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Methods for decreasing non-point source pollution from poultry manure

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US005928403A

United States Patent [19]

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Moore, Jr.

[45] Date of Patent: ***Jul. 27, 1999**

[54] **METHODS FOR DECREASING NON-POINT SOURCE POLLUTION FROM POULTRY MANURE**

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[73] Assignees: **Trustees of University of Arkansas, Fayetteville, Ark.; The United States of America as represented by the Secretary of Agriculture, Washington, D.C.**

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[*] Notice: This patent is subject to a terminal disclaimer.

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[21] Appl. No.: **08/717,067**

OTHER PUBLICATIONS

[22] Filed: **Sep. 20, 1996**

Derwent Assession No. 1990-122131.

Related U.S. Application Data

Primary Examiner—Robert H. Harrison
Attorney, Agent, or Firm—Needle & Rosenberg, P.C.; Arthur J. Plantamura

[60] Continuation-in-part of application No. 08/437,991, May 10, 1995, Pat. No. 5,622,697, which is a division of application No. 05/129,742, Sep. 30, 1993, abandoned.

[51] **Int. Cl.⁶** **C05F 3/00**
 [52] **U.S. Cl.** **71/21; 588/221; 588/224; 588/236**
 [58] **Field of Search** 210/903, 916, 210/906; 71/11, 15, 18, 21, 901; 588/221, 224, 236, 242, 246

[57] ABSTRACT

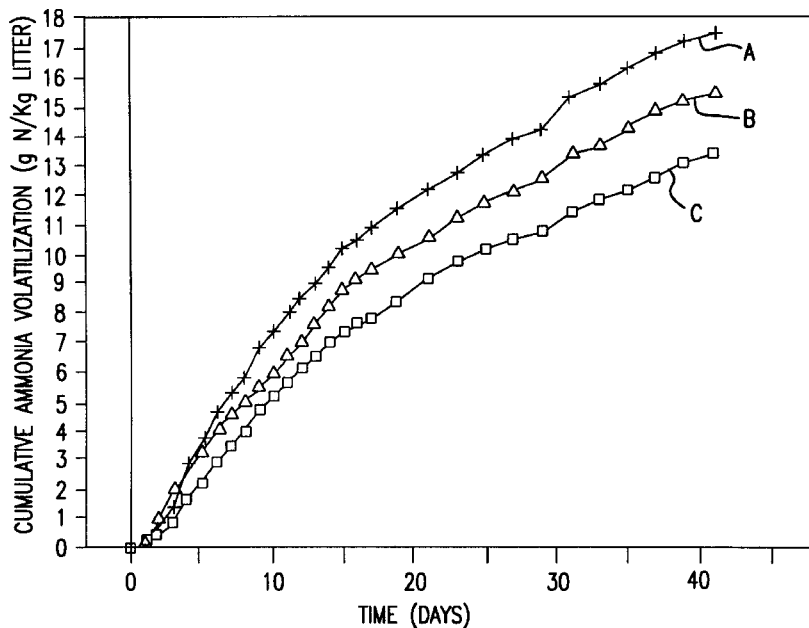
Poultry production is improved by treating poultry manure in the growing location with alum in an amount of from about 0.75 to about 1.5 tons of alum per 10000 birds raised, or at least 0.15 to about 0.25 pounds of alum per bird raised. Poultry manure treatment with alum improves weight gain and feed conversion and decreases mortality for birds grown on treated manure as compared with birds grown on untreated manure. The alum-treated manure may also be used as an agricultural fertilizer. When used as agricultural fertilizer in agricultural runoff water studies, plots fertilized with alum-treated manure exhibit decreased concentrations of phosphorus and heavy metals such as arsenic, copper, iron and zinc as compared with plots fertilized with untreated, normal poultry manure.

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11 Claims, 22 Drawing Sheets



