reagent grade, broiler litter, and broiler ash and allowed to incubate for 30 days after which maximum P adsorption rates were determined using the Langmuir equation.

The average kg of litter produced per bird based on 12 houses was 1.11. Phosphorus and Ca concentrations did not change as temperature increased in the furnace. In terms of total yield for the sorghum-sudangrass greenhouse experiment, the BAK treatment is significantly the greatest followed by BLK and RGPK treatments. Phosphorus uptake for broiler litter and BAP treatments was not significantly different for harvest one of ryegrass. There was no significant difference in K uptake for the second harvest between BLP and BAP or BAK and BLK. The broiler ash treatments increased in adsorption as KH_2PO_4 was added at 10 mg, 20 mg, and 40 mg. The control treatment had the greatest predicted maximum adsorption rate of 159 mg kg^{-1}.

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I. INTRODUCTION

Poultry is a major agricultural product in the U.S. and around the world. The southeastern United States is a particularly important region for broiler chicken production. Some of the advantages of the Southeast for poultry production include labor supply, climate, numerous small farms, cost efficient transportation, and positive attitudes by the government towards poultry (Strawn et al., 1995). As a result of poultry production, a large amount of poultry waste is produced. It is estimated that in Alabama almost 1.8 million Mg of broiler litter (manure and bedding) are produced every year (Donald et al., 1996).

Poultry manure is the most valuable of any livestock manure when properly handled. It has been historically used as a soil amendment and fertilizer (Mitchell and Donald, 1995). An early litter survey in Alabama reported an average N-P_2O_5-K_2O fertilizer grade of 3-3-2 (Stephenson et al., 1990). A fertilizer grade of 3-3-2 represents 30-30-20 kg of N, P_2O_5, and K_2O per Mg of broiler litter. Broiler litter use for crops is based mainly on N content, but P and K in litter has also been found to be valuable. A major concern of applying broiler litter is the environmental impact to the soil either by nutrient buildup or surface runoff. Areas such as the Sand Mountain region in northeast Alabama are of particular concern, because of the high broiler litter production. A study showed that long term litter application in the region created a substantial pool of mineralizable N (Kingery et al., 1994). There are several uses of broiler litter other than fertilizer. Broiler litter has been used as a potting soil media as well as a source of feed for beef cattle. A new use for broiler litter being explored is that of a fuel used to generate electricity. Broiler litter has a gross energy value that is similar to wood and about half of coal (Dagnall, 1992). Ash that results from incineration of broiler litter is a by-product that has value due to its relatively high P and K concentration. Its potential use as a fertilizer can be particularly important in meeting the P and K requirements for forages such as ryegrass (*Loliu multiflorum Lam.*) and sorghum-sudangrass (*Sorghum bicolor L.*), because the ash can be applied to satisfy the P requirement of the plant therefore not building up the soil with excess P as can happen when litter is applied based on N content to forages year after year.

There is relatively little published research on the value and benefits of using broiler litter ash as a fertilizer. Bock (1999) found broiler litter ash P and K concentrations to be as much as five times greater than broiler litter. Many questions remain regarding plant uptake of P and K from broiler litter ash compared to other sources, and how this affects plant quality and soil properties.

II. LITERATURE REVIEW

Broiler Production

The states of Alabama, Florida, Mississippi, South Carolina, North Carolina, Georgia, and Arkansas produce 72% of U.S. broiler chickens. Alabama produces 14% of nation's broilers (National Agricultural Statistics Service, 2001), and ranks third in broiler production behind Arkansas and Georgia (Strawn et al., 1995). The economic impact of poultry production in Alabama is tremendous. Poultry and poultry products made up 82% of total livestock products sold in the state of Alabama (National Agricultural Database, 1997). The poultry industry has a 7.5 billion dollar impact annually with 2 billion dollars in wholesale value. Of the 7.5 billion, 6.7 billion was from broilers with the other 800 million from eggs. The industry is directly responsible for 24,000 jobs and 54,000 when allied positions are included (Strawn et al., 1995).

The most common organization and infrastructure for broiler production includes a processing plant, hatchery, feed mill, rendering plant, and many supportive activities. Companies contract with farmers and they receive birds, feed, medicine, and any expert techniques. The farmer owns the broiler production houses and some transportation equipment. In Alabama there are 28 processing plants, 25 feed mills, and 21 million chicks hatched weekly (Strawn et al., 1995).

Poultry Manure

The two types of poultry wastes in Alabama are broiler litter and caged layer manure. Broiler litter originates from floor type birds such as broilers, pullets, and floor layers. Wood shavings and peanut hulls are used as bedding materials to help absorb liquids. Caged layer manure is higher in moisture content and free from litter material. Both types include feathers and wasted feed. Caged layer manure is more variable in its chemical analysis than broiler litter (Mitchell and Donald, 1995).

The factors affecting chemical analysis of broiler litter are moisture, temperature, amount and kind of bedding, soil picked up in clean out, how many batches reared, and conditions in which manure is stored (Mitchell and Donald, 1995). The N-P-K levels increased during the first five flocks but did not change from 5-28 flocks (Chamblee and Todd, 2002). The average N-P-K levels for broiler litter in g kg^{-1} for Georgia, Alabama, and Mississippi are given in Table 1. The average N, P, and K for the four studies in Table 1 was 33 g kg^{-1}, 21 g kg^{-1}, and 23 g kg^{-1} respectively. The values vary from state to state and even in the two separate surveys for Alabama. Differences in poultry house management and feed formulations from farmer to farmer can be the source of different N-P-K values, litter moisture, and litter quality produced between states (Chamblee and Todd, 2002).

One-third of the N in broiler litter is in the NH_4-N form and the rest in organic form. The combination of these determines the availability of N for plant uptake (Mitchell and Donald, 1995). Litters that are high in carbon can retard nitrate accumulation (Vest et al., 1994). Nitrogen available for plant growth is determined by rate of mineralization of organic N, and non-volatilized ammonium (Givens and Collins, 1986). In Alabama, 60% of organic N mineralizes during the first year for a total of 70% available N in the first year while surface applied litter N losses are less than 20% (Mitchell and Donald, 1995). The availability of P and K in broiler litter is around 80% of a commercial fertilizer (Zhang et al., 2003). There is rapid inorganic P released in the first rainfall (Robinson and Sharpley, 1995). Most of P in broiler litter is in the organic form. Its availability is slowed because of being bound by elements in the soil. Potassium is highly available in broiler litter but can be lost by leaching (Vest et al., 1994).

Broiler Litter as a Fertilizer

Broiler litter is used as a fertilizer in a variety of cropping systems from forages to conventional row crops such as cotton. A study on cotton took place at the Tennessee Valley Substation near Belle Mina, Alabama and the E.V. Smith Research Center near Shorter, Alabama (Mitchell et al., 1995). Broiler litter was applied and incorporated before spring planting while commercial fertilizer was split into two applications with one at preplant and the other at squaring. In five of seven site-years the yield response was the same whether the N came from broiler litter or ammonium nitrate. Rank cotton was not observed to be a problem. The study concluded that broiler litter can be used as another source of N fertilizer for cotton (Mitchell et al., 1995). Evers (2002) found that N, P, and K uptake was increased along with yield when a combination of broiler litter and commercial N fertilizer was applied to a ryegrass-bermudagrass forage system. Treatments including 56 kg N ha^{-1} in December and again in March proved to be the most effective. In a conservation tillage system that included cotton, pearl millet, wheat, and canola, broiler litter proved to be a valuable amendment (Gascho et al., 2001). Gascho et al. (2001) also found that the yield and economic value of peanut was decreased when broiler litter was applied to the land before planting. Peanuts had a greater amount of *Rhizoctonia* limb rot damage where broiler litter was applied. Limiting yearly or biyearly litter applications to 4.5 Mg ha^{-1} and using commercial fertilizers for any additional nutrient requirements appears to be the best option (Gascho et al., 2001). In another study (Adams et al., 2003), peanut yields increased on 7 of 13 sites where litter was used. There was only a significant increase in yield from commercial fertilizer on 2 of 13 sites. Adams et al. (2003) concluded the Ca in the litter had a significant effect on the increased yields.

Using poultry litter as a N source on a long-term basis has been shown to benefit bermudagrass yields (Wood et al., 1993). The source of N whether poultry litter or ammonium nitrate did not change crude protein, total digestible nutrients, and crude fiber measurements for a two year period. The nitrate levels in the bermudagrass were less than the critical limit for feeding. Poultry litter application to bermudagrass represents a viable N source for the production of hay along with an environmental and economically sound option to dispose of litter (Wood et al., 1993). Litter should be applied to bermudagrass only after minimum temperatures are greater than those for optimum growth (Brink et al., 2002). Brink also found that the P uptake was not affected by different application rates and there were no benefits in splitting except when an initial 9 Mg ha^{-1} application was divided between the spring and summer. It was concluded the greatest benefit of splitting applications was the possibility of less surface runoff of nutrients (Brink et al., 2002).

A major concern of using broiler litter as a fertilizer is the potential for buildup of nutrients in soil. In a study conducted at two sites in Alabama (Mitchell et al., 1995), soil nitrate levels did not exceed 5.3 mg kg^{-1} to a depth of 102 cm. The extractable plow-layer K and P increased dramatically on broiler litter plots when compared with conventional fertilized plots (Mitchell et al., 1995). Excess soil P and K that comes from broiler litter application in a ryegrass-bermudagrass forage system may be decreased with commercial N fertilization (Evers, 2002). Phosphorus, K, Ca, Mg, Zn, Mn, and Cu concentrations were increased in the surface soil because of broiler litter application (Gascho et al., 2001). The high Zn concentrations may lead to peanut toxicity (Gascho et al., 2001).

Application of N contained in broiler litter in the Sand Mountain region exceeded plant requirements creating a heightened level of nitrate near bedrock and creating potential for groundwater pollution (Kingery et al., 1994). There were also high levels of P found in soils, as well as Cu and Zn concentrations that may reach toxic levels in the future. Unfavorable livestock problems such as grass tetany may also result from long-term broiler litter applications (Kingery et al., 1994).

Surface runoff losses from broiler litter are a major concern. Broiler litter application increased NH_4-N and dissolved reactive phosphorus (DRP) concentrations above initial background levels for single runoff events (Pierson et al., 2001). There was a rapid decrease of ammonium after broiler litter application due to volatilization of N, plant or microorganism use, or the conversion to nitrite and nitrate. The runoff volume or time after application did not affect ammonium concentration strongly. Time after application and runoff volume did affect DRP concentration. It did not decrease rapidly like NH_4 (Pierson et al., 2001). In another study on runoff losses (Wood et al., 1999), NO_3-N and NH_4-N concentrations were greatest when 18 Mg ha^{-1} of broiler litter was applied. The same rate also produced the highest dissolved phosphorus (DP) and total phosphorus (TP) flow-weighted concentrations, and gave the highest total nutrient flow-weighted concentrations of Ca, Mg, K, and Mn. Commercial fertilizers gave higher sediment nutrient flow-weighted concentrations for K, Mg, and Mn (Wood et al., 1999). The study went on to show that all concentrations of nutrients except Ca were high enough to support algae growth. The conclusion was that the optimal broiler litter rate for least environmental impact is 9 Mg ha^{-1}.

Broiler Litter as a Potting Soil Media

Another possible use for broiler litter is as a potting soil media. Flynn et al. (1995) showed that broiler litter mixed with a commercial potting mix acted as a good medium for potting soil. The study also showed that broiler litter that was composted with peanut hulls and then mixed with a commercial potting mix had the greatest lettuce yields. The litter mixed with potting soil resulted in higher lettuce yields than potting soil alone. The lettuce also showed no physiologic problems that could have been the result of nutrients in broiler litter compost (Flynn et al., 1995). Guertal et al. (1996) showed there to be no size difference for cabbage, collards, or broccoli transplants when they were grown in either a 50/50 mix of broiler litter and potting soil or 100% potting soil. The type of potting mix did not affect tomato wet or dry weight. Type of potting mix did not affect final yields of broccoli, cabbage, and collards. The conclusion of the study was that greenhouses producing vegetable transplants can use composted broiler litter as a part of potting mix (Guertal et al., 1996).