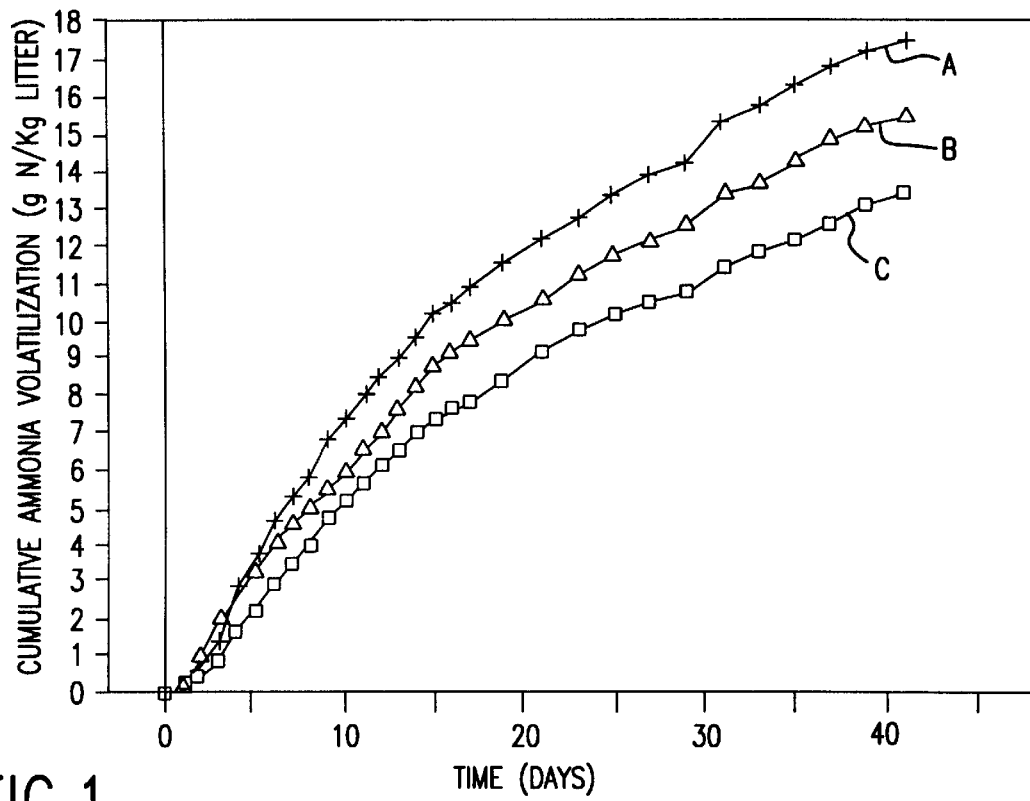


FIG. 1

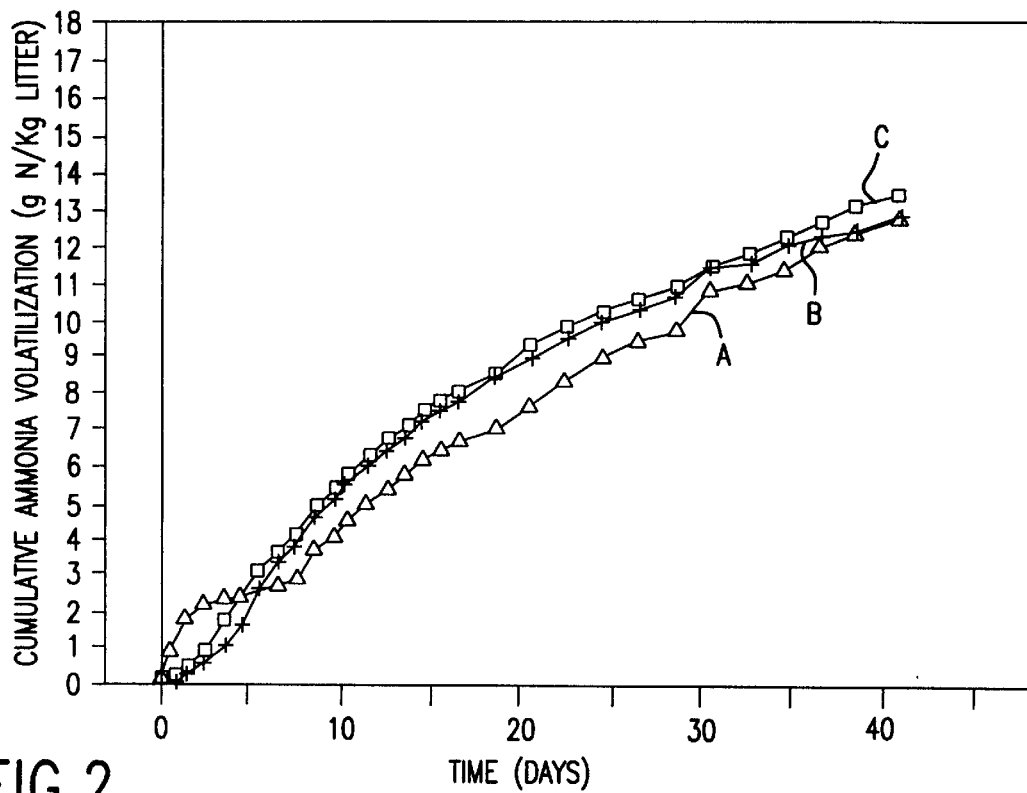


FIG. 2

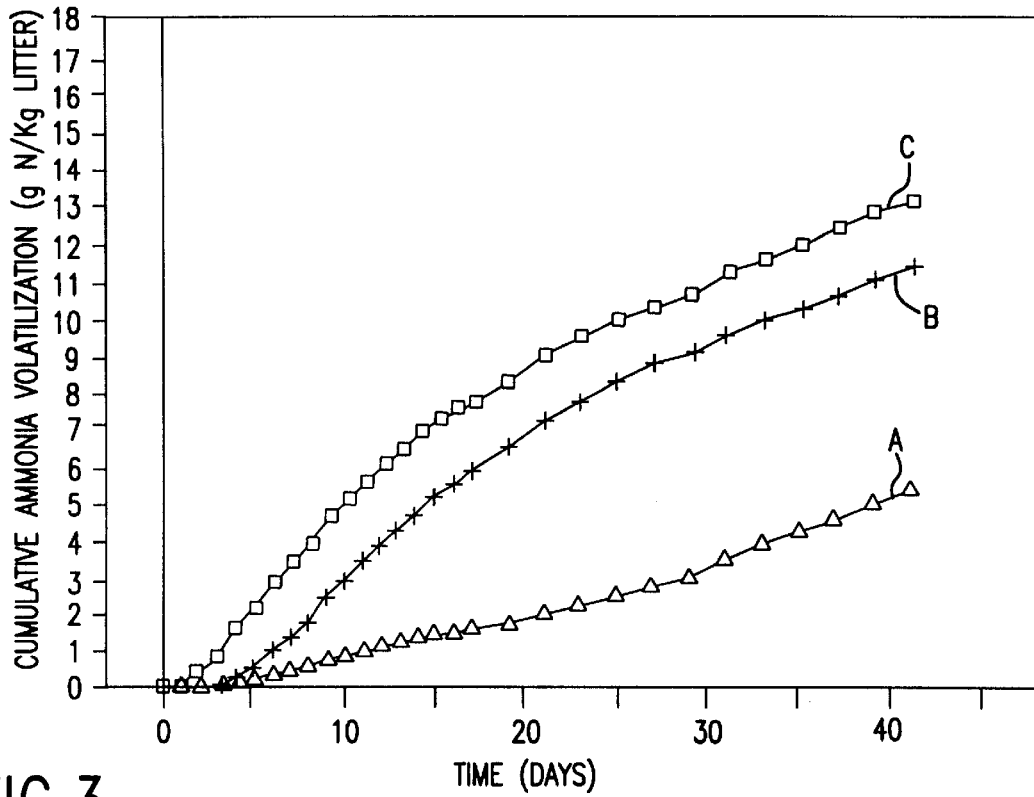


FIG.3

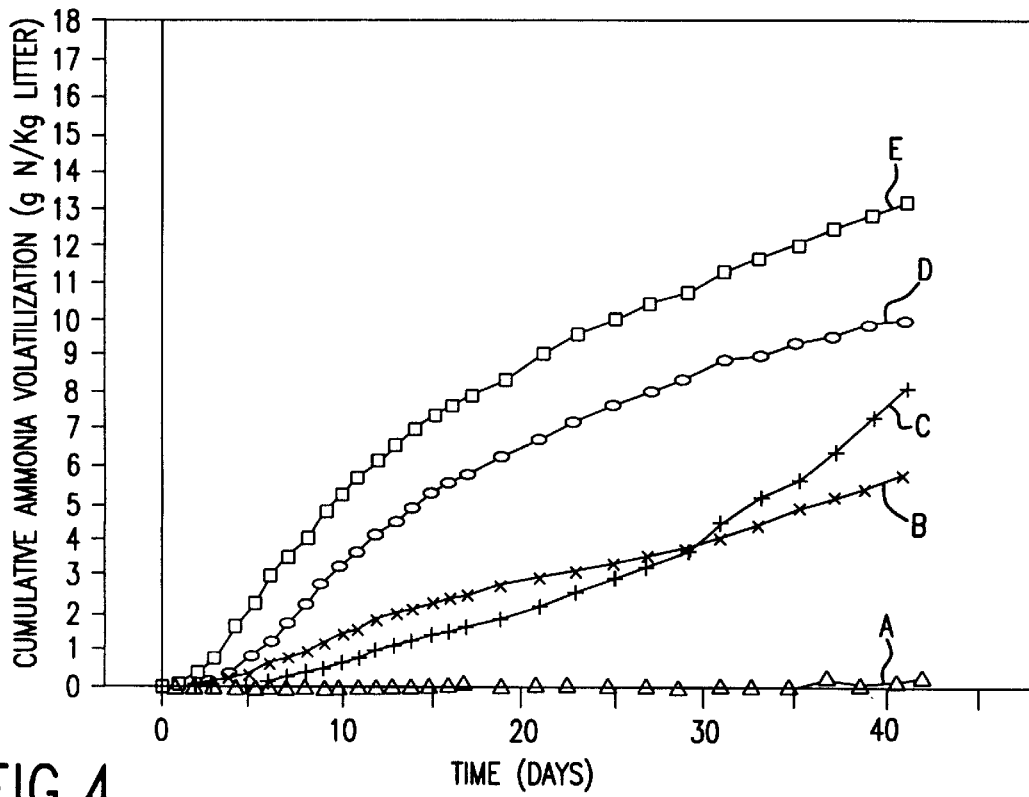


FIG.4

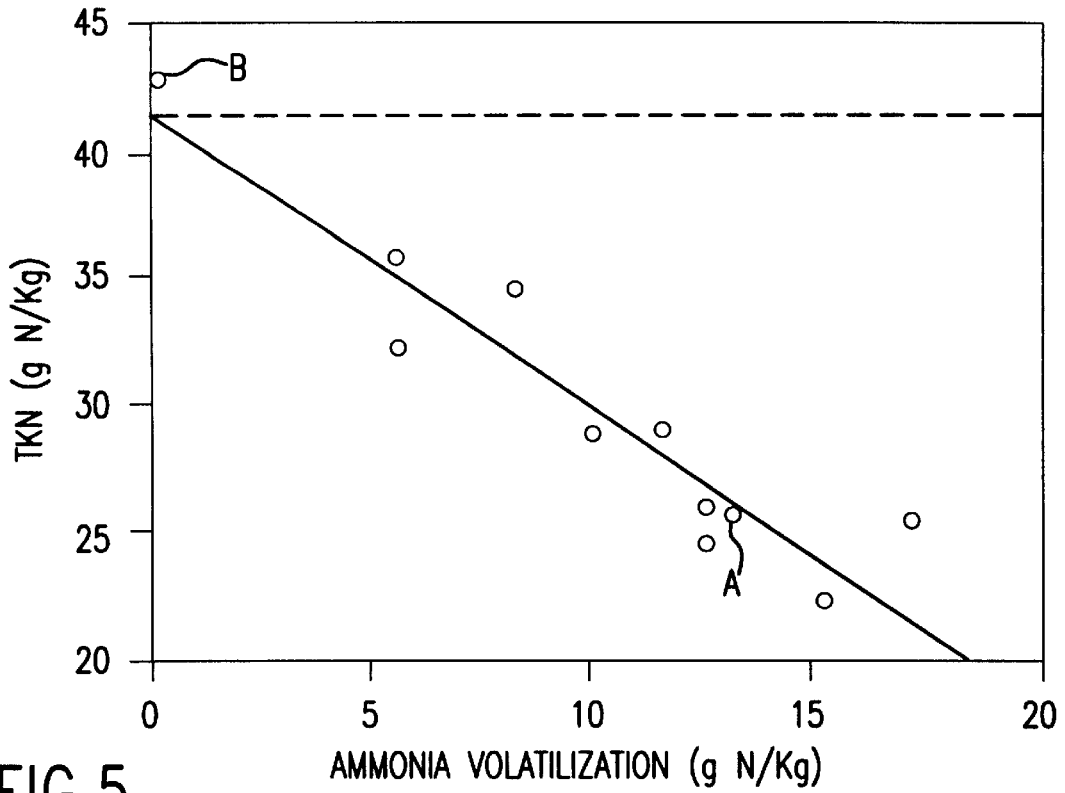


FIG.5