Broiler Litter as Cattle Feed

An important past use for broiler litter was as a feed supplement for beef cattle. The United States Department of Health and Human Services (2004) banned the practice of using poultry litter as a feed source for ruminant animals. There was concern over the possible mixture of certain proteins that are banned in ruminant feed such as bovine meat and bone meal with the poultry litter collected from the house. However, there are no recorded harmful effects to humans from eating cattle that are fed with broiler litter (Rankins, 2000).

The bedding material in broiler houses acted as a low quality feed and increased in nutrient quality when feathers, excrement, and waste feed were added to litter (Rankins, 2000). Rankins (2000) shows the value of broiler litter as a feed to be four times greater than its value as a fertilizer. Vest et al. (1994) showed that poultry litter that was properly used is a good source of calcium, roughage, P, and supplemental protein. The value of total digestible nutrients for broiler litter ranges from 25 to 60 percent (Vest et al., 1994). Conserving plant nutrients was another benefit of using broiler litter as a feed ingredient (Rankins, 2000). The cattle distribute nutrients such as N, P, and K to the pasture as manure. Its economic value as a feed was not reduced by long distance transportation (Rankins, 2000).

Fractionating Broiler Litter

One possible way to maximize efficiency of land application is through the idea of litter fractionation (Ndewga, 1991). The broiler litter would be sieved into fine, medium, and coarse fractions. Sawdust and small wood chips would make up the medium fraction, with manure and spilled feed comprising the fine fraction. Large wood chips and clods would make up the coarse fraction which could be used as a mulch or compost. Because of a higher N content in the fine fraction it could be better served to be used as a fertilizer. The medium fraction could be reused for bedding material in broiler houses (Ndewga, 1991).

Broiler Litter as a Fuel

Using broiler litter as a fuel has become a recent possibility that has already achieved success in some places. Most of the work on broiler litter as a fuel has taken place in Europe but it is now beginning to be looked at seriously in the U.S. A sample of broiler litter that has moisture of 16.3 %, volatile matter of 61.4 %, fixed carbon of 13.3%, and an ash of 9% will have a moisture and ash free heat value of 18,010 kJ kg^{-1} (Dagnall, 1993). The heating values vary from sample to sample of broiler litter as they have different characteristics such as moisture, ash, and fixed carbon. The heating value for some other commonly used fuels are as follows. The heating value for coal, bituminous, high volatile A is 32,379 kJ kg^{-1}. The value for No. 2 distillate fuel oil is 38,509 kJ L^{-1}, 42,222 kJ L^{-1} for residual fuel oil, and 25,350 kJ L^{-1} for propane. The value for natural gas is 36,225 kJ m^{-3} (Perry Chemical Engineers' Handbook, 1984). It is obvious to see that the value for broiler litter is well below all of the standard fuels used today.

The process generating electricity from poultry litter is straightforward. The litter arrives at the power plant and then is conditioned and stored until ready to use (Western Area Power, 2001). It is then moved to the furnace where it is combusted at over 816 ^{o}C. Then the ash from the furnace goes to a storage area where it is blended for future use as a fertilizer. Combustion of litter at high temperature heats a boiler which produces steam that turns a turbine and generates electricity. The acid gases and dust are removed. The gaseous emissions produced by the poultry plants are very low. The remaining fly ash goes in the ash hall (Western Area Power, 2001).

There are pros and cons to using broiler litter as a fuel. High N, S, moisture, and ash make broiler litter a lower quality fuel than coal (Texas A&M, 2003). Broiler litter has a low heating value. Combustion may be aided due to the fact that broiler litter compared to coal has a higher volatile matter when measured on a dry ash free basis. Volatile oxides are high in litter fuels which can cause high fouling rates. The fuel cost of 100% coal and 90:10 (Coal:BL) are very similar (Texas A&M, 2003). It has been shown that broiler litter can be used as a fuel in a cost effective way without a tipping fee or subsidy from the government (Martin and Lefcort, 2000).

There are numerous examples of broiler litter already being used in Europe to produce electricity. Broiler litter is used as a fuel to heat seven broiler houses at a broiler production site in England (Dagnall, 1992). Because of the system, the farm no longer has to purchase heating fuel. The savings from this system paid for the new heating system in 12 to 18 months (Dagnall, 1992). At the present time there are three power plants operating in the UK that produce electricity with animal manure. Fibrominn is the company that operates all three plants. They are proposing to build a 50-MW poultry litter generator in Minnesota (Western Area Power, 2001).

Broiler Litter Ash

There are a few other benefits to using broiler litter as a fuel besides the production of energy in a clean, environmentally safe way. The sale of carbon dioxide offsets from broiler litter can be used as a revenue source (Martin and Lefcort, 2000). Broiler litter burns very clean compared to other fuels creating a favorable environmental impact to the air. The other main benefit is the sale of the ash by-product as a fertilizer. This is a relatively new product where not much is known. All N and S will be lost from the broiler litter when combusted at the high temperatures (Bock, 1999). The nutrient value of N in broiler litter ash is near zero because of conversion of N to gaseous forms escaping during combustion. The N is converted mainly to N_2 in oxidizing energy conservation systems and ammonia gases that escape in the highly reducing conservation systems (Bock, 1999). Bock (1999) has shown that if 907 kg of broiler litter has an ash content of 16.9% that 154 kg of ash from the broiler litter can be expected. The ash would have 9 kg P (21 kg P_2O_5) and 24 kg of K (29 kg K_2O) (Martin, 1999). Assuming a 20% broiler ash content on a dry basis, the broiler litter ash concentrations can be about five times greater than broiler litter. Broiler litter ash concentrations with some unreacted carbon can have P and K concentrations greater than broiler litter (Bock, 1999). The decrease in the bulkiness of litter by using ash is very important in regard to transportation costs. Manure is generally very bulky with a density around 320-400 kg/m^3. Transportation costs can range from $7-12/metric ton with as much as $18/metric ton for commercial operating delivered cost (Vest et al., 1994).

One recent study has already pointed to the potential benefits of poultry ash as a fertilizer (Codling et al., 2002). The study showed that poultry litter ash and potassium phosphate treatments showed no significant difference in wheat dry matter yields. The poultry litter ash treatments also had greater P concentrations in plant tissue than the potassium phosphate or the control treatments. Soil treated with poultry litter ash had the greatest water soluble P, soil pH, and Mehlich 3-extractable P (Codling et al., 2002).

Phosphorus

Phosphorus may be absorbed as either a monovalent ion ($H_2PO_4^-$) in acid soils or a divalent ion (HPO_4^{-2}) in alkaline soils (Brady and Weil, 2002). Acid soils may decrease phosphate availability (Bohn et al., 2001a). Plant roots mainly uptake P by diffusion (Foth and Ellis, 1997). Phosphorus is quickly adsorbed after application, then increasingly changes into unavailable forms (Bohn et al., 2001a). The P not absorbed during year of application can still be available several years after the initial application (Ball et al., 1991).

The soil P that bonds to soil compounds not having a discrete mineral phase is known as adsorbed P. The amount of P in agricultural drainage waters increase when there are soils that are sandy and have a low capacity to adsorb P (Foth and Ellis, 1997). The Langmuir equation is commonly used to describe P adsorption. The Langmuir equation defines an adsorption limit that can be used to help with estimating adsorption capacity of soil for phosphate (Bohn et al., 2001b).

Potassium

Potassium is mobile in the plant and taken up in very large amounts (Foth and Ellis 1997). Potassium is a cellular enzyme activator that in the cell stays in its ionic form (K^+) and helps plants adjust to environmental stresses such as insects, disease, and drought (Brady and Weil 2002). A study showed that K supply is critical for allowing forages in the subtropics to survive winter freeze spells (Pant et. al., 2004). It also works in stabilization of pH and the K concentration within cells that affect osmotic potential (Marschner 1986).

The objectives of this study were to (1) summarize a broiler litter survey conducted in Sand Mountain, Alabama and report nutrient content of litter and litter produced per bird, (2) determine nutrient loss in broiler litter upon ignition, and determine the effectiveness of broiler litter ash versus broiler litter and reagent grade materials as a source of plant nutrients in a ryegrass and sorghum-sudangrass greenhouse study, and (3) determine P adsorption rates for a sandy soil amended with reagent grade materials, broiler litter, and broiler litter ash.

II. MATERIALS AND METHODS

Broiler Litter Survey

A broiler litter survey was conducted in the Sand Mountain region of northeast Alabama. The objective of the study was to determine the amount of litter and nutrients removed from broiler houses on Sand Mountain during cake removal and final cleanout. Sand Mountain/Lake Guntersville Watershed Project personnel along with Sand Mountain Substation personnel selected a minimum of 25 broiler houses that were scheduled for clean-out in the spring of 2000. The broiler houses were followed through the stages of cleanout including several cake removals and final cleanout from March 15, 2000 to July 30, 2001.

Truck scales were brought to the growers on the day of cleanout and trucks were weighed along with sampling of litter. Each truck was weighed before and after cake/litter was loaded. Project and station personnel took a representative sample by gathering a minimum of 20 handfuls at various spots in the truck and placing them in a 5-gallon bucket followed by mixing. The cake/litter was transferred from the bucket into a 1-gallon zip-lock bag with the end result being a full gallon bag for each truckload sample. Each bag was labeled with the date, farmer's name, house number/name, and truckload number. Total C and N of litter were determined by the combustion method using a LECO CHN-600 (LECO Corporation, St. Joseph, MI). The broiler litter was dry ashed and analyzed using a ICAP (Thermo Jarrell Ash, Franklin, MA) to determine P, K, Ca, Cu, Zn, Fe, Mn, and Al. The elemental concentration averages for litter and kg litter bird^{-1} were determined from the Sand Mountain survey.

Broiler Litter Ignition

The experiment was designed to determine change in nutrient concentration when broiler litter is ignited. Fresh broiler litter was obtained from the Alabama Agricultural Experiment Station Wiregrass Substation and transported back to Auburn University. The broiler litter was dried at 60 ^{o}C for 24 hours, and then ground in a Thomas-Wiley high speed grinder to pass a 1mm screen. Four 0.5 g samples of litter plus a blank were dry ashed in a muffle furnace at 450 ^{o}C (Hue and Evans 1986). The same procedure was repeated in the muffle furnace at 650 ^{o}C, 850 ^{o}C, and 1000 ^{o}C. They were removed from the oven and evaluated for visual differences. The ash was dissolved in a HNO_3:HCl mixture and analyzed for P, K, Ca, Mg, Cu, Mn, Fe, Zn, B, Mo, Al, Ba, Co, Cr, Pb, Si, and Na, using an inductively coupled argon plasma spectrophotometer (ICAP) (Jarrel-Ash Division/Fisher Scientific Co., Waltham, MA). The means and standard errors were determined for each element.

Greenhouse Experiment

The experiment was designed to evaluate uptake of P and K from broiler litter, broiler litter ash, and reagent grade materials applied to Marshall annual ryegrass (*Lolium multiflorum* Lam.) and Summergrazer III sorghum-sudangrass hybrid (*Sorghum bicolor L.*). The experiment was conducted in 2004 at the Auburn University Plant Science Research Center.

The A_p horizon of a Lucedale very fine sandy loam (fine-loamy, siliceous, thermic Rhodic Paleudult) was obtained for the greenhouse study from the Alabama Agricultural Experiment Station at Monroeville Field Experiment Station. The soil was sieved to pass a 10 mesh screen, air dried and autoclaved at 130 ^{o}C (Tuttnauer, Jerusalem, Israel). Particle size analysis was determined by the pipette method (Puckett et. al., 1985) and pH, extractable Ca, Mg, P, and K was determined by the Auburn University Soil Testing Laboratory (Table 2) (Hue and Evans, 1986).