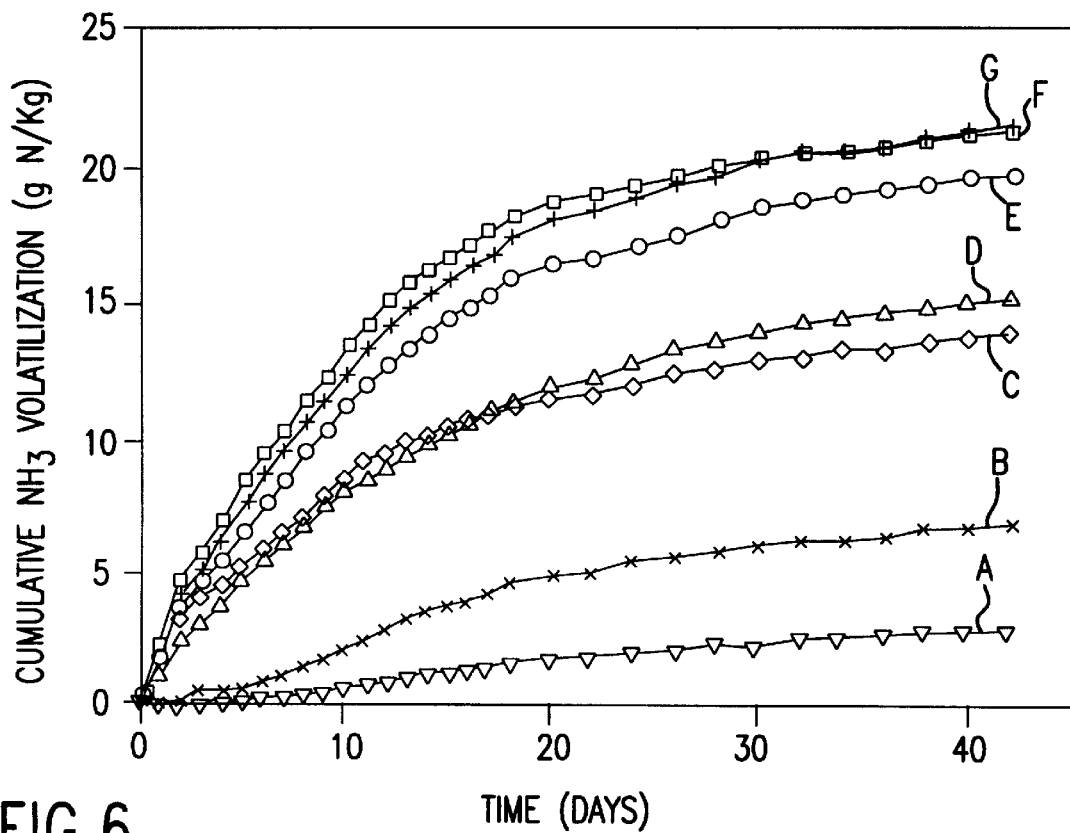


FIG.6

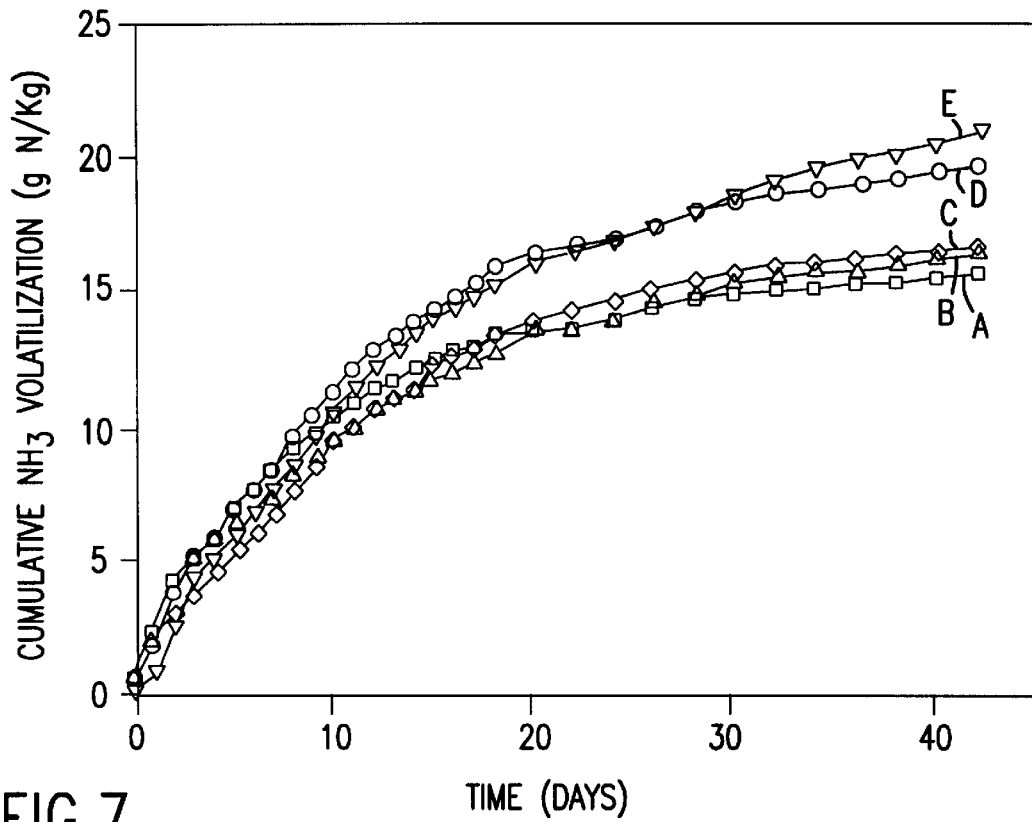


FIG. 7

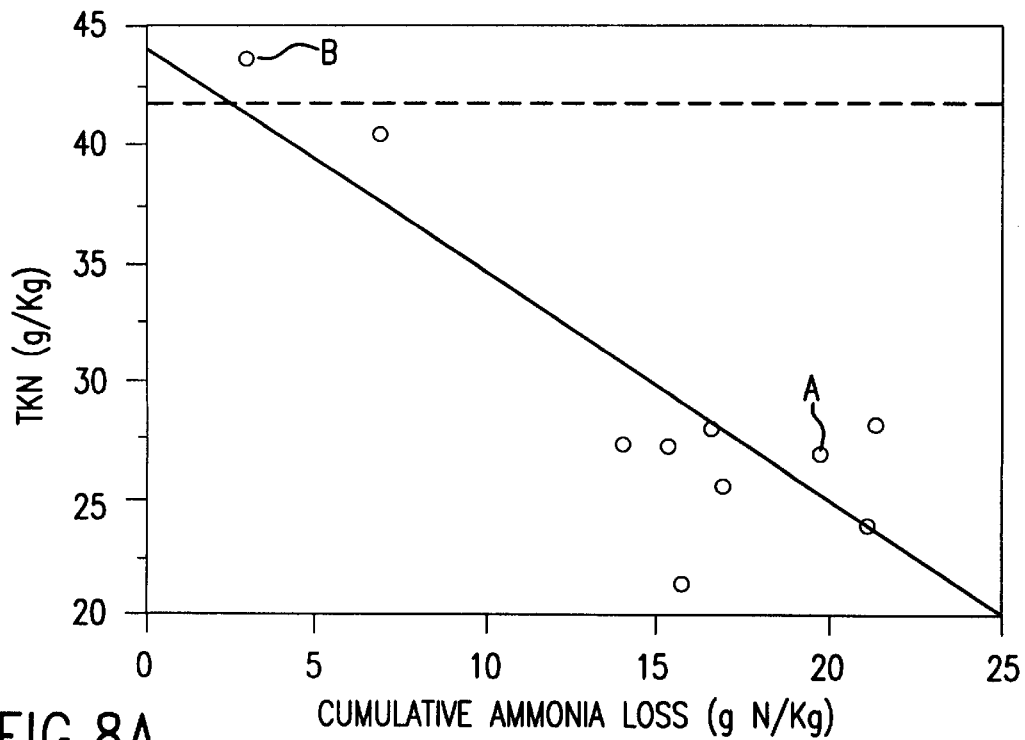


FIG. 8A

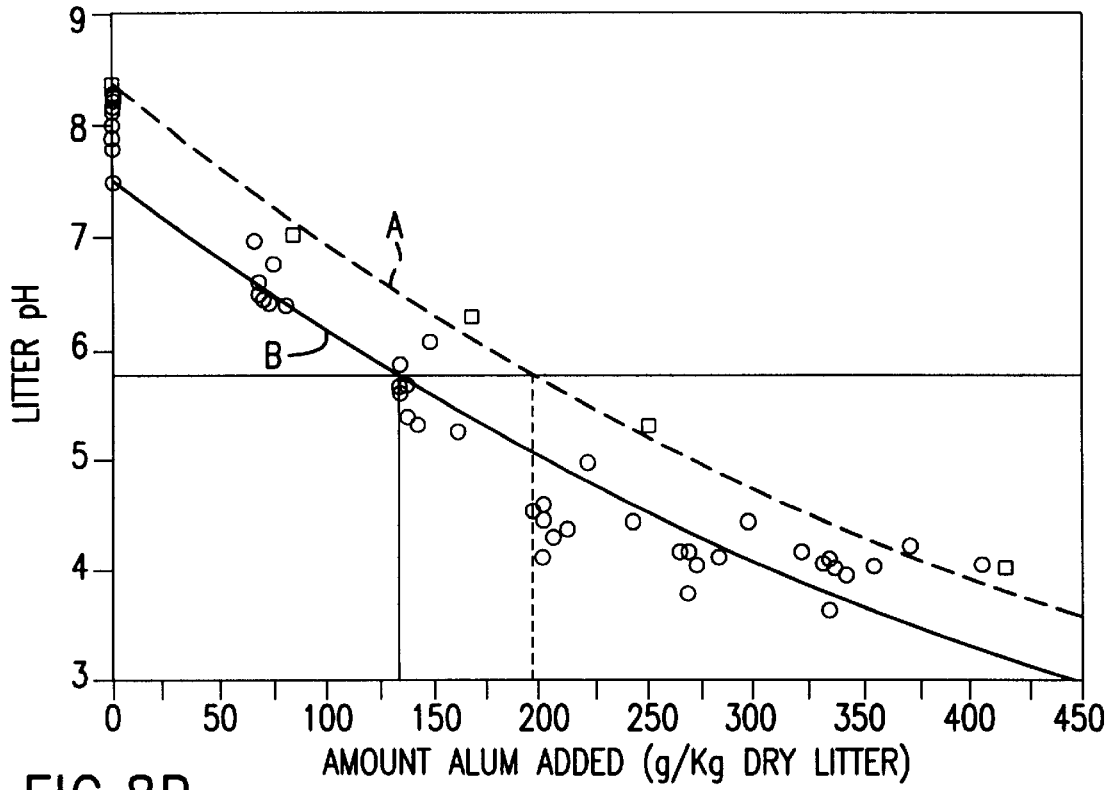


FIG.8B

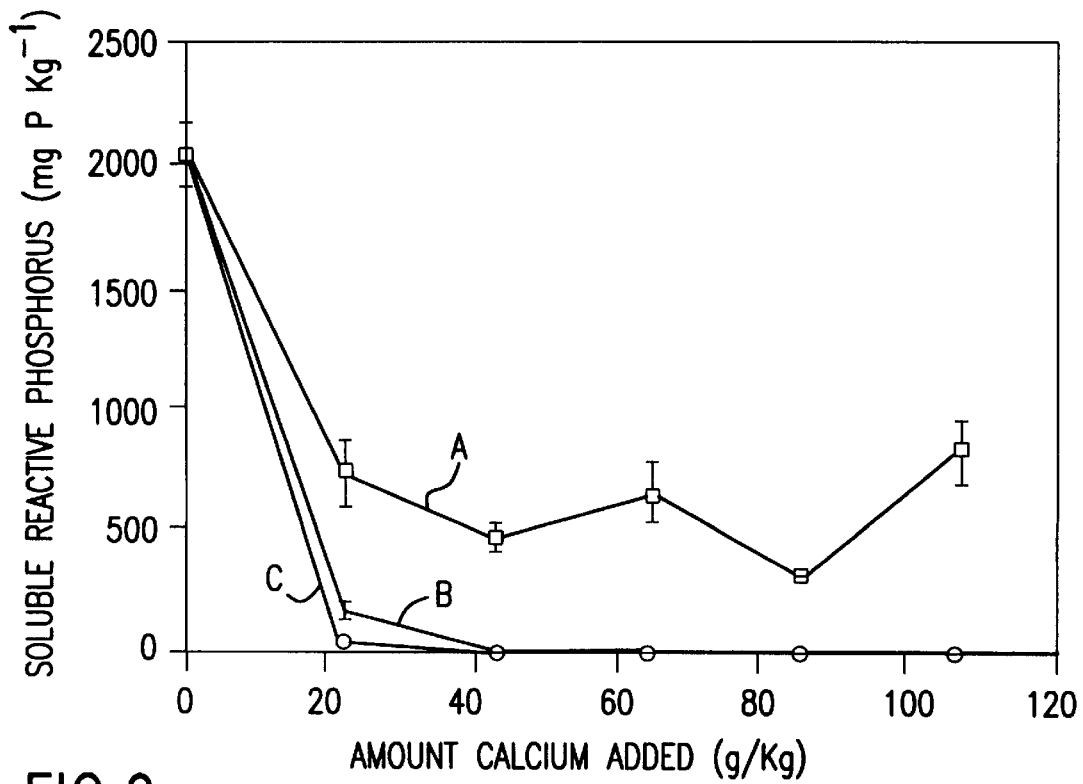


FIG.9

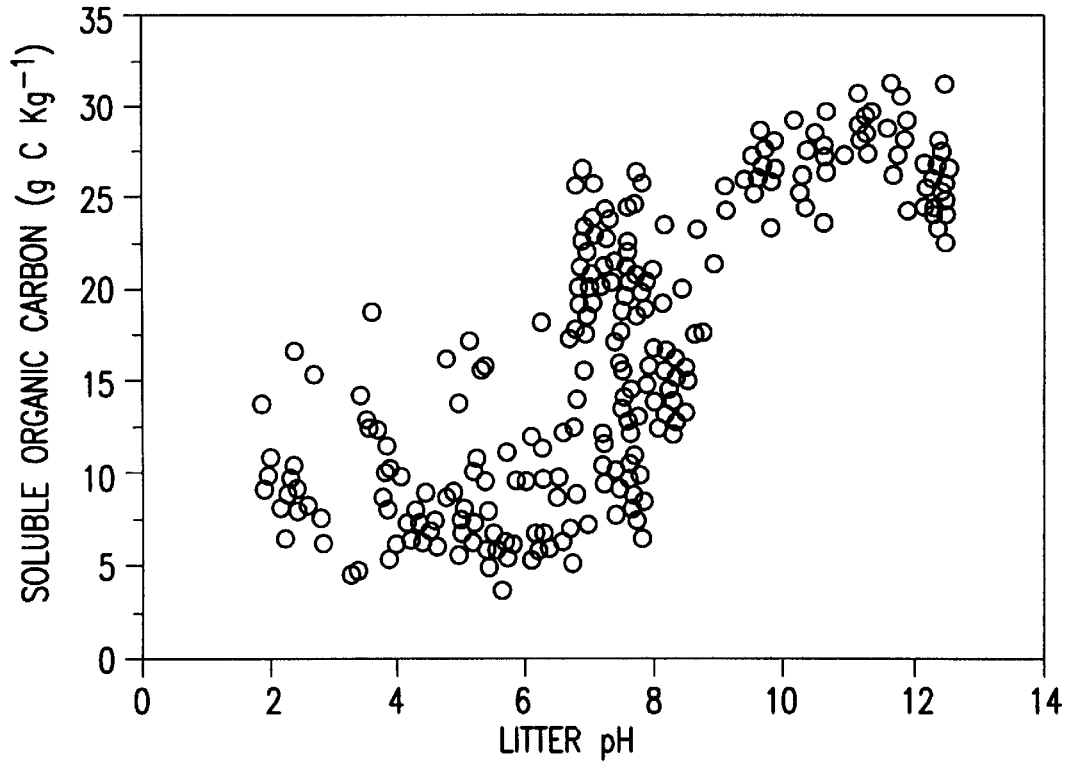


FIG. 10

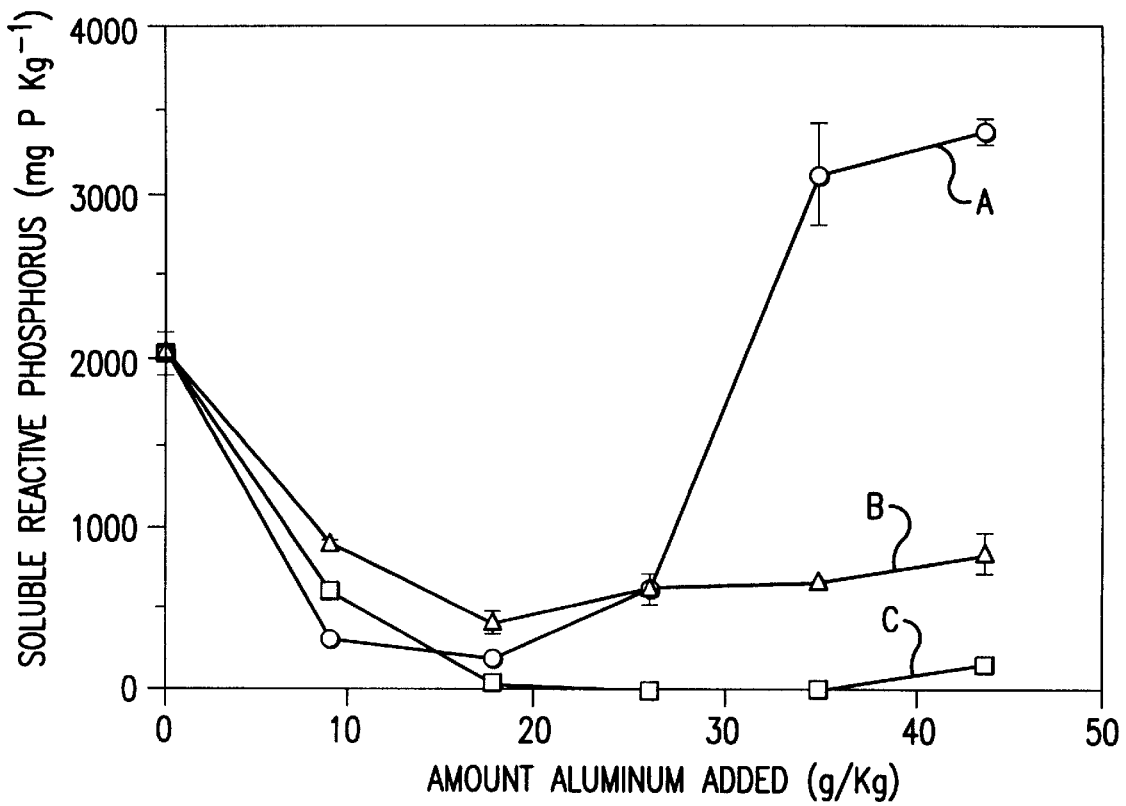


FIG. 11

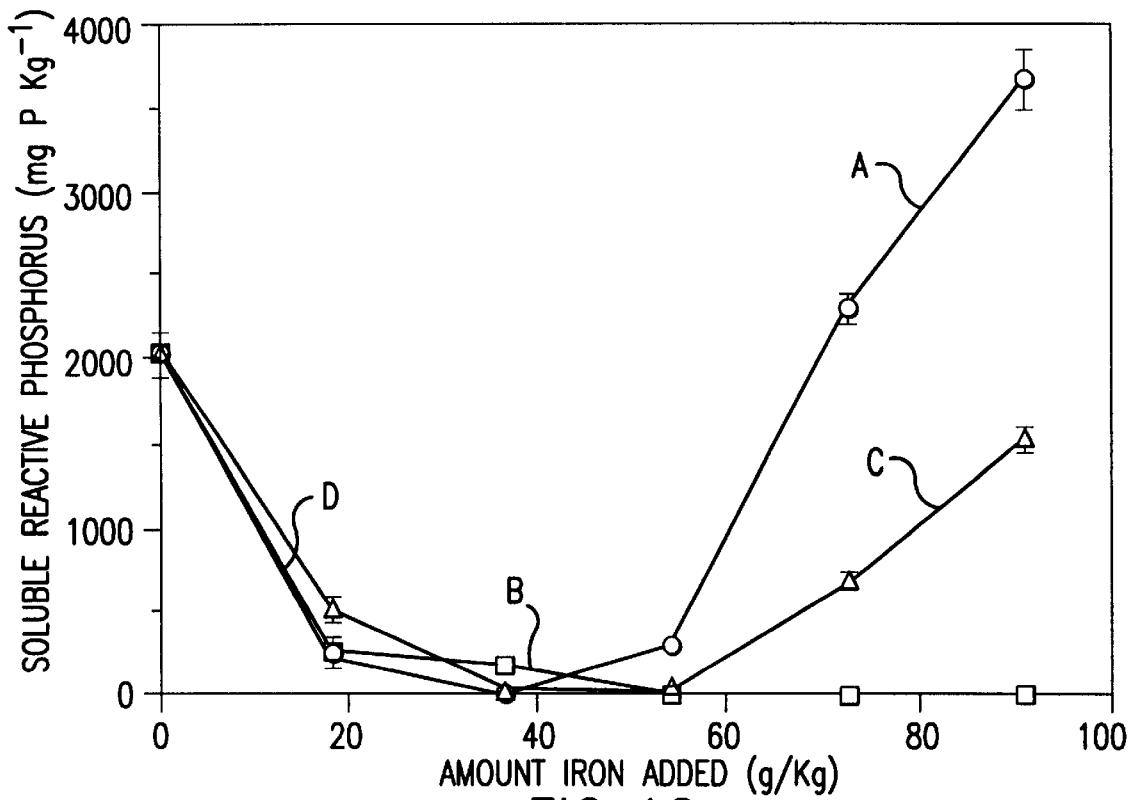


FIG. 12

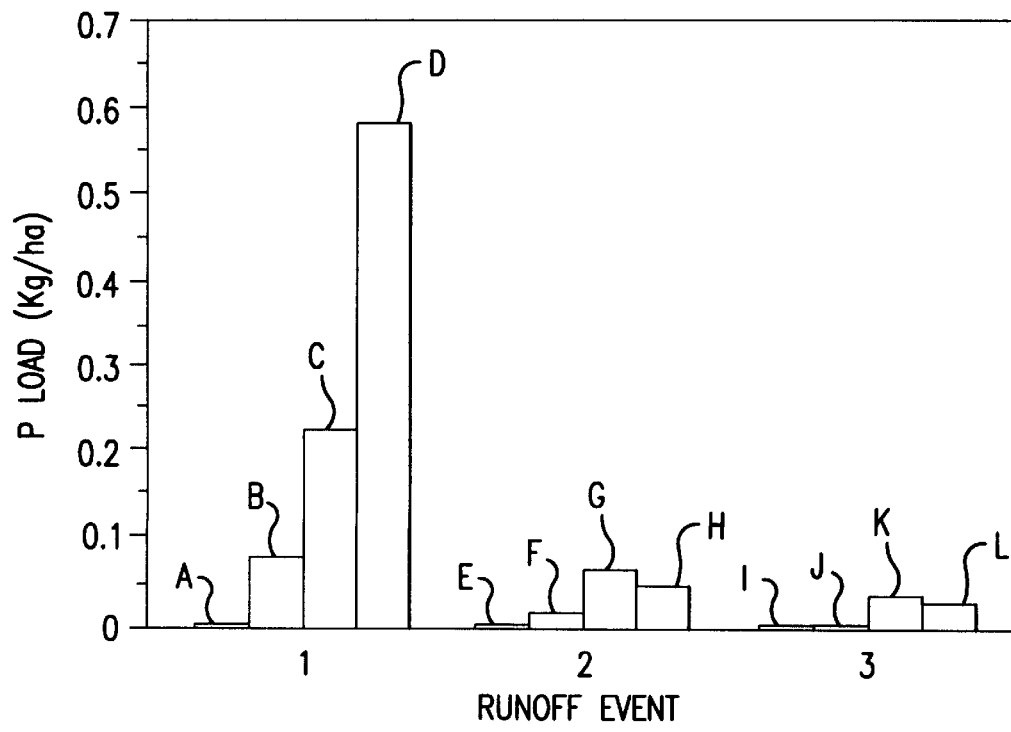


FIG. 14

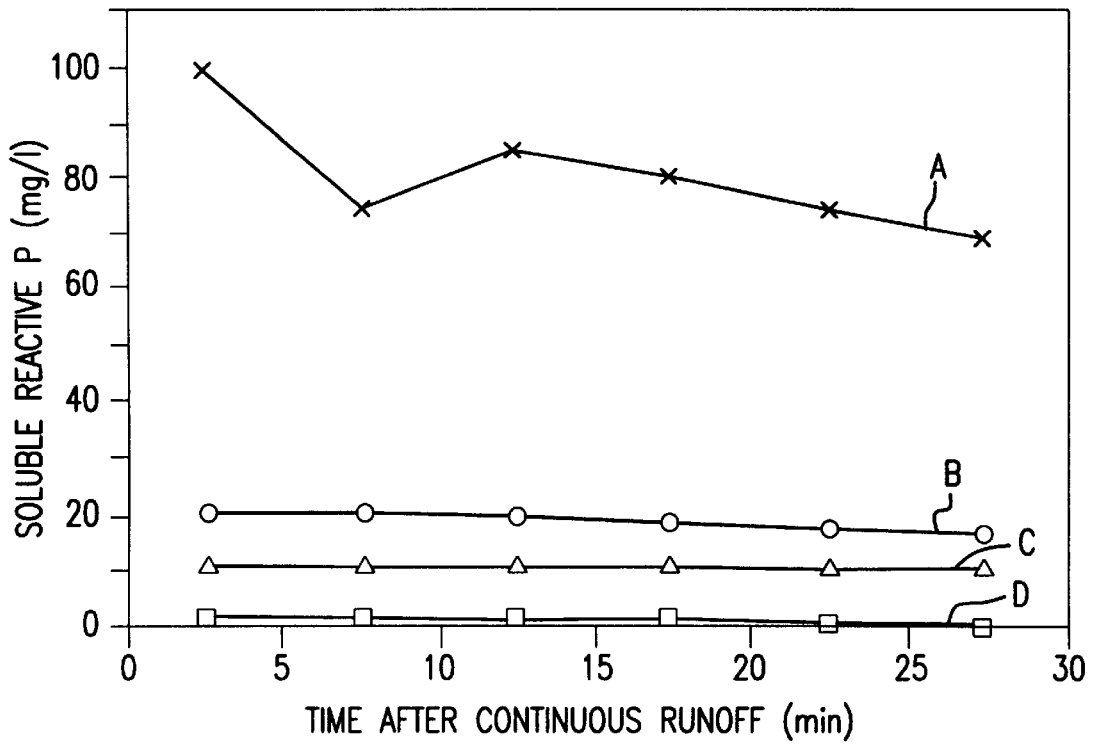


FIG. 13A

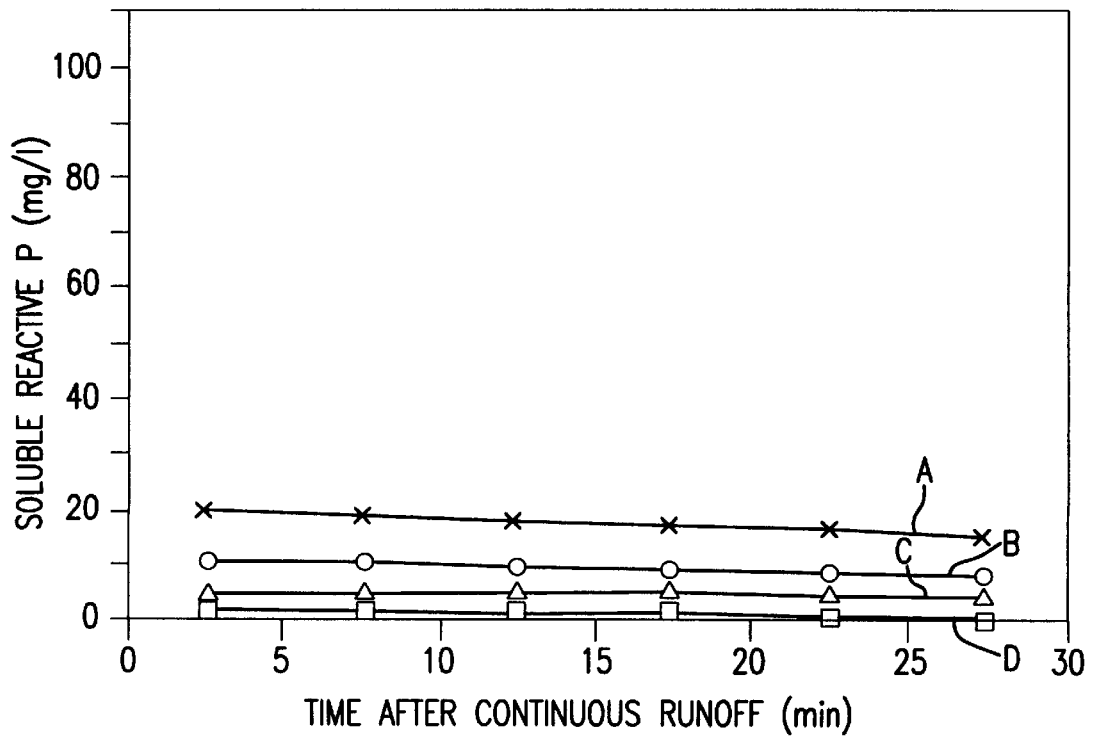