Soil amendments consisted of broiler litter, broiler ash, and reagent grade materials. Broiler litter was obtained from the Alabama Agricultural Experiment Station Wiregrass Substation. The broiler litter was dried at 60 ^{o}C for 24 hours and ground in a Thomas-Wiley high speed grinder to pass a 1mm screen and analyzed for selected properties (Table 3). Four 0.5 g samples of litter plus the blank were dry ashed in a muffle furnace at 450 ^{o}C (Hue and Evans 1986) and analyzed for P, K, and Ca using an AA Instrumentation Laboratory Spectrophotometer. An inductively coupled plasma spectrophotometer (ICP) (Spectro Ciros SOP, Germany) was used to analyze for Mg, Zn, Cu, As, and Mn. Total C and N were determined using a LECO-CHN 600 (LECO Corp., St. Joseph, MI.).

Five trash cans of fresh broiler litter were taken to the Auburn University College of Veterinary Medicine and incinerated at 1430 ^{o}C for 12 hours. The ash was allowed to cool down, and then cleaned out of the incinerator (Table 3). Using the dry ash method (Hue and Evans 1986), broiler ash was analyzed for P, K, and Ca using the AA and Mg, Zn, Cu, As, and Mn using the inductively coupled plasma spectrophotometer (ICP) (Spectro Ciros SOP, Germany). The reagent grade K source, potassium chloride (KCl), contained 52.4% K. The reagent grade P source, monocalcium phosphate ($Ca(H_2PO_4)_2$ * H_2O), contained 24.6% P and 15.9% Ca. The reagent grade N source, ammonium nitrate (NH_4NO_3), contained 35% N.

The experimental design was completely random with treatments consisting of broiler litter, broiler ash, reagent grade materials, and a control. There were eight treatments and four replications of each treatment. The reagent grade treatments were reagent grade P (RGP), reagent grade K (RGK), and reagent grade P+K (RGPK). The broiler ash treatments were broiler ash P (BAP) and broiler ash K (BAK). The broiler litter treatments were broiler litter P (BLP) and broiler litter K (BLK). The BAP and BLP treatments were applied on the basis of P requirement. The BAK and BLK treatments were applied on the basis of potassium requirement. The fertilizer rates were determined from soil test recommendations from the Auburn University Soil Testing Laboratory. Nitrogen, P_2O_5, and K_2O were applied at rates of 224, 224, and 224 kg ha^{-1} for annual ryegrass and 134, 134, and 224 kg ha^{-1} for sorghum-sudangrass hybrid. The control received no N, P_2O_5, and K_2O for annual ryegrass. The sorghum-sudangrass experiment control received N after the first harvest.

The soil was mixed with amendments and annual ryegrass seeds were planted on January 8, 2004 for a total of 32 pots. Each plastic pot contained 3 kg of air dried, sieved soil plus amendments and seeds. The pots were placed in a cool season greenhouse and kept near or at field capacity throughout the experiment with deionized water. They were moved three times a week to account for light differences. The annual ryegrass was harvested twice, initially on February 17, 2004 and final harvest on April 10, 2004. The soil was left in pots after the annual ryegrass final harvest. The soil from each individual pot was dumped out, broken up, air dried, sieved, and placed back in the pot. The soil was mixed with amendments and sorghum-sudangrass seeds were planted on May 12, 2004. The pots were placed in a warm season greenhouse and kept near or at field capacity throughout the experiment. Pots were moved three times a week to account for light differences. Plants were initially harvested on June 24, 2004 and final harvest was on July 22, 2004. Plant heights, leaf widths, and deficiency symptoms were recorded before each harvest. Plants were cut at the lip of the pots and weighed, placed in paper bag, and dried for 48 hours at 50 ^{o}C and reweighed then ground in a plant grinder. Plant material was dry ashed in a muffle furnace at 450 ^{o}C for at least 4 hours and then dissolved in HNO_3:HCl mixtures (Hue and Evans 1986). The digests were analyzed for P and K using an ICP (Spectro Ciros SOP, Germany).

Analysis of variance was performed for each experiment by harvest using the Means Comparisons procedures provided by the Statistical Analysis System (SAS 1985). The treatment means were compared using LSD's considered significant at the 10 % level.

Broiler Ash Fractionation

The experiment was conducted to determine whether different size fractions of broiler ash were different in nutrient analysis. A 500 g sample of broiler ash was taken and sieved through a 10 and 60 mesh screen one time. The amount of ash passing each screen was weighed, recorded, and digested using the dry ash method (Hue and Evans 1986). The solution was analyzed for P, K, Ca, Mg, Zn, Cu, As, and Mn using the (ICP (Spectro Ciros SOP, Germany).

P Adsorption Study

The experiment was conducted to determine P adsorption to a Lucedale very fine sandy loam. Soil was oven dried at 55 ^oC for 24 hours and sieved. Phosphorus was applied to the soil at rates of 50, 100, 150, and 200 mg P_2O_5 kg as broiler litter, broiler litter ash, and reagent grade materials for a total of 12 treatments and a control for a total of 13 jars. The rates were 112, 224, 336, and 448 kg P_2O_5 ha^{-1}. The soil and amendments were brought to field capacity with deionized water and sealed in air tight mason jars and placed in the lab at room temperature 23 ^oC on January 24, 2005. They were unsealed once a week to allow aeration. The study was concluded on February 22, 2005. Soil was removed from each jar and oven dried at 55 ^oC for 24 hours. Ten, 10 g samples of each treated soil were placed into 125 ml Erlenmeyer flasks. Solutions containing 0, 10, 20, 40, and 80 ml of a 100 ppm KH_2PO_4 were added in duplicate to the flasks. Each flask was brought up to a total volume of 100 ml with deionized water. There were a total of 10 flasks for each treatment. The flasks were then shaken on the mechanical shaker for two hours then allowed to stand overnight. They were then filtered through No. 42 filter paper and analyzed by ICP for P.

III. RESULTS AND DISCUSSION

Broiler Litter Survey

The broiler litter survey data collected from houses in the Sand Mountain region of Alabama was summarized and kg of litter bird^{-1} and elemental concentrations of broiler litter are reported. The survey showed that on average 1.11 kg of litter bird^{-1} is produced after each cleanout. The average kg of litter bird^{-1} ranged from 0.71-1.53 with a standard error of 0.09. This was based on 12 broiler houses that had completed bird and litter sheets. An earlier study in Alabama showed 1.03 kg litter bird^{-1} (Donald et al., 1996). The average kg litter bird^{-1} in Georgia was 1.13 (Vest et al., 1994). The figures for litter produced per bird can vary due to the number of flocks produced before cleanout. Chamblee and Todd (2002) reported in a survey from Mississippi that after five flocks of production, 1.45 kg litter bird^{-1} was produced, but then decreased to 0.91 kg litter bird^{-1} after 10 flocks or two years of production. The decrease could be the result of microbial decomposition over time. The kg litter bird^{-1} for the Sand Mountain survey was based on houses that were cleaned out after each flock.

The average elemental concentrations for the survey are listed in Table 3. These are based on 22 houses that submitted broiler litter samples for each cleanout. The total N and total C of the samples were 32 g kg^{-1} and 375 g kg^{-1} for a C:N ratio of 12:1. The average P and K of the samples were 19 g kg^{-1} and 28 g kg^{-1}, respectively. Four other litter surveys including two from Alabama were summarized (Stephenson et. al., 1990, Vest et. al., 1994, Mitchell and Donald 1995, Patterson et. al., 1998). The average N, P, and K for the Alabama surveys were 36 g kg^{-1}, 22 g kg^{-1}, and 22 g kg^{-1} respectively. In this study, the micronutrient with the greatest concentration was Fe at 1778 mg kg^{-1} (Table 3). The elemental concentrations for the Sand Mountain Survey are similar to those of previous surveys in Alabama and the Southeast. The factors affecting chemical analysis of broiler litter are moisture, temperature, amount and kind of bedding, soil picked up in cleanup, how many batches reared, and conditions in which manure is stored (Mitchell and Donald, 1995).

Broiler Litter Ignition

The results of the broiler litter ignition study are shown in Table 4. Nitrogen and S concentrations were not determined because of their loss from litter when burned. The N in broiler litter escapes as gases from the ash upon combustion while the S is converted to gaseous forms (Bock, 1999). The concentration of P and Ca in the litter did not change as temperature increased from 450 ^{o}C to 1000 ^{o}C. The concentration of K decreased from 40 g kg^{-1} at 450 ^{o}C to 5 g kg^{-1} at 1000 ^{o}C. Volatilization of K in broiler litter is directly correlated with Cl content in litter (Baxter et al.,1996). Magnesium decreased after reaching a temperature of 650 ^{o}C. The Si concentration did not change as temperature increased. The concentration of Cu decreased from 675 mg kg^{-1} to 132 mg kg^{-1} from 450 to 650 ^{o}C respectively. The Fe and Al concentrations decreased the greatest after reaching 850 ^{o}C. The Zn and Mn concentrations also decreased as temperature was increased. Elemental concentrations of metals decreasing with increasing temperature make it less likely that application of broiler ash would increase metal concentration in soils any more than fresh broiler litter does or possibly less. The boiling points of Cu, Mn, and Al are 2567 ^oC, 1962 ^oC, and 2467 ^oC, respectively (Handbook of Chemistry and Physics, 1986). These element did not reach those temperatures in the oven therefore did not change from a liquid to a gas.

Greenhouse Experiment

The ryegrass yields were greatest for the reagent grade P+K (RGPK), broiler ash P (BAP), and broiler ash K (BAK) treatments for harvest one (Table 5) than all other treatments. The reagent grade K (RGK), RGPK, and BAK treatments had yields significantly greater for the second harvest of ryegrass than all other treatments. There was a significant difference between the broiler ash and broiler litter treatment yields for harvest one and two. The control treatment which received no N, P, or K had the lowest plant yields for harvest one and two. The yield increased from the first to second harvest in all treatments except for broiler litter P (BLP), broiler litter K (BLK), and BAP. This could be the result of using N in broiler litter as the N source for the broiler litter treatments. The reagent grade N source was only used on broiler litter treatments to make up for remaining N required for annual ryegrass requirements. Nitrogen availability in broiler litter can range from 30 % to 80 % during application year. Incorporating the broiler litter into the soil rather than surface application can increase availability (Zhang et al., 2003). The sums of the first and second harvest yields for ryegrass are shown in Figure 1. The BAK and RGPK treatments had greatest total ryegrass yield. Broiler ash treatments had significantly greater total ryegrass yield than broiler litter treatments.

Sorghum-sudangrass yields were greatest in the BAK and RGPK treatments for harvests one and two respectively (Table 5). Yield for the BAK treatment was almost three times greater than the yield of any of the reagent grade treatments for the first harvest. All broiler ash and broiler ash treatments were significantly greater than reagent grade treatments for harvest one of sorghum-sudangrass. This could be the result of leftover P and K from the previous application for annual ryegrass that is now available to plant or a benefit of micronutrients in the litter and ash. The RGPK treatment increased 13.8 g from harvest one to two and had the greatest yield in the second harvest. There was no significant difference in yield between BAK and BLK or BAP and BLP for the second harvest. Yield increased for each treatment from the first to second harvest. The application of N to all 32 pots at the rate of 134 kg ha^{-1} could have contributed to the increased yield from harvest one to two. Sorghum-sudangrass responds well to N (Ball et al., 1991). The RGK treatment which received no P had the lowest yield for each harvest.

In terms of total yield for the sorghum-sudangrass greenhouse experiment, the BAK treatment was the greatest followed by BLK and RGPK treatments (Figure 2). There was no significant difference in total yield for sorghum-sudangrass between broiler litter and broiler ash treatments based on the P requirement. Total biomass yield for the greenhouse experiment is shown in Figure 3. The BAK treatment was significantly greater than all other treatments. There is no significant difference in yield for broiler litter and broiler ash treatments based on P requirement. Total biomass yield is greatest in treatments that received full amount of required K and P.

Harvest one plant heights were greatest in the BAK treatment (Table 6). Broiler ash potassium, RGK, and reagent grade P (RGP) treatments were greatest for the second harvest of ryegrass. The control treatment which received no N, P, or K had the lowest plant height for the first and second harvest. From the first to second harvest height decreased in each treatment. Plants exhibited N deficiency which could have contributed to decreasing height. The treatments with greatest plant heights also had the greatest plant yields.