FIG. 13B

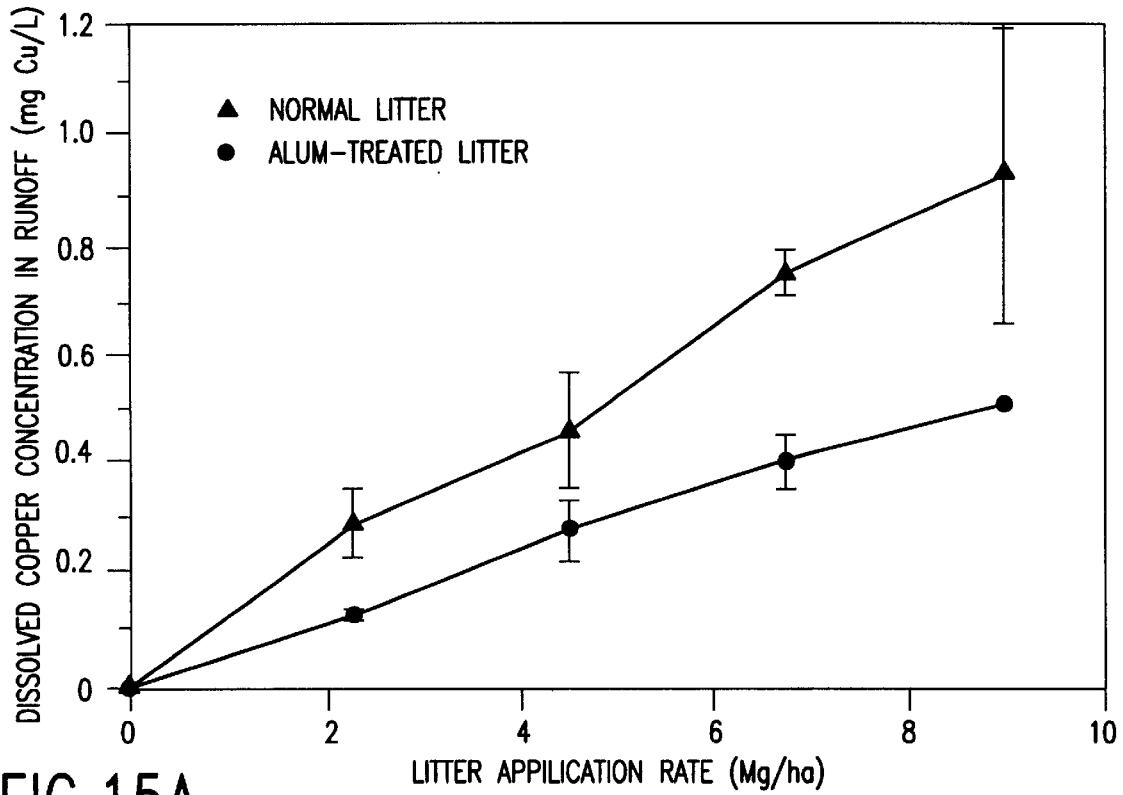


FIG. 15A

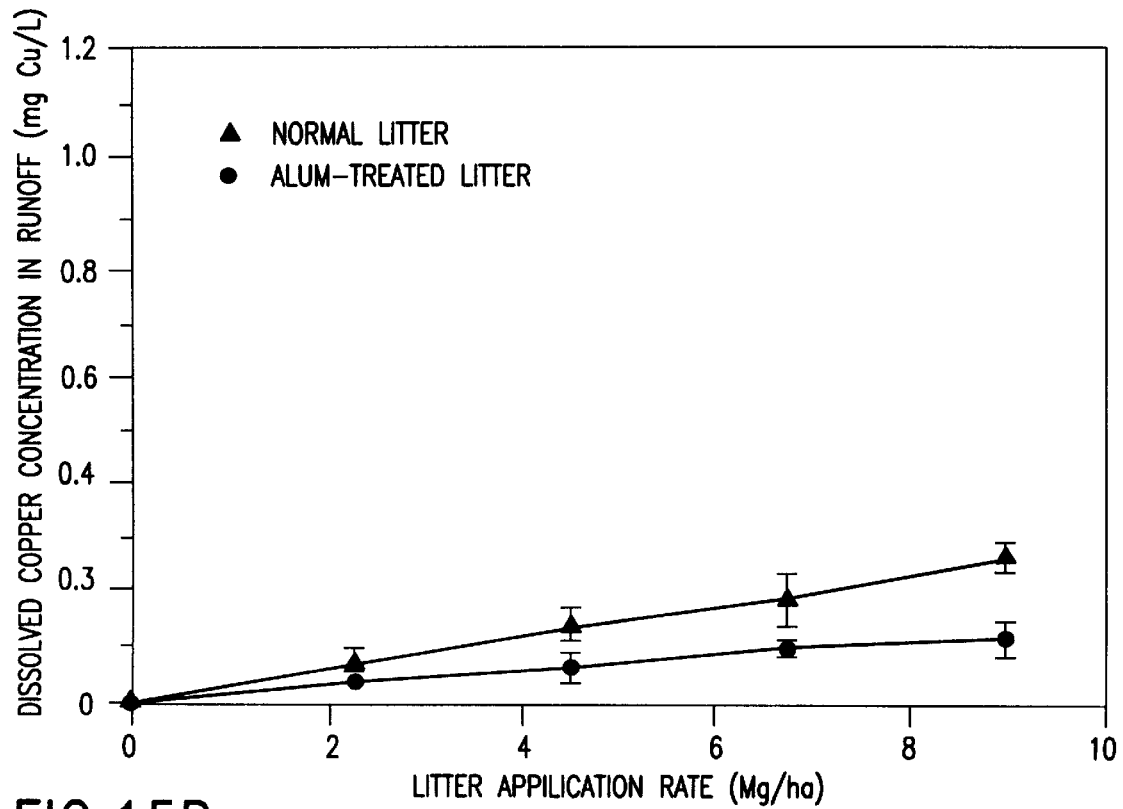


FIG. 15B

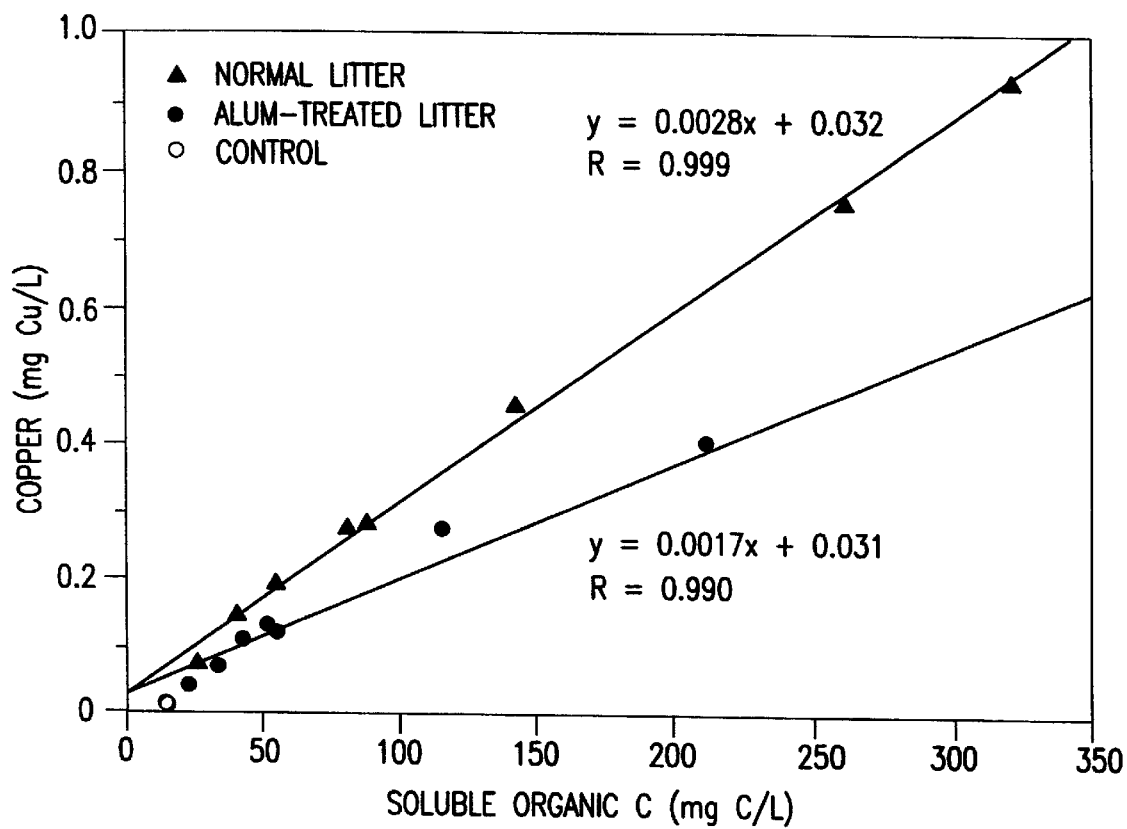


FIG.16

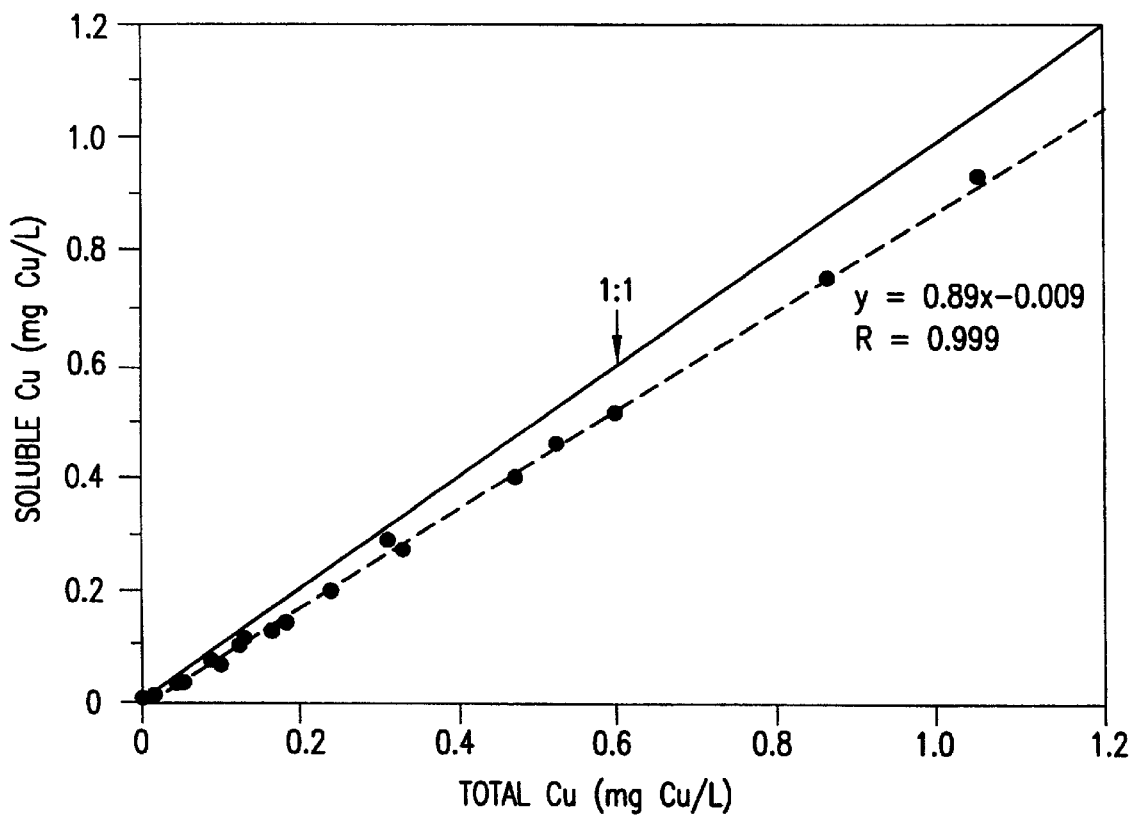


FIG.17

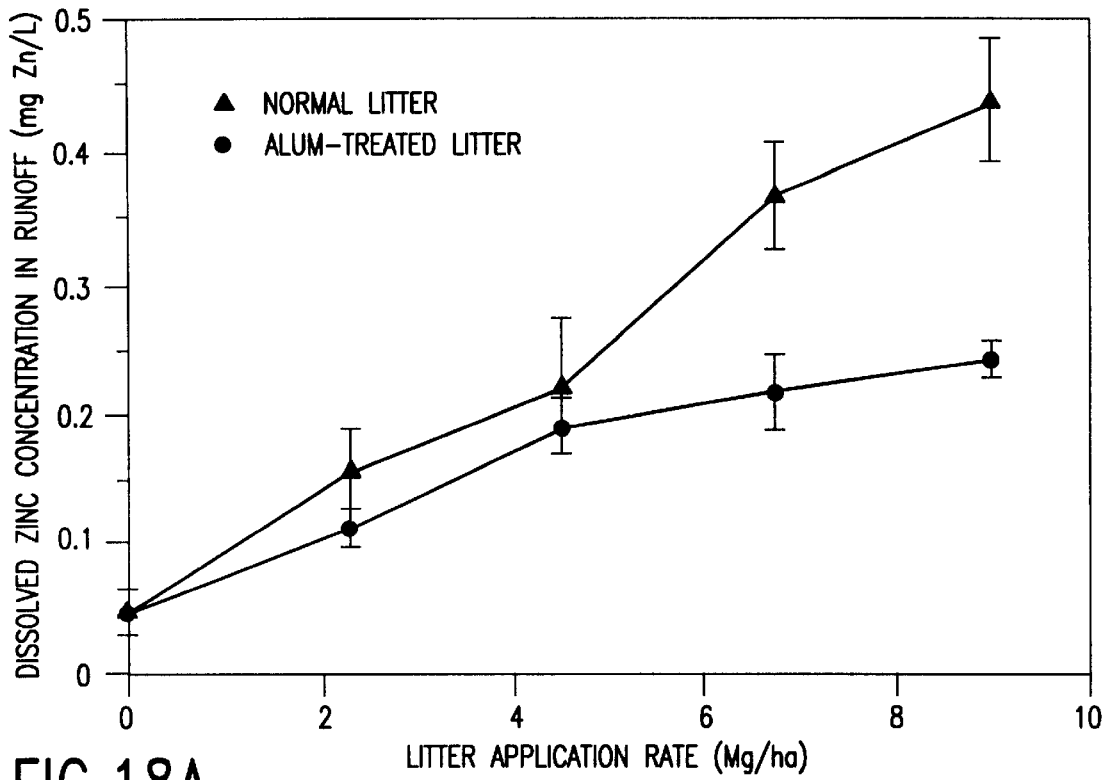