Sorghum-sudangrass plant heights were greatest in broiler ash and BLP treatments for harvest one, which were the highest yielding treatments after the first harvest (Table 6). The RGPK treatment which had the greatest yield also had the greatest plant height after harvest two at 87.75 cm. Plant height increased from the first to second harvest in all reagent grade treatments and the control. Control plant height may have increased because of addition on N fertilizer after first harvest. The plant heights decreased slightly for the broiler ash and BLP treatments which could be related to a decrease in availability of P and K from broiler litter and ash.

Ryegrass P uptake was greatest in the BAK and RGPK treatments (Table 7). These two treatments also had the greatest yields for the first harvest. Forage production and P uptake are directly related (Evers, 2002). The RGP treatment had the greatest P uptake for the second harvest. Phosphorus uptake for broiler litter and BAP treatments was not significantly different for harvest one. There was no significant difference in P uptake between broiler litter and broiler ash treatments for the second harvest of ryegrass. The P uptake decreased from harvest one to two in all treatments except the RGP. The P uptake for harvest one ranged from 2.98 mg pot^{-1} to 15.57 mg pot^{-1} and 2.50 mg pot^{-1} to 14.83 mg pot^{-1} for harvest two. The total P uptake for ryegrass was significantly the greatest in the RGPK and RGP treatments (Table 7). Ryegrass P uptake overall was greatest where reagent grade sources of phosphorus were used.

Broiler litter and broiler ash treatments based on K requirement along with RGK had the greatest potassium uptake for ryegrass harvest one (Table 7). The RGPK treatment had the significantly greatest K uptake for harvest two. There was no difference in K uptake between the BLK and BAK treatments for the first or second harvest. The control and RGP treatments which neither received K had the lowest uptake. The K uptake decreased in every treatment from harvest one to two. The K uptake ranged from 14.93 mg pot^{-1} to 133.60 mg pot^{-1} for the first harvest and 11.78 mg pot^{-1} to 62.37 mg pot^{-1} for the second. Total K uptake for ryegrass was significantly greatest in the RGPK, RGK, and BAK treatments. Reagent grade sources of K were took up in higher level by ryegrass than broiler litter and broiler ash sources of K. Broiler litter and broiler ash treatments based on the K requirement were significantly different in K uptake.

Sorghum-sudangrass had the greatest P uptake for the first harvest in the BLK treatment (Table 8). There was no significant difference in P uptake between treatments BLP and BAP for harvest one or two of sorghum-sudangrass. The RGPK treatment had the greatest significant P uptake for the second harvest at 23.32 mg pot^{-1}. There was no significant difference in P uptake for harvest two between the BAK and BLK treatments. The P uptakes from the first to second harvest increased in each treatment and increased the greatest amount in the RGPK treatment. There was N added to each treatment after the first harvest. When N fertilizers are added, the P absorption of a plant increases (Adams, 1980). The RGK and control had the lowest levels of P uptake. Total P uptake for sorghum-sudangrass was significantly the greatest in the BLK and RGPK treatments at 34.78 and 34.36 mg pot^{-1} respectively.

Potassium uptake was greatest in treatments BLK and BAK for harvest one of sorghum-sudangrass (Table 8). The K uptake for BLK and BAK was twice as much as that of treatment RGPK. However, for the second harvest the greatest K uptake was 99.74 mg pot^{-1} in the RGPK treatment. There was no significant difference in K uptake for the second harvest between BLP and BAP or BAK and BLK. The K uptake decreased in every treatment from the first to second harvest except for RGPK and the control. The RGK treatment had the lowest levels of K and P uptake for the first and second harvest. Total K uptake was significantly the greatest in the BLK and BAK treatments at 178.31 and 177.53 mg pot^{-1} respectively (Table 8).

The soil used was a very fine sandy loam with initial P, K, and Ca values of 12 mg kg^{-1}, 19 mg kg^{-1}, and 340 mg kg^{-1} with a pH of 6.9. The particle size distribution of sand, silt, and clay for the Lucedale vfsl was 51.1 %, 35.8 %, and 13.1 % respectively. The amount of P and K supplied by each treatment to the ryegrass is given in Table 9. Both P and K were supplied in every treatment except the control, RGP, and RGK. The RGP contained no K and likewise the RGK did not contain P. The BLP and BAP treatments contained the P required but contained 67 mg pot^{-1} and 88 mg pot^{-1} of K below the K required respectively (Table 9). The BAK and BLK contained the required amount of K required plus an extra 125 mg pot^{-1} and 87 mg pot^{-1} of P respectively over the required amount. This affected the uptake rates in that more P was applied in the BAK and BLK treatments than the others.

The same criteria for treatments were used for sorghum-sudangrass as in ryegrass. The amount of P and K supplied by each treatment is given in Table 10. The BLP and BAP treatments contained the required P but had 160 mg pot^{-1} and 173 mg pot^{-1} below the K requirement, respectively (Table 10). The BAK and BLK contained the required amount of K plus an extra 245 mg pot^{-1} and 207 mg pot^{-1} over the required amount of P respectively.

The final soil test results after harvest two of sorghum-sudangrass are given in Table 11. The pH for all treatments except RGK ranged from 6.3-6.6. The RGK treatment had a pH of 5.8. The pH decreased in all treatment from the initial pH of 6.9 before planting of ryegrass. Soil pH decreased significantly the least in treatments BLK, BLP, and BAK. This could be the result of Ca in broiler litter and broiler ash. The amount of extractable K was significantly the greatest in the RGK treatment at 64 mg kg^{-1}. The RGK treatment also had the lowest pH at 5.8 along with lowest yields and levels of K uptake for sorghum-sudangrass. There was a significant difference in extractable K left tin soil between RGPK and the BLK treatment. Extractable P left in the soil was significantly the greatest in the BAK treatment. The BAK treatment received 370 mg pot^{-1} P over the recommended amount. There was no significant difference in the BLP and RGPK treatments. Studies have shown that the P in broiler litter is assumed to be about 80 % as available as a commercial fertilizer (Zhang et al., 2003), while in broiler ash P is assumed to be about 50 % as available as a commercial fertilizer based on several studies (Bock, 1999). Extractable soil P levels were raised in broiler ash treatments compared to reagent grade and broiler litter treatment but not extractable soil K levels.

Broiler Ash Fractionation

The broiler ash concentrations at different particle sizes are listed in Table 12. The P, K, and Mg concentration increased as the particles became smaller. Application of broiler ash in the U.K. is done in a non-granulated finely divided form which goes with the principle that P fertilizers are more available when their particle size is small (Engelstad et al., 1993). The K concentration increased the most from 96 g kg^{-1} for the largest size to 145 g kg^{-1} for the smallest particle size. The Ca concentration was greatest for particles that passed a 10 mesh screen but did not pass a 60 mesh screen. The majority of the broiler ash passed a 10 mesh screen.

Copper, Mn, and Zn concentrations increased as particle size became smaller (Table 12). The Cu concentration increased the most from 1213 mg kg^{-1} to 2214 mg kg^{-1} from largest to smallest particle respectively. The results show that as particle size for broiler ash becomes smaller the elemental concentrations of P, K, Ca, Mg, Cu, Mn, and Zn will increase.

P Adsorption Study

The P adsorption for reagent grade, broiler litter, broiler ash, and control treatments at each amount of KH_2PO_4 added is listed in Table 13. The control which received no P had the highest adsorption of P at each rate of added P. The reagent grade 100 (RG100) had adsorption levels of 67 mg kg^{-1}, 101 mg kg^{-1}, and 97 mg kg^{-1}, respectively (Table 13). The RG400 treatment had the lowest level of adsorption for the reagent grade treatments at 10 mg, 20 mg, and 40 mg of added P. The broiler ash treatments increased in adsorption as KH_2PO_4 was added at 10 mg, 20 mg, and 40 mg. The broiler ash 100 (BA100) treatment adsorbed the most at 10 mg and 20 mg of added P with 76 mg kg^{-1} and 116 mg kg^{-1}, respectively. The BA200 treatment adsorbed the most P at 40 mg of added P with 124 mg kg^{-1}. The broiler litter treatments increased adsorption as KH_2PO_4 was added at 10 mg, 20 mg, and 40 mg of P (Table 13). The broiler litter treatment with the greatest adsorption at 10 mg, 20 mg, and 40 mg of added P was broiler litter 100 (BL100) with 73 mg kg^{-1}, 107 mg kg^{-1}, and 132 mg kg^{-1} respectively.

The P adsorption for reagent grade, broiler ash, and broiler litter at 10, 20, and 40 mg of KH_2PO_5 added is graphed in Figures 4, 5, and 6 plotting x/m vs. Solution C. Figure 4 shows P adsorption to increase for reagent grade treatments to increase from 10 to 20 mg of added P before leveling off from 20 to 40 mg of added P. Broiler ash treatments increase in P adsorption at each level of added P except for the BA100 treatment which remains constant from 20 to 40 mg of added P (Figure 5). Broiler litter treatments increase in P adsorption at each level of added P (Figure 6). The reagent grade, broiler ash, and broiler litter treatments all increase greatest in P adsorption from 10 to 20 mg of added P. The control treatment which received no P during incubation is closest to a linear line.

The control, reagent grade, broiler litter, and broiler ash P adsorption was graphed using the Langmuir equation for maximum P adsorption in Figure 7, 8, and 9. Figure 7 shows that P adsorption for RG100 and RG200 are similar then decreases for RG300 and further decreased with RG400. Figure 8 shows that P adsorption for soils amended with broiler ash increases from BA100 to BA200. The BA100 and BA200 treatments are very similar on the graph before decreasing at the BA400 treatment level. Previous studies have shown that coal fly ash increases in Langmuir P adsorption as rate of fly ash increased; this may have been the result of precipitation as a calcium phosphate (O'Reilly and Simms, 1995). Figure 9 shows the P adsorption as greatest for the BL100 treatment then decreasing for the BL200 treatment before increasing once again for the BL300 treatment. The BL300 and BL400 treatments are nearly equal. The control treatment was graphed on each figure against the reagent grade, broiler litter and broiler ash treatment and had the greatest P adsorption in each one.

Table 14 lists the Langmuir predicted maximum anion adsorption rates for the reagent grade, broiler litter, and broiler ash treatments. The control treatment had the greatest predicted maximum adsorption rate of 159 mg kg^{-1}. There was no source of P applied to the control during incubation therefore this resulted in a high adsorption rate of P when KH_2PO_4 was added. The broiler ash and reagent grade treatments reduced predicted maximum absorption of P at 336 kg P_2O_5 ha^{-1}. Therefore, the soil reaches it maximum adsorption capacity at the rate of 224 kg P_2O_5 ha^{-1} for the reagent grade and broiler ash treatments. The soil adsorbed more P from the reagent grade treatments than the broiler litter and broiler ash treatments during incubation for all rates of P applied. The P in the broiler litter could have been tied up in the organic fraction. There was no difference in P adsorbed during incubation for broiler litter and broiler ash treatments at the 336 and 448 kg P_2O_5 ha^{-1}. The broiler ash treatments adsorbed more P than the broiler litter treatments during incubation at the rate of 112 kg P_2O_5 ha^{-1}. The broiler litter treatments reduced predicted maximum adsorption of P at 224 kg P_2O_5 ha^{-1}. The predicted maximum adsorption increased again from the BL200 to BL300 treatment. This could possibly be the result of an error in preparing the jars as this is not the distribution expected.

V. CONCLUSIONS

The Sand Mountain data sheets of the broiler litter survey found that 1.11 kg of litter bird^{-1} was produced based on 12 broiler houses that had completed bird and litter data sheets. The total C and total N of the samples were 375 g kg^{-1} and 32 g kg^{-1} for a C:N ratio of 12:1. The average P and K were 19 g kg^{-1} and 28 g kg^{-1}.

Broiler litter ignition did not change the concentration of Ca and P as temperature increased. Potassium decreased in concentration from 40 g kg^{-1} to 5 g kg^{-1} as temperature increased, possibly as a result of K interacting with Cl in litter under high temperatures. The micronutrients such as Cu, Fe, AL, Zn, and Mn all decreased in concentration as temperature increased. Reason for this is unknown as micronutrients did not reach their boiling points.

The results of the greenhouse experiment showed that yield for broiler ash treatments was significantly greater than that for broiler litter treatments for the first and second harvest of ryegrass. Broiler ash treatments were significantly greater in total yield for ryegrass than broiler litter treatments. The broiler ash K treatment provided yield increases for sorghum-sudangrass after the first harvest. The broiler litter and broiler ash treatments were greater than the reagent grade treatments for the first sorghum-sudangrass harvest. The broiler litter and broiler ash treatments showed no significant difference in yield for the second harvest of sorghum-sudangrass. The reagent grade P+K treatment provided the greatest yield increase from the first to second harvest for sorghum-sudangrass. There was no significant difference in total yield for sorghum-sudangrass between broiler litter and broiler ash treatments based on the P requirement.

There was no significant difference in P uptake for ryegrass between broiler litter and broiler ash treatments for harvest 2. There was no significance difference in K uptake between BLK and BAK for harvest 1 or 2 of ryegrass. There was no significant difference in P uptakes in treatments BLP and BAP for harvest one or two of sorghum-sudangrass. The P uptakes from the first to second harvest in sorghum-sudangrass increased in each treatment. More P was left in the soil in broiler ash treatments than in broiler litter treatments. The amount of extractable K in the soil did not increase from the levels after the second harvest of ryegrass except in the reagent grade K treatment.

The broiler ash fractionation study showed that the majority of the broiler ash passed a 10 mesh screen. The P, K, and Mg concentration all increase as the broiler ash particles become finer. The micronutrient concentrations of Cu, Mn, and Zn increased as particle size decreased.

The P adsorption study resulted in the control which received no P having the highest levels of P adsorption at 10 mg P, 20 mg P, and 40 mg P. The broiler ash and reagent grade treatments reduced predicted maximum absorption of P at 336 kg P ha^{-1}. The soil adsorbed more P from the reagent grade treatments than the broiler litter and broiler ash treatments during incubation for all rates of P applied. There was no difference in P adsorbed during incubation for broiler litter and broiler ash treatments at the 336 and 448 kg P ha^{-1}.

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Table 1. Nutrient concentrations from Broiler Litter surveys in the Southeast States.

State	N	P	K	Reference
	------------g kg^{-1}------------			
Alabama	40	16	23	Stephenson et. al., 1990
Alabama	31	27.7	20.4	Mitchell and Donald 1995
Georgia	33	25	20	Vest et. al., 1994
Mississippi	28.5	14.5	29.5	Patterson et. al., 1998
Average	33	21	23	

Table 2. Analysis of soil amendments used in greenhouse and P adsorption study.

Element	Broiler Litter	Broiler Ash
	---------------g kg^{-1}----------------	
Nitrogen	25	-
Phosphorus	23	89
Potassium	34	120
Calcium	34	121
Magnesium	7	28
Ash	280	-
Carbon	264	-
C:N Ratio	105	-
	-------------mg kg^{-1}-------------	
Copper	575	1762
Aresnic	10.5	46
Manganese	566	2003
Zinc	510	1575

Table 3. Sand mountain broiler litter survey nutrient concentrations.

Element	Mean	Std. Dev.	Std. Error	Min	Max
	---------------------g kg^{-1}-----------------------				
Total C	375	16	3.5	336	397
Total N	32	2.4	0.52	28	38
P	19	1.01	0.21	16	20
K	28	2.2	0.48	25	33
Ca	26	3.2	0.69	20	37
	---------------------mg kg^{-1}--------------------				
Cu	500	195	42	277	919
Zn	433	56	12	303	518
Fe	1778	712	152	912	4072
Mn	432	60	13	294	539
Al	1513	859	183	579	4437

Table 4. Broiler Litter concentration at ignition in Muffle Furnace.

	Muffle Furnace Temperature			
Element	450 C	650 C	850 C	1000 C
	---------------------g kg^{-1}--------------------			
P	27 ± 1.30†	26 ± 0.79	27 ± 0.51	27 ± 0.33
K	40 ± 1.87	28 ± 1	19 ± 0.58	5 ± 0.63
Ca	38 ± 1.96	38 ± 1.06	35 ± 0.79	39 ± 0.31
Mg	7 ± 0.30	7 ± 0.19	6 ± 0.08	4 ± 0.09
Si	0.3 ± 0.03	0.4 ± 0.02	0.4 ± 0.03	0.4 ± 0.08
Na	10 ± 0.41	9 ± 0.45	9 ± 0.41	8 ± 0.15
	----------------mg kg^{-1}--------------------			
Cu	675 ± 25	132 ± 19	161 ± 22	103 ± 11
Fe	1899 ± 62	1741 ± 39	1575 ± 24	539 ± 15
Mn	591 ± 26	569 ± 15	447 ± 7	281 ± 3
Zn	590 ± 24	453 ± 13	271 ± 8	91 ± 9
B	82 ± 4	83 ± 3	74 ± 3	20 ± 4
Al	2202 ± 116	2222 ± 65	1967 ± 31	994 ± 143
Ba	32 ± 6	54 ± 27	32 ± 4	43 ± 7
Co	1 ± 0.1	1 ± 0.1	1 ± 0.1	0.2 ± 0.1
Cr	42 ± 4	29 ± 3	45 ± 4	33 ± 3
Pb	17 ± 0.6	9 ± 0.5	16 ± 0.6	13 ± 0.8

† Mean values and standard error

Table 5. The effects of Broiler Litter, Broiler Ash, and Reagent Grade materials on ryegrass and sorghum-sudangrass yields.

		Control	Broiler Litter		Broiler Ash		Reagent Grade			P>F	$LSD_{0.10}$
Crop	Harvest		BLP	BLK	BAP	BAK	RGP	RGK	RGPK		
		g pot^{-1}									
Ryegrass	1	1.08	4.08	3.83	4.50	4.66	3.20	3.43	4.59	<.0001	0.32
	2	1.80	3.32	3.42	4.16	4.79	3.94	4.77	4.79	<.0001	0.58
Sorghum-Sudangrass	1	0.67	7.53	6.02	7.25	9.65	2.33	0.48	2.93	<.0001	0.59
	2	3.35	10.79	14.83	10.91	13.56	4.61	0.61	16.68	<.0001	1.43

Table 6. The effects of Broiler Litter, Broiler Ash, and Reagent Grade materials on ryegrass and sorghum-sudangrass plant heights.

		Control	Broiler Litter		Broiler Ash		Reagent Grade			P>F	$LSD_{0.10}$
Crop	Harvest		BLP	BLK	BAP	BAK	RGP	RGK	RGPK		
			cm								
Ryegrass	1	15.05	22.75	22.38	23.63	25.50	22.63	21.65	23.50	<.0001	1.74
	2	8.00	11.43	11.98	12.80	13.18	12.08	13.25	13.25	<.0001	0.40
Sorghum-Sudangrass	1	27.75	65.00	62.75	66.50	69.25	37.25	16.75	40.75	<.0001	5.00
	2	43.25	60.50	63.75	61.50	65.75	47.25	22.50	87.75	<.0001	8.45

Table 7. Phosphorus and Potassium uptake from Broiler Litter, Broiler Ash, and Reagent Grade sources for ryegrass.

		Control	Broiler Litter		Broiler Ash		Reagent Grade			P>F	$LSD_{0.10}$
Element	Harvest		BLP	BLK	BAP	BAK	RGP	RGK	RGPK		
		----------	mg pot^{-1}	----------							
Phosphorous	1	2.98	12.03	12.49	10.86	14.65	12.99	5.74	15.57	<.0001	1.99
	2	2.50	6.31	7.91	6.21	7.96	14.83	5.02	10.95	<.0001	1.90
Total P Uptake		5.48	18.34	20.40	17.07	22.61	27.82	10.75	26.52	<.0001	2.38
Potassium	1	14.93	107.10	126.33	94.80	130.23	22.78	116.36	133.60	<.0001	10.81
	2	12.06	30.00	48.24	25.28	40.91	11.78	62.37	50.49	<.0001	7.42
Total K Uptake		26.99	137.1	174.57	120.09	171.14	34.56	178.73	184.09	<.0001	10.99

Table 8. Phosphorus and Potassium uptake from Broiler Litter, Broiler Ash, and Reagent Grade sources for sorghum-sudangrass.

		Control	Broiler Litter		Broiler Ash		Reagent Grade			P>F	$LSD_{0.10}$
Element	Harvest		BLP	BLK	BAP	BAK	RGP	RGK	RGPK		
		mg pot^{-1}									
Phosphorous	1	1.04	9.53	16.68	8.46	14.07	10.29	0.43	11.03	<.0001	1.46
	2	1.93	10.36	18.09	11.23	17.89	15.62	0.38	23.32	<.0001	2.57
Total P Uptake		2.97	19.89	34.78	19.69	31.96	25.91	0.81	34.36	<.0001	2.51
Potassium	1	5.71	61.91	124.76	47.78	125.62	7.38	5.01	61.94	<.0001	9.29
	2	7.70	20.38	53.55	26.21	51.91	5.43	4.70	99.74	<.0001	11.10
Total K Uptake		13.41	82.29	178.31	73.99	177.53	12.81	9.71	161.68	<.0001	10.58

Table 9. Phosphorus and Potassium supplied by Broiler Litter, Broiler Ash, and Reagent Grade sources to ryegrass.

Treatment	Rate	P_2O_5	K_2O
	---mg pot^{-1}---	----------mg pot^{-1}---------	
		Reagent Grade	
RGP	533	300	0
RGK	477	0	300
RGPK	1010	300	300
		Broiler Litter	
BLP	5650	300	233
BLK	7282	387	300
		Broiler Ash	
BAP	1472	300	212
BAK	2083	425	300

Table 10. Phosphorus and Potassium supplied by Broiler Litter, Broiler Ash, and Reagent Grade sources to sorghum-sudangrass.

Treatment	Rate	P_2O_5	K_2O
	---mg pot^{-1}---	----------mg pot^{-1}---------	
		Reagent Grade	
RGP	320	180	0
RGK	478	0	300
RGPK	798	180	300
		Broiler Litter	
BLP	3390	180	140
BLK	7282	387	300
		Broiler Ash	
BAP	883	180	127
BAK	2083	425	300

Table 11. Final Soil test results for all treatments after sorghum-sudangrass harvest 2.

Treatment	pH	P	K	Mg	Ca
		---------------mg kg^{-1}	------------------		
Control	6.5c†	7d	10de	44a	505c
RGP	6.3dc	24c	9e	29c	479c
RGK	5.8e	7d	64a	47a	493c
RGPK	6.3d	21c	15b	30c	486c
BLP	6.4bac	20c	11de	31c	510bc
BLK	6.6a	33b	12dc	39b	570ba
BAP	6.3bdc	31b	13c	31c	512c
BAK	6.5a	52a	15b	39b	569a

† Numbers followed by same letter within column are not significant at $p < 0.10$.

Table 12. Broiler Ash nutrient concentration at different size fractions

	Mesh Screen Size		
Element	<10	Pass 10	Pass 60
	--------------------g kg^{-1}-------------------		
P	79	98	104
K	96	109	145
Ca	107	137	128
Mg	22	22	34
	-------------------mg kg^{-1}-----------------		
Cu	1213	1339	2214
Mn	1583	1636	2244
Zn	1174	1296	1883

Table 13. P adsorption at each level for Reagent Grade, Broiler Ash, and Broiler Litter amended soil.

KH_2PO_4 added	Control	RG100	RG200	RG300	RG400
-----mg------	-------------------mg kg^{-1}---------------------				
10	73	67	64	63	62
20	115	101	91	92	91
40	141	97	97	93	88
KH_2PO_4 added	Control	BA100	BA200	BA300	BA400
-----mg-----	-------------------mg kg^{-1}---------------------				
10	73	76	70	71	65
20	115	116	111	99	93
40	141	115	124	120	104
KH_2PO_4 added	Control	BL100	BL200	BL300	BL400
-----mg-----	-------------------mg kg^{-1}---------------------				
10	73	73	73	67	61
20	115	107	96	98	92
40	141	132	102	115	99

Table 14. Langmuir maximum P adsorption for Reagent Grade, Broiler Ash, and Broiler Litter treated soil.