FIG. 18A

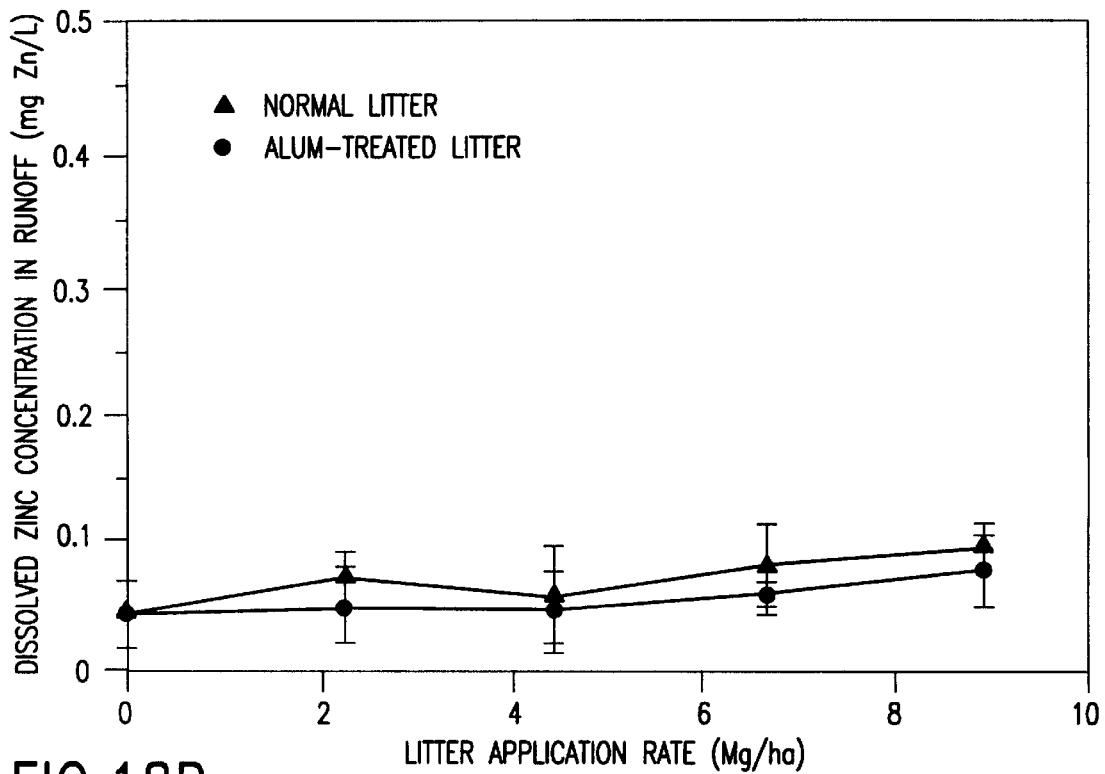


FIG. 18B

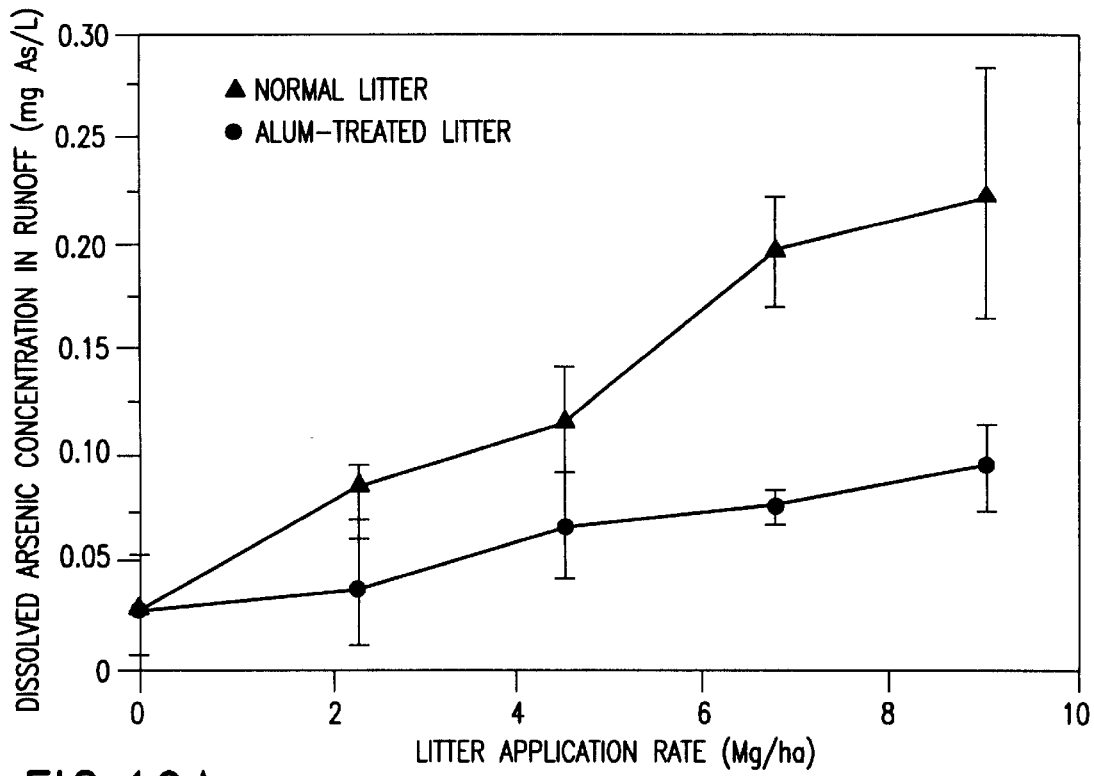


FIG. 19A

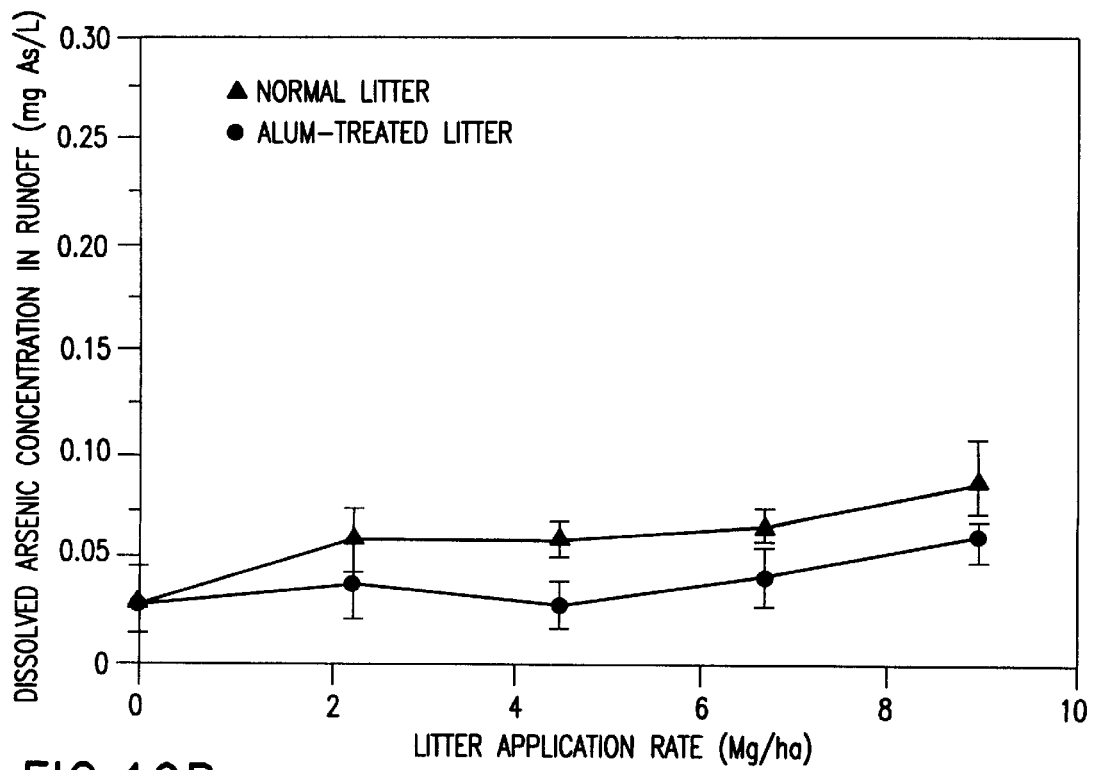


FIG. 19B

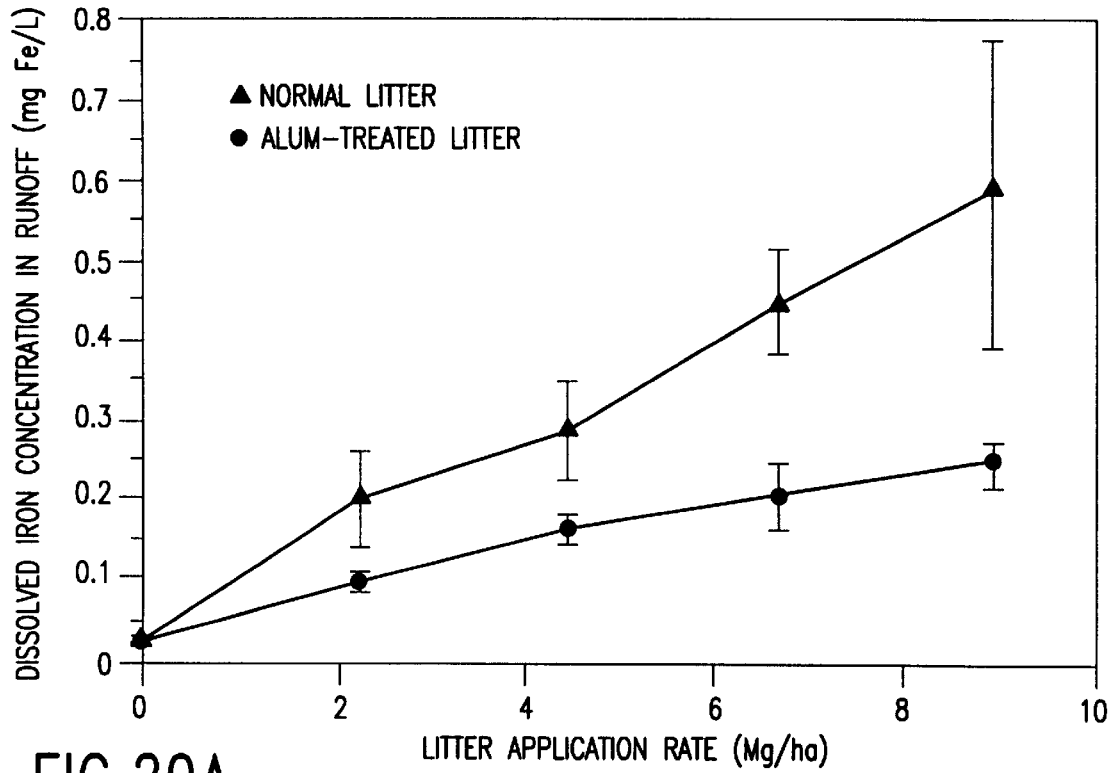


FIG. 20A

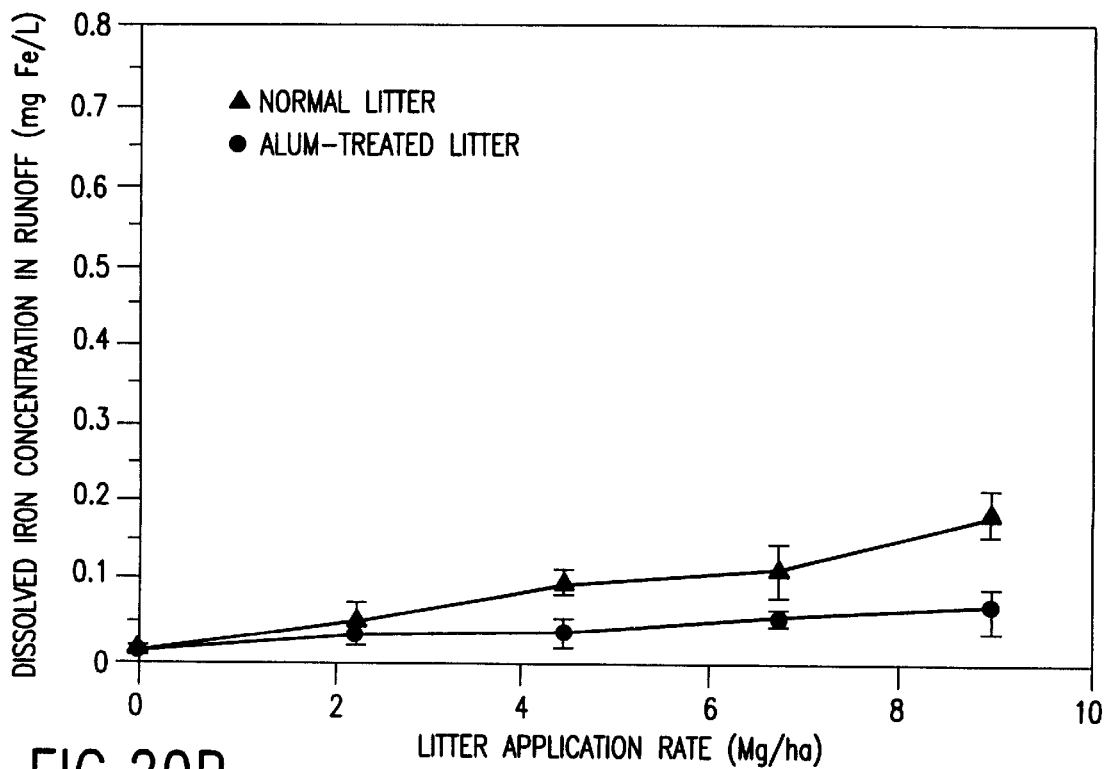