Treatment	kg P_2O_5 ha^{-1} added	1 b^{-1}	b (mg kg^{-1})
Control	0	0.0063	159
		Reagent Grade	
RG100	112	0.0099	101
RG200	224	0.0097	103
RG300	336	0.0101	99
RG400	448	0.0109	92
		Broiler Ash	
BA100	112	0.0084	119
BA200	224	0.0074	135
BA300	336	0.0077	130
BA400	448	0.0089	112
		Broiler Litter	
BL100	112	0.0068	147
BL200	224	0.0094	106
BL300	336	0.0079	127
BL400	448	0.0092	109

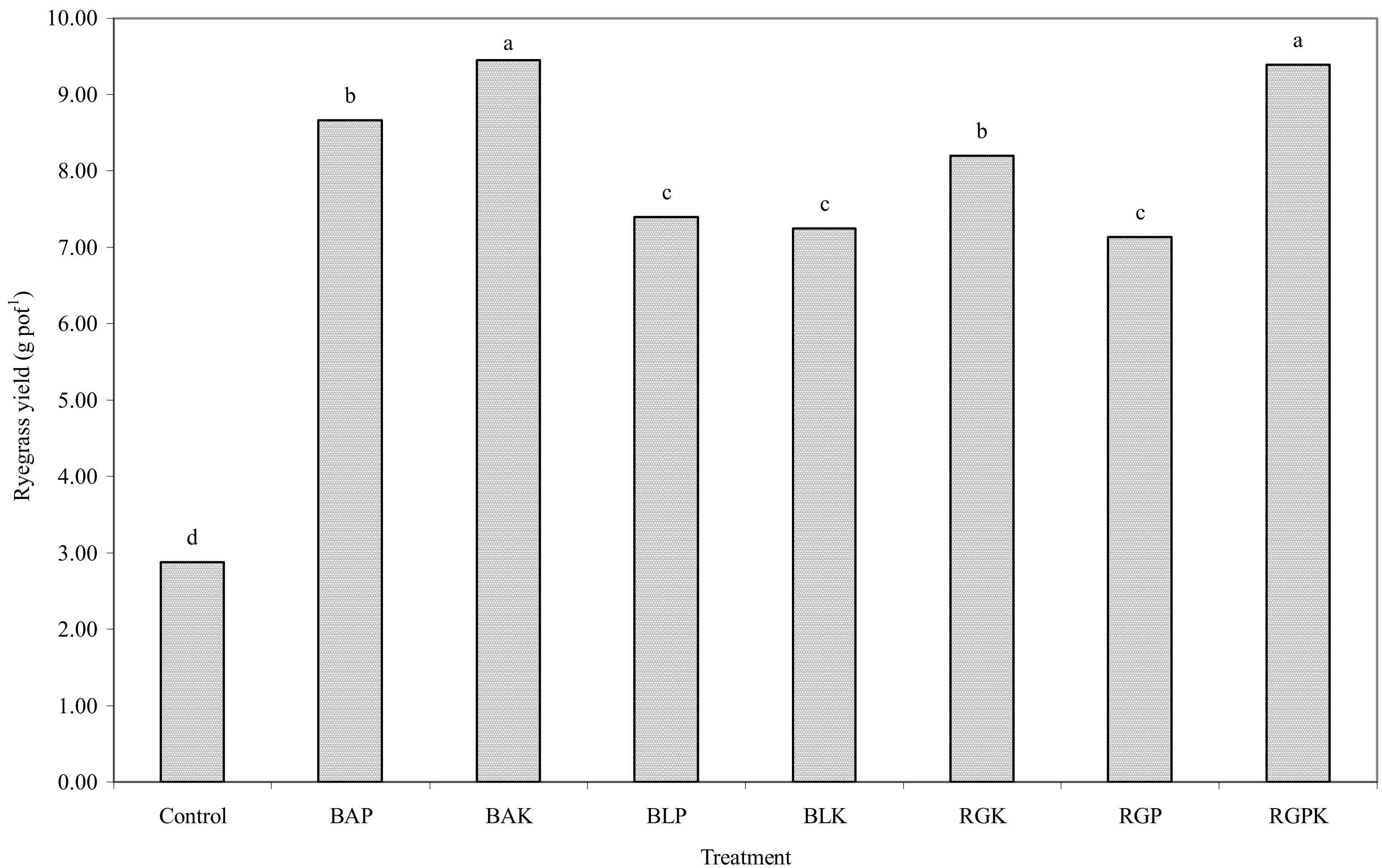

Figure 1. Total ryegrass yields for greenhouse experiment. Letters a-d represent significant differences at the 0.10 probability level.

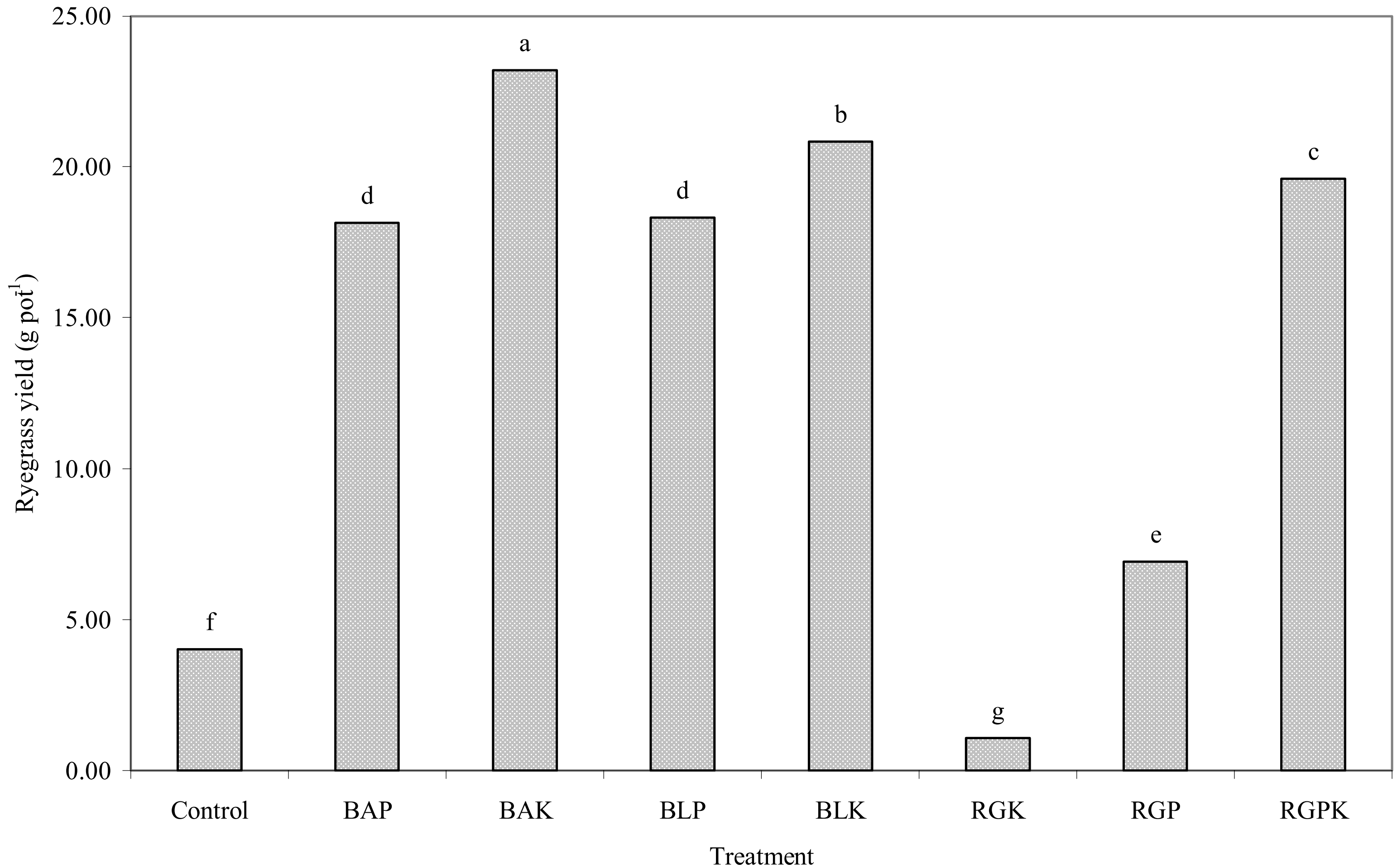

Figure 2. Total sorghum-sudangrass yield for greenhouse experiment. Letters a-g indicate significant differences at the 0.10 probablility level.

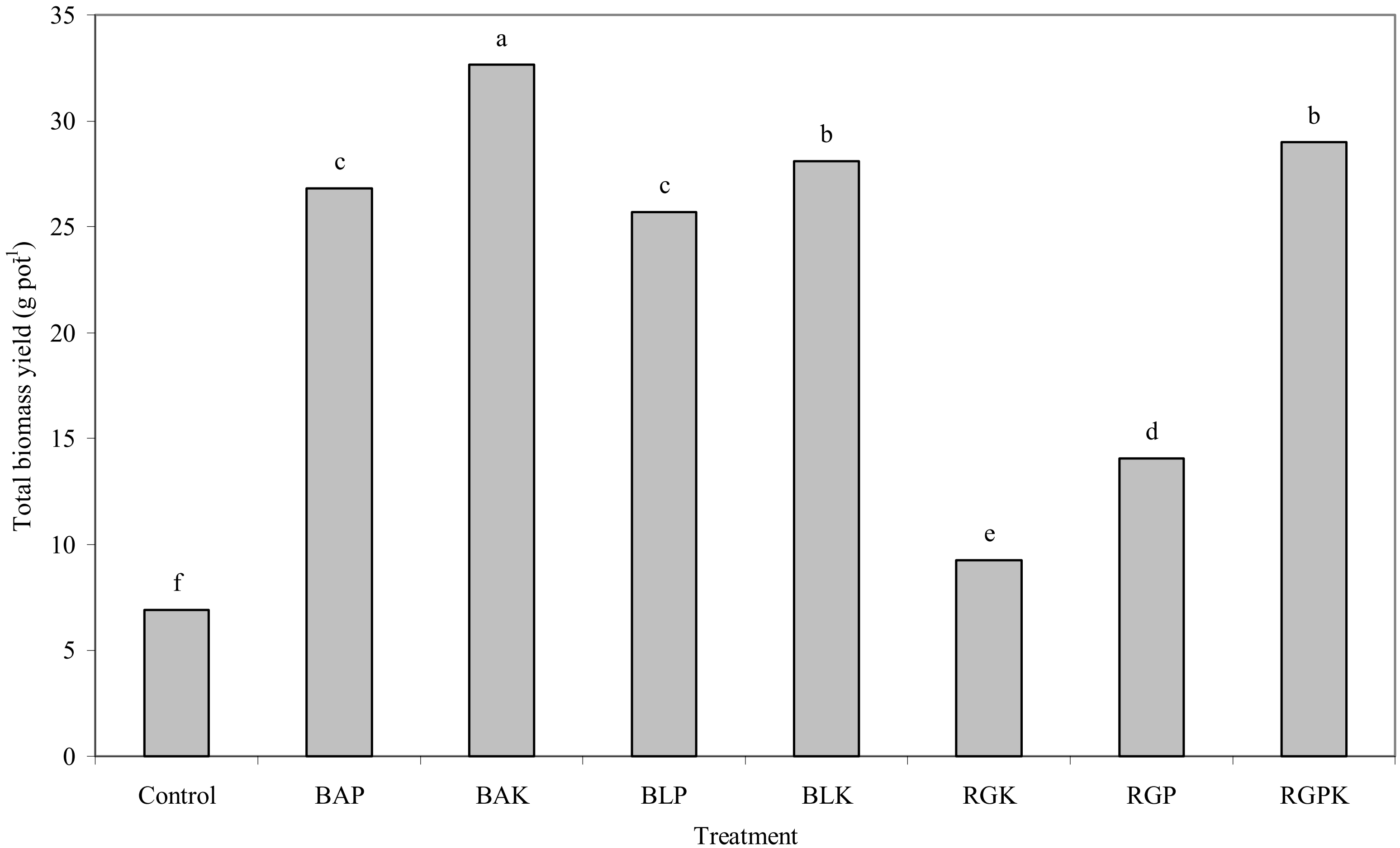

Figure 3. Total biomass yield for greenhouse experiment .Letters a-f represent significant difference at the 0.10 probability level.