FIG. 20B

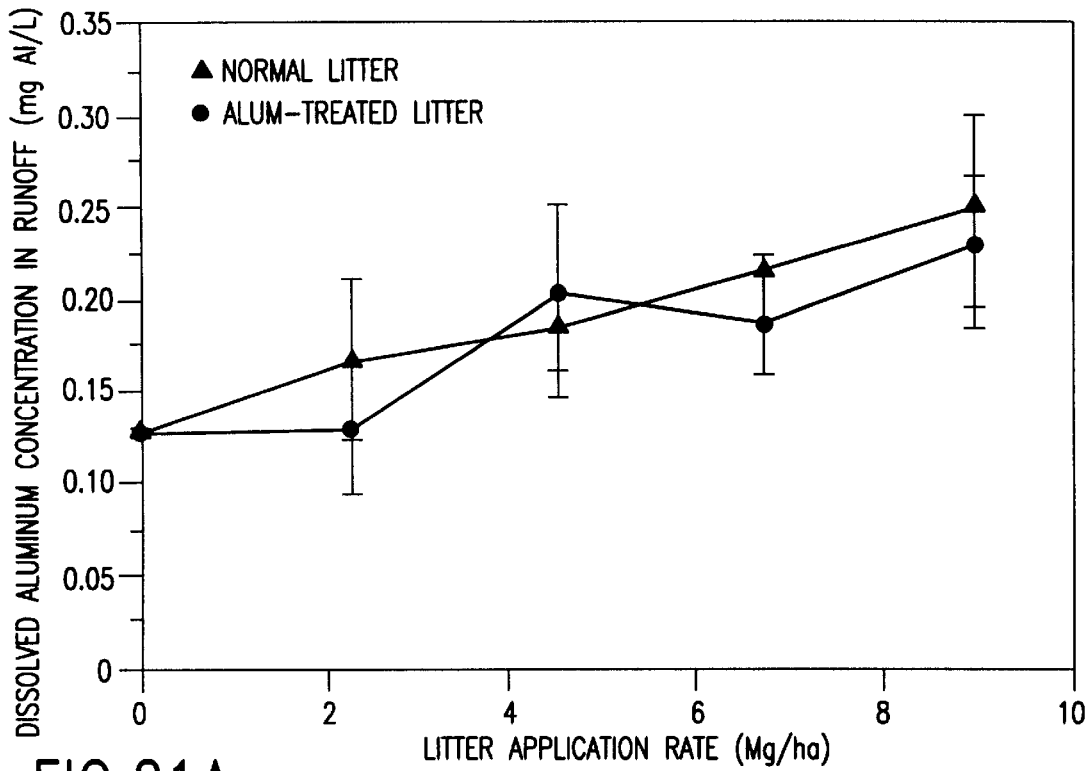


FIG. 21A

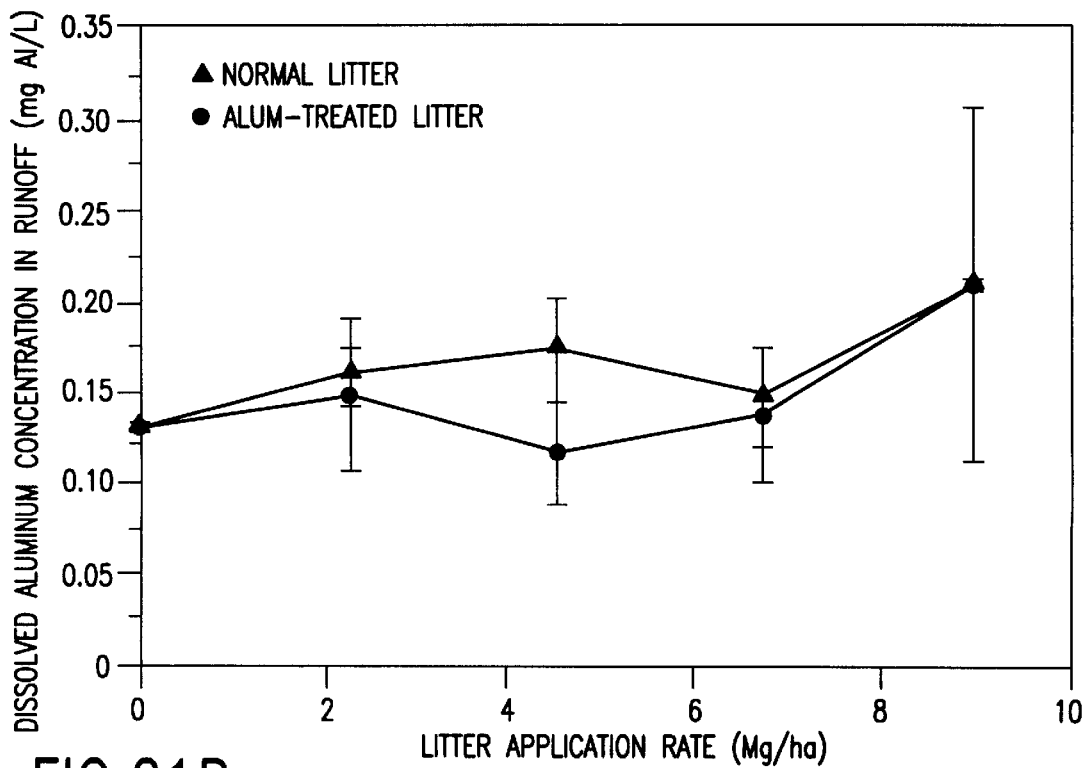


FIG. 21B

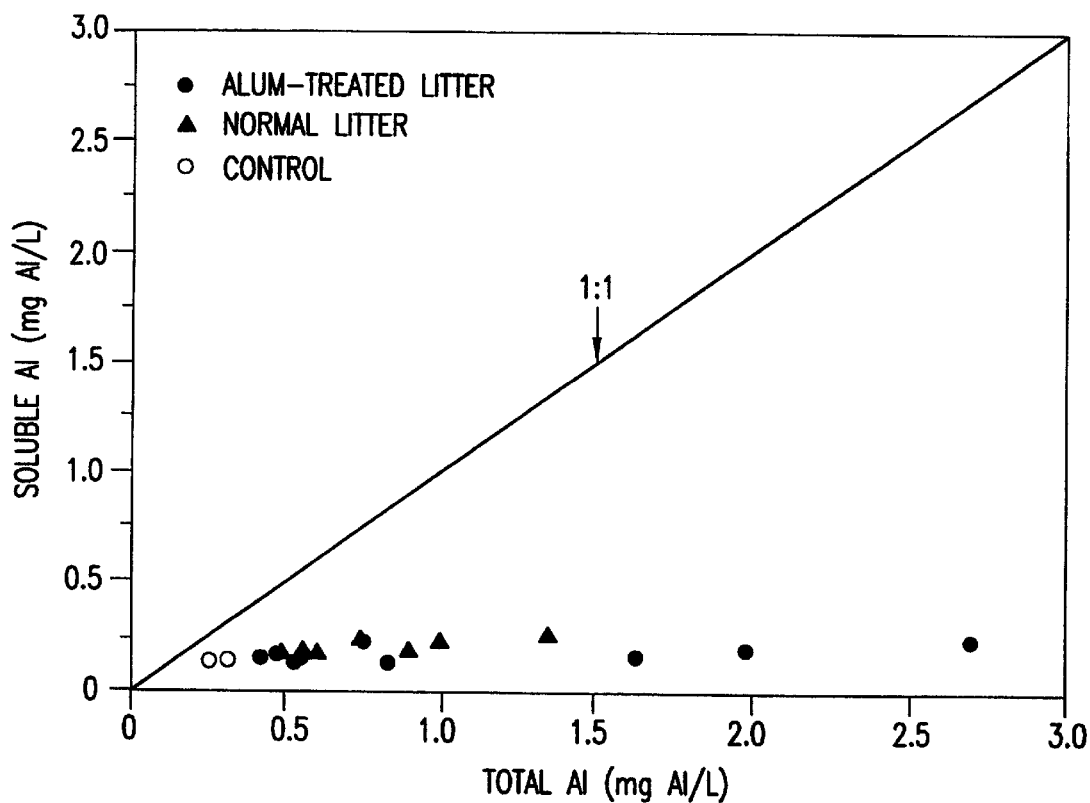


FIG.22

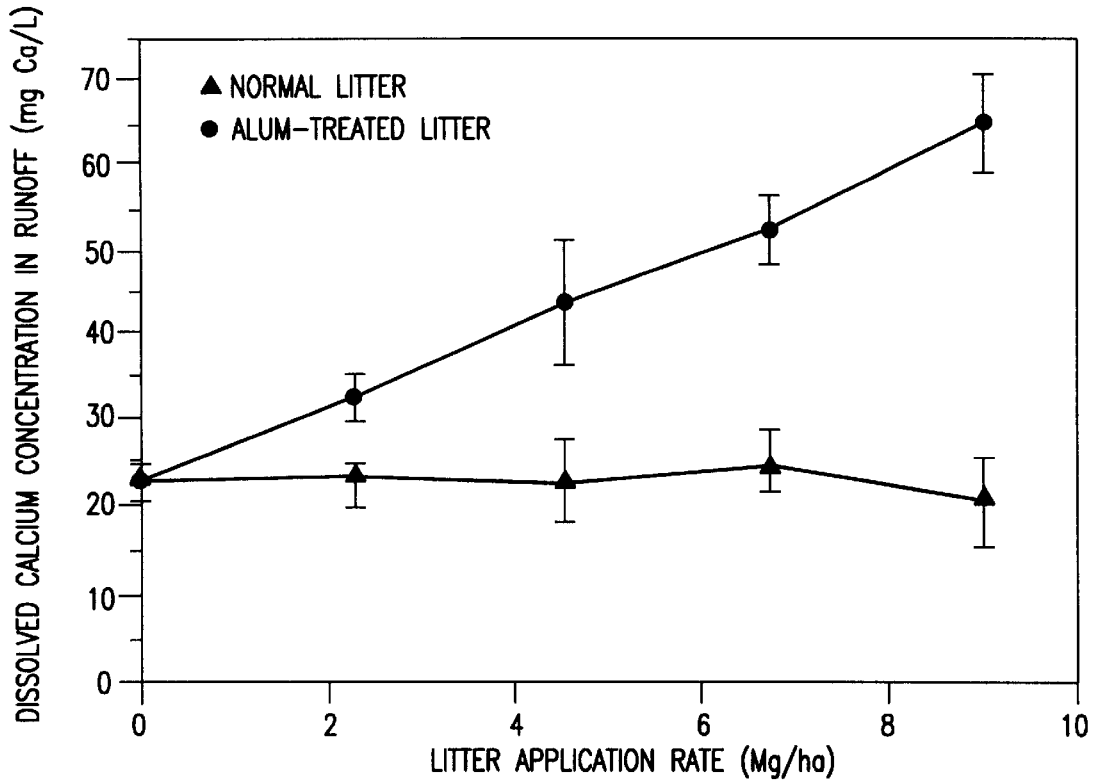


FIG.23A

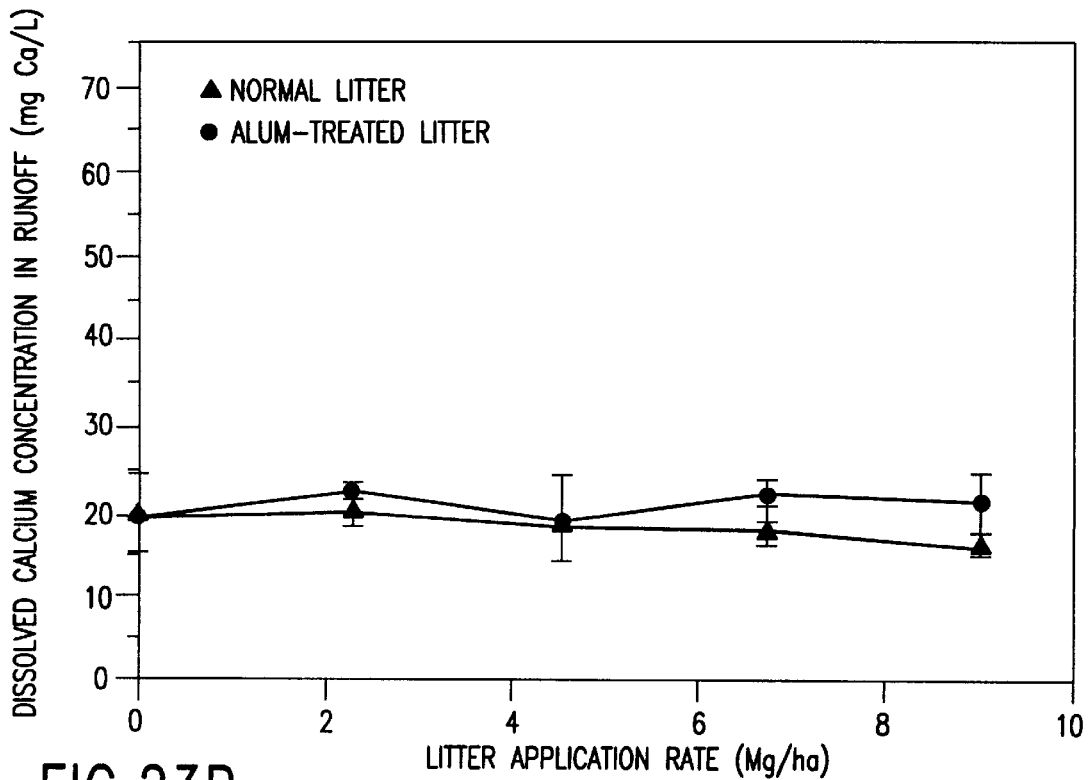