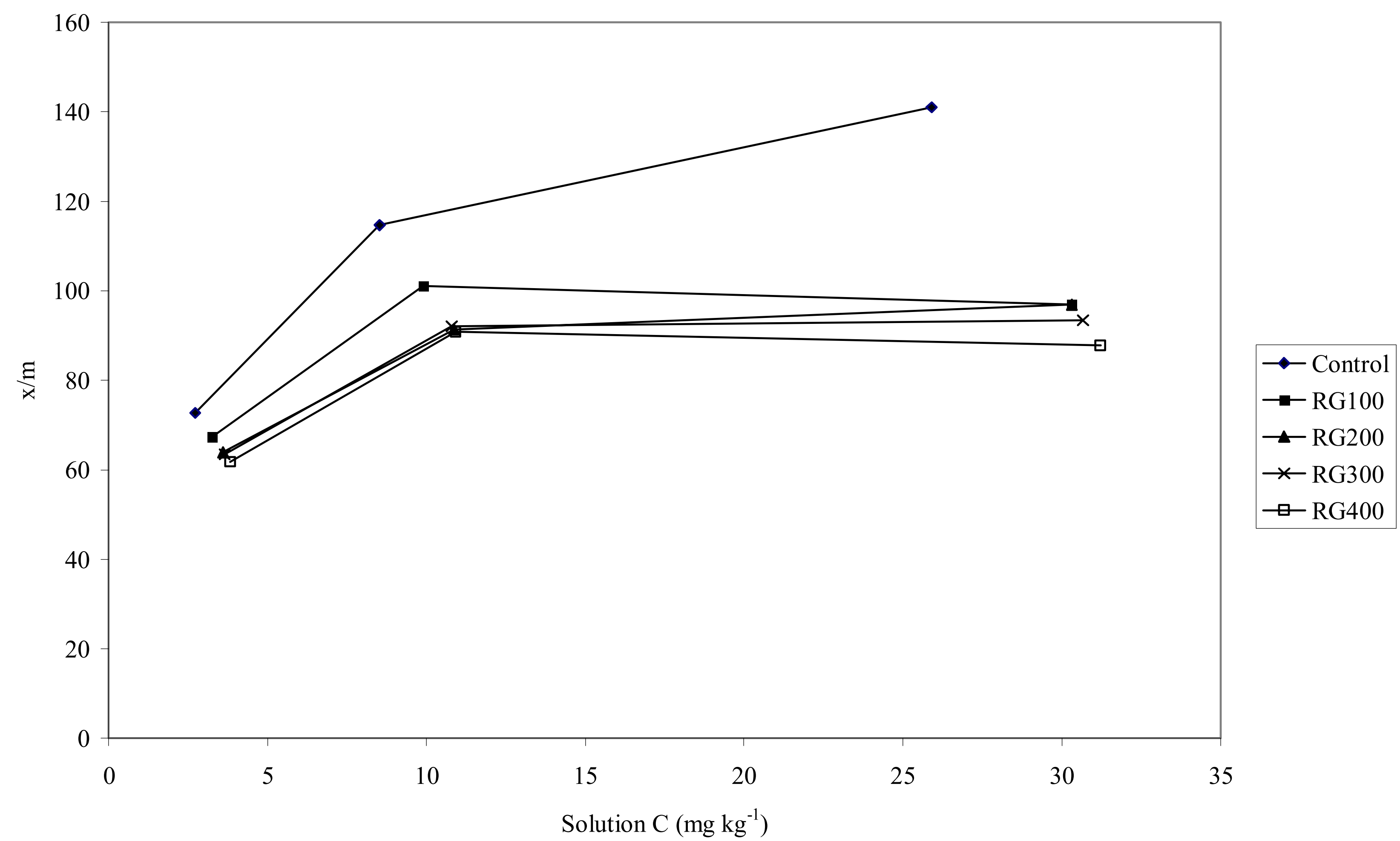

Figure 4. Reagent Grade P adorption at 10, 20, and 40 mg of KH_2PO_5 added .

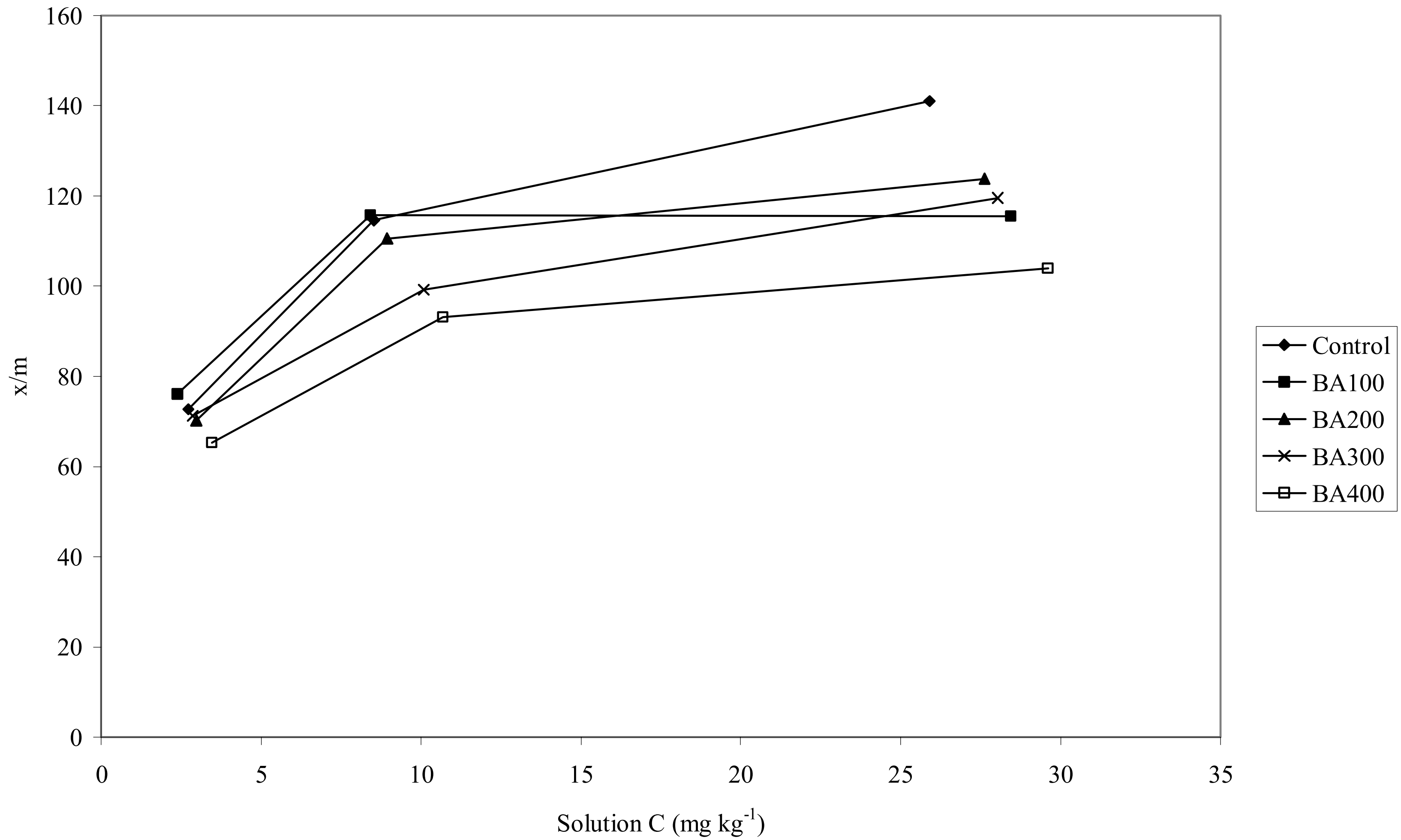

Figure 5. Broiler Ash P adsorption at 10, 20, and 40 mg of KH_2PO_4 added.

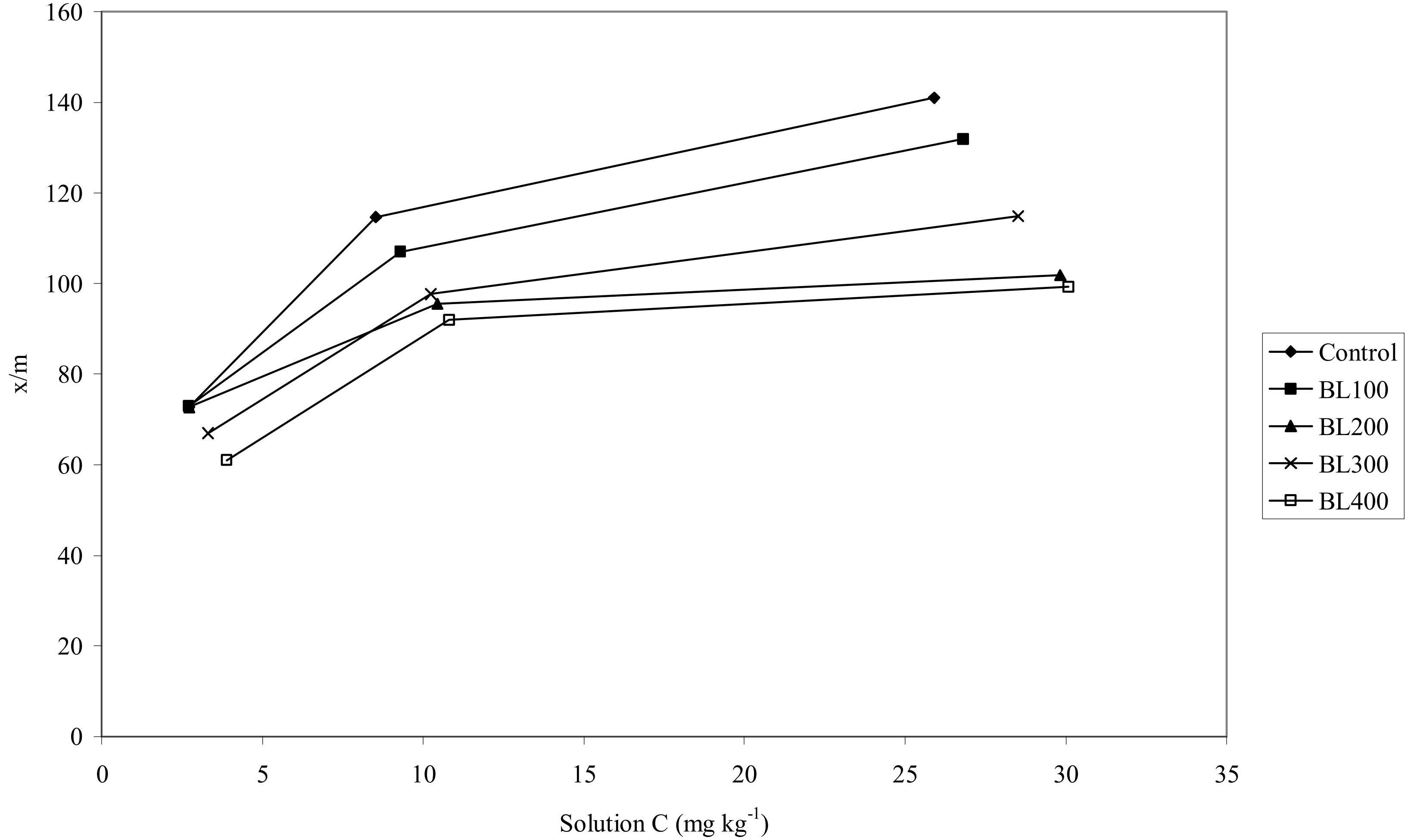

Figure 6. Broiler Litter P adsorption at 10, 20, and 40 mg of KH_2PO_5 added.

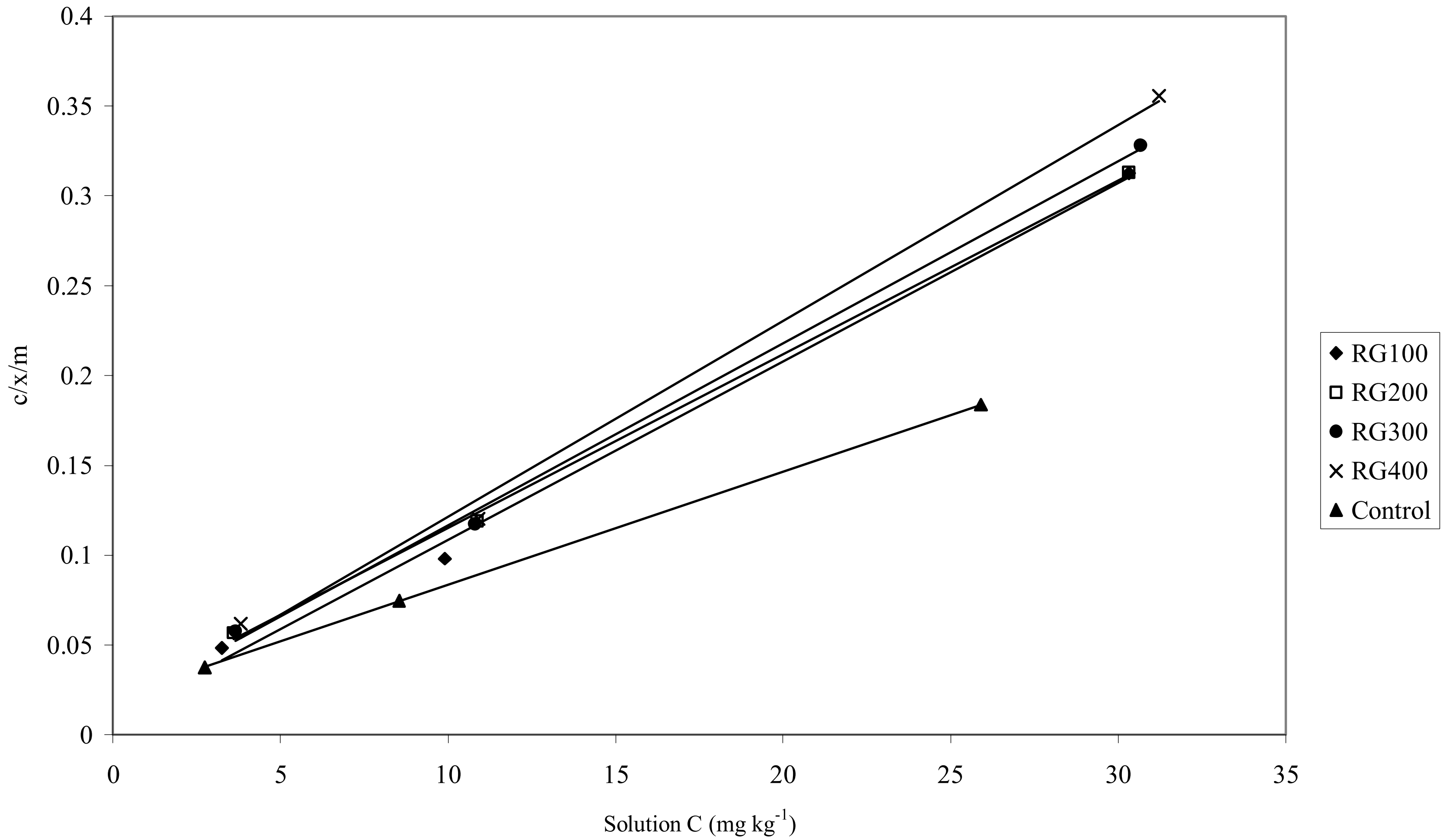

Figure 7. Reagent Grade maximum P adsorption equilibrium based on the Linear form of the Langmuir equation.

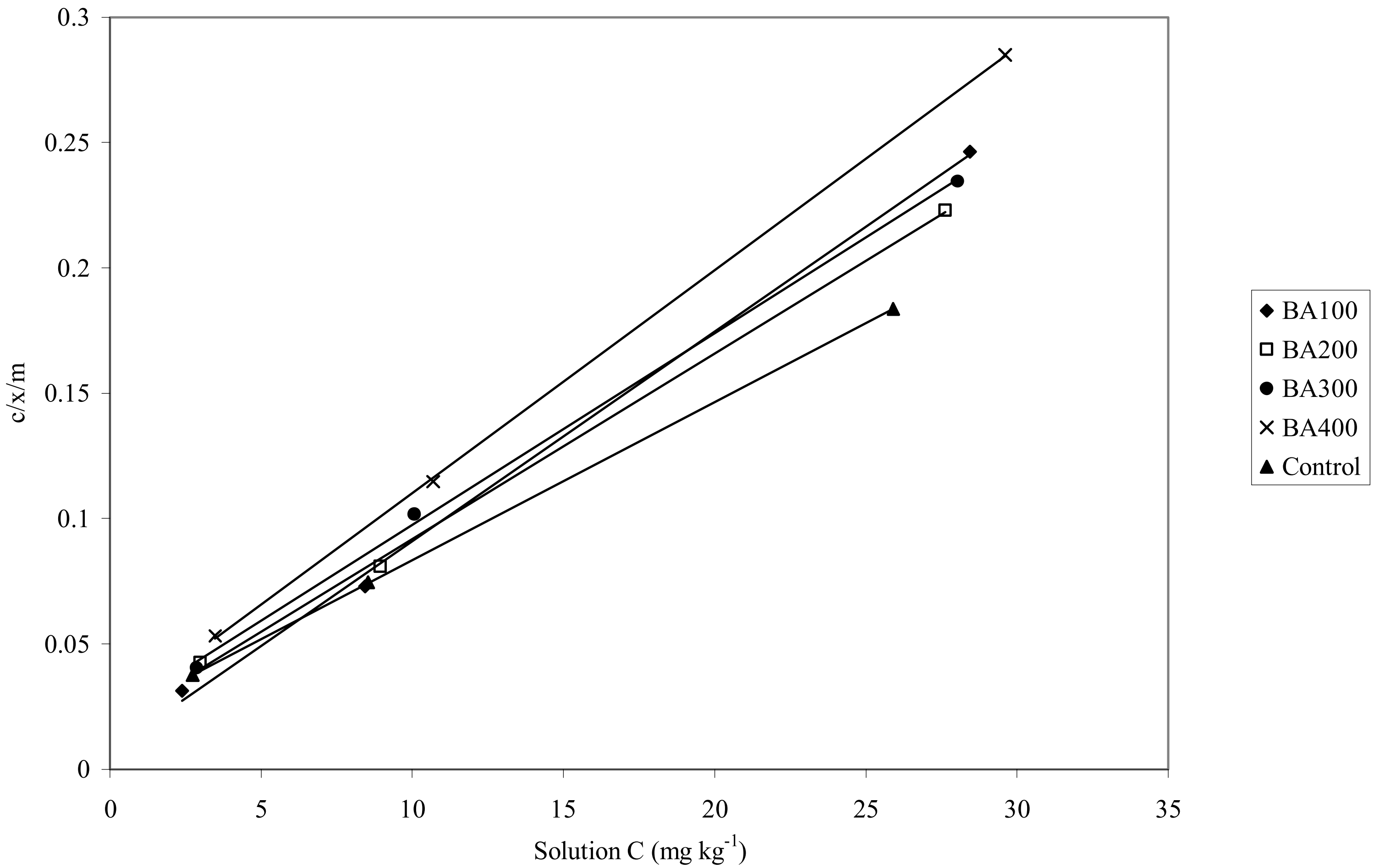

Figure 8. Broiler Ash maximum P adsorption equilibrium based on the Linear form of the Langmuir equation.

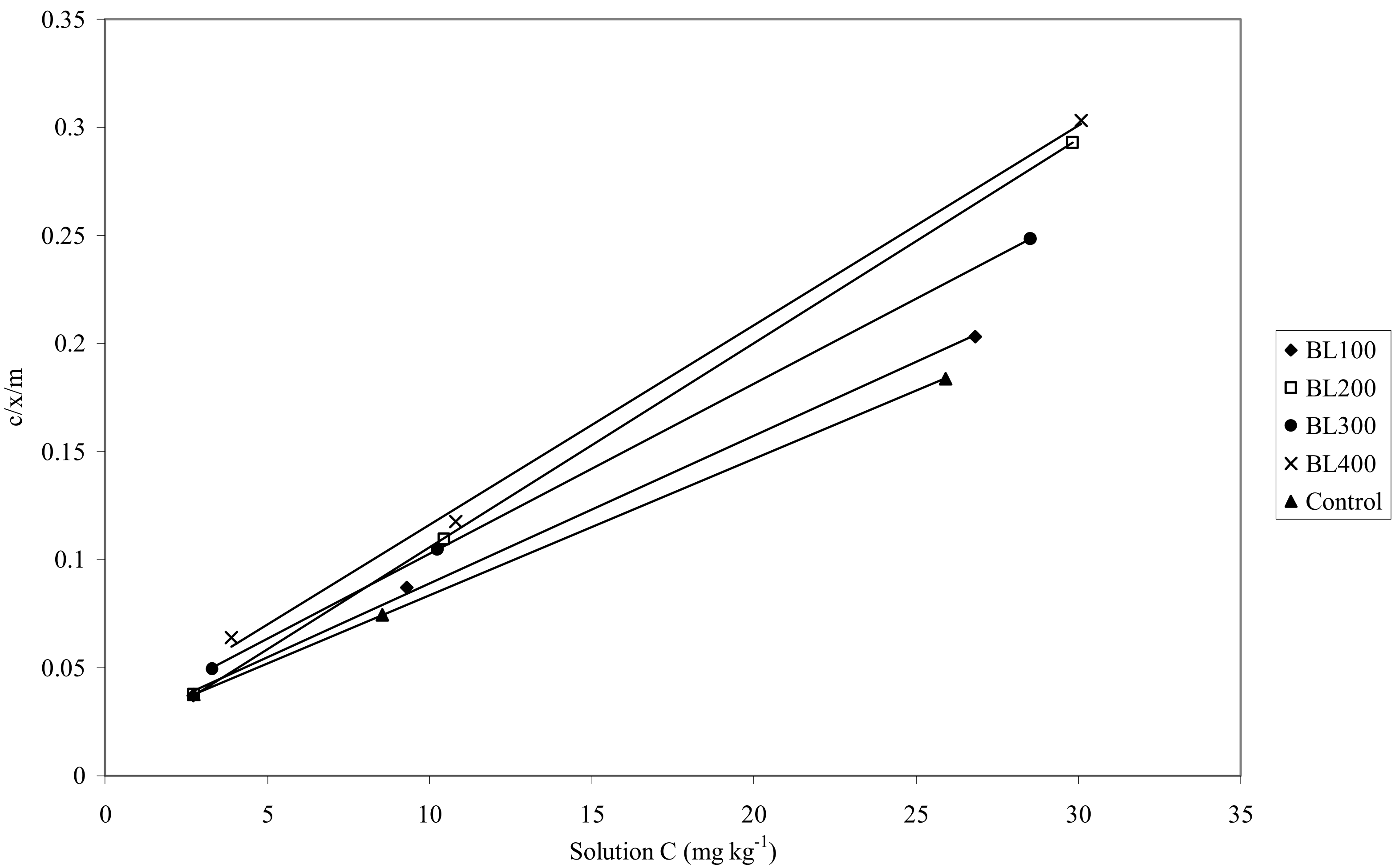

Figure 9. Broiler Litter maximum P adsorption equilibrium based on the Linear form of the Langmuir equation.