FIG.23B

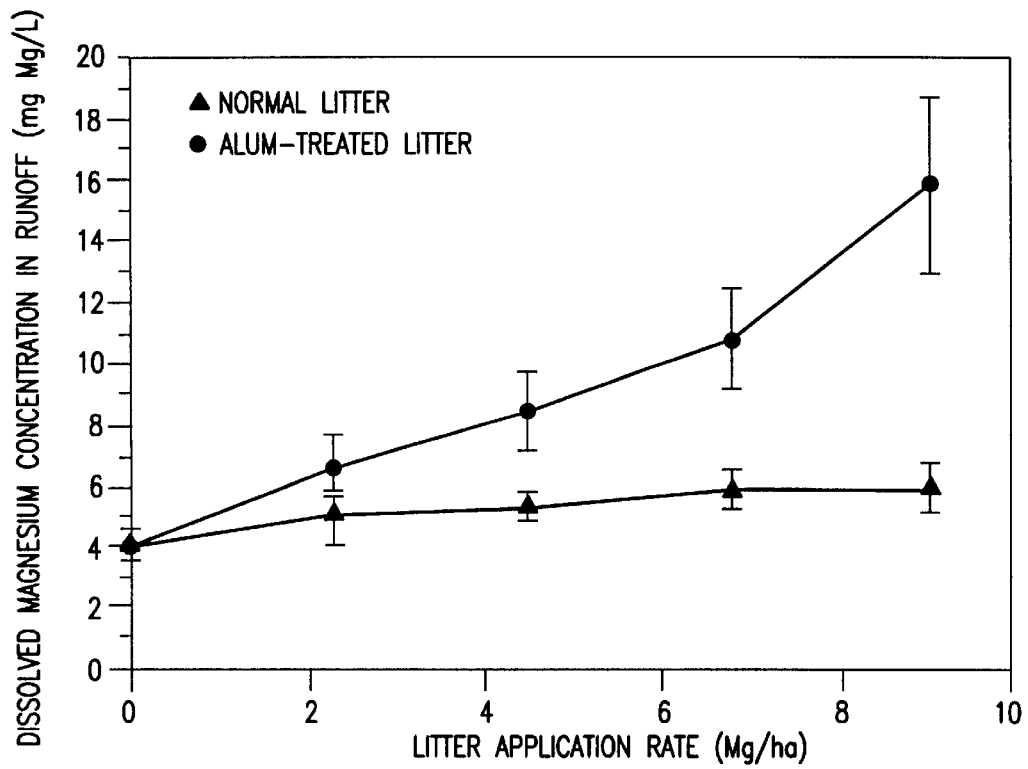


FIG.24A

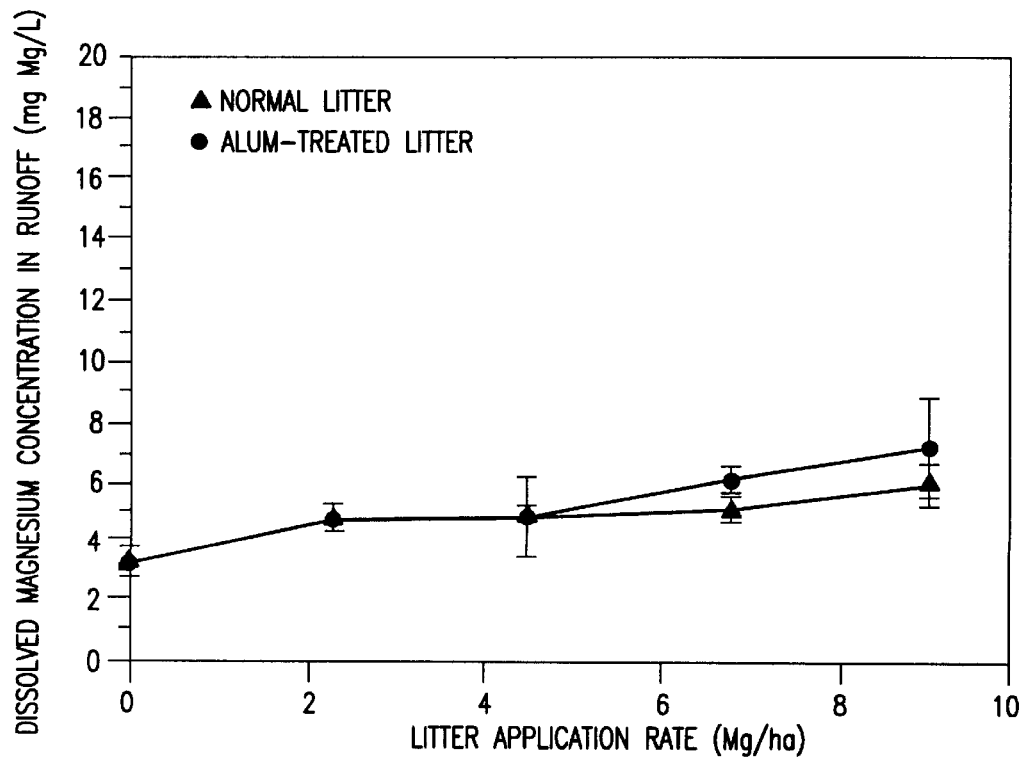


FIG.24B

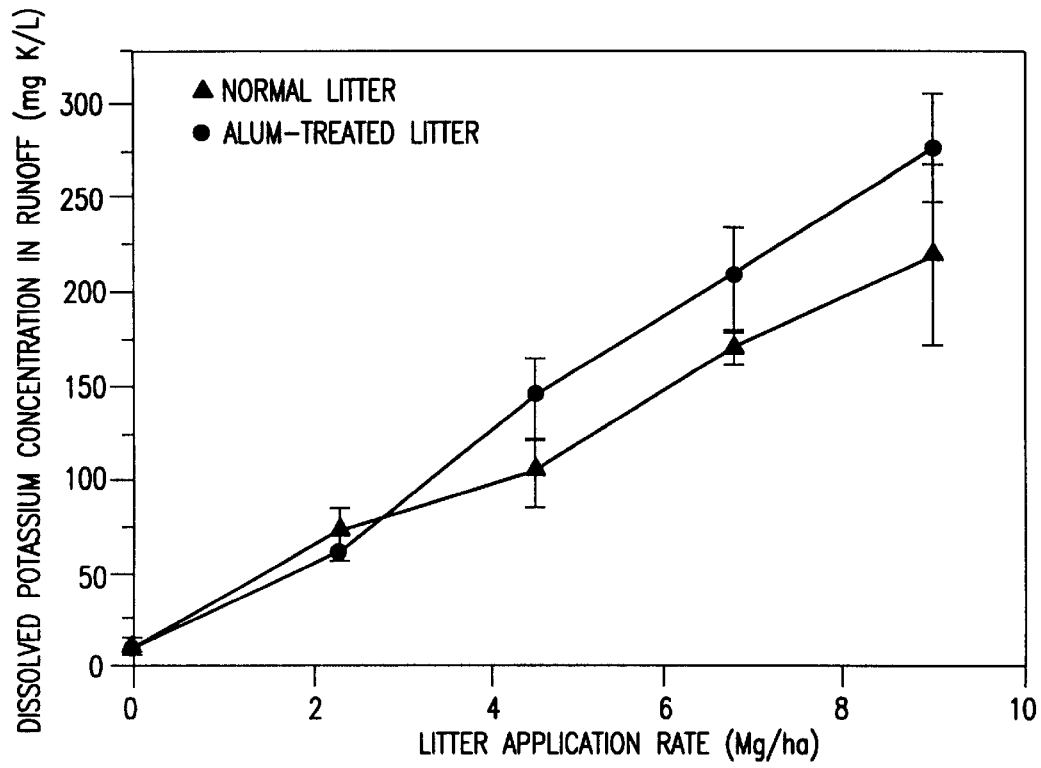


FIG.25A

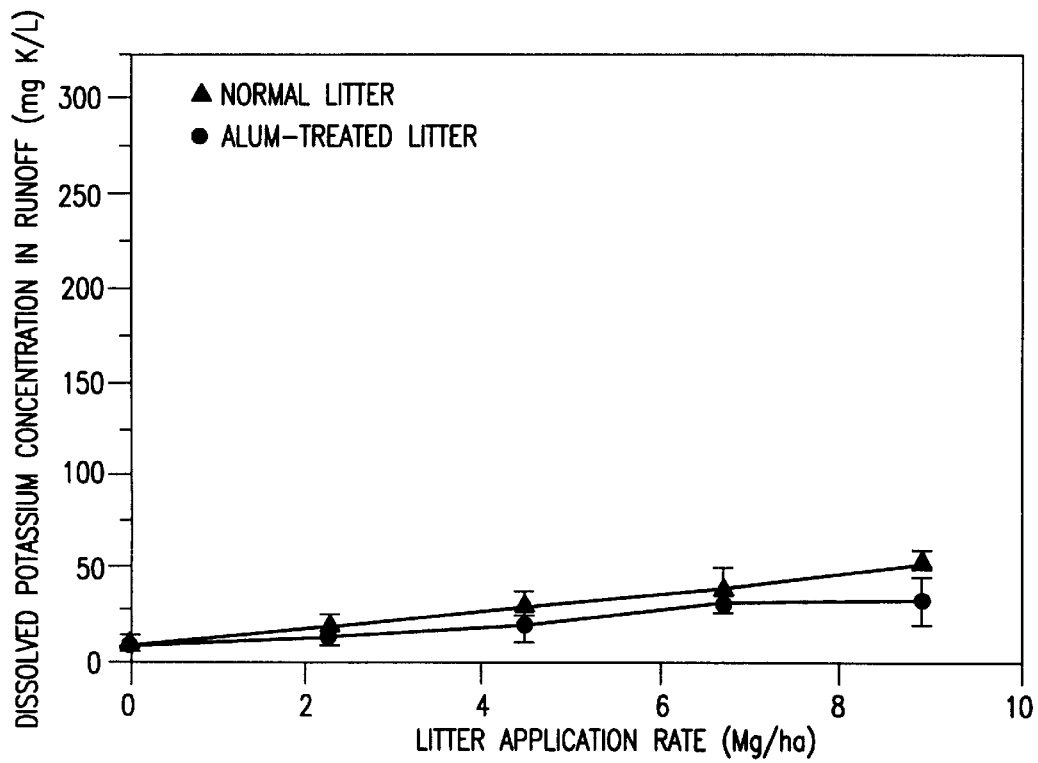


FIG.25B

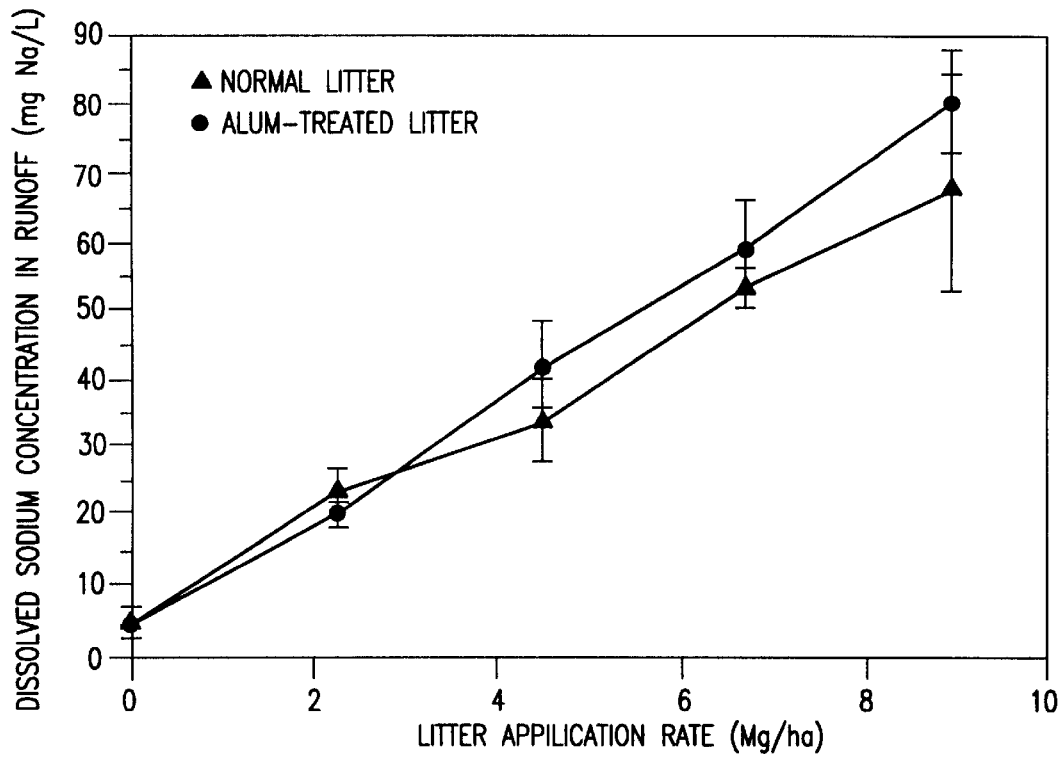


FIG.26A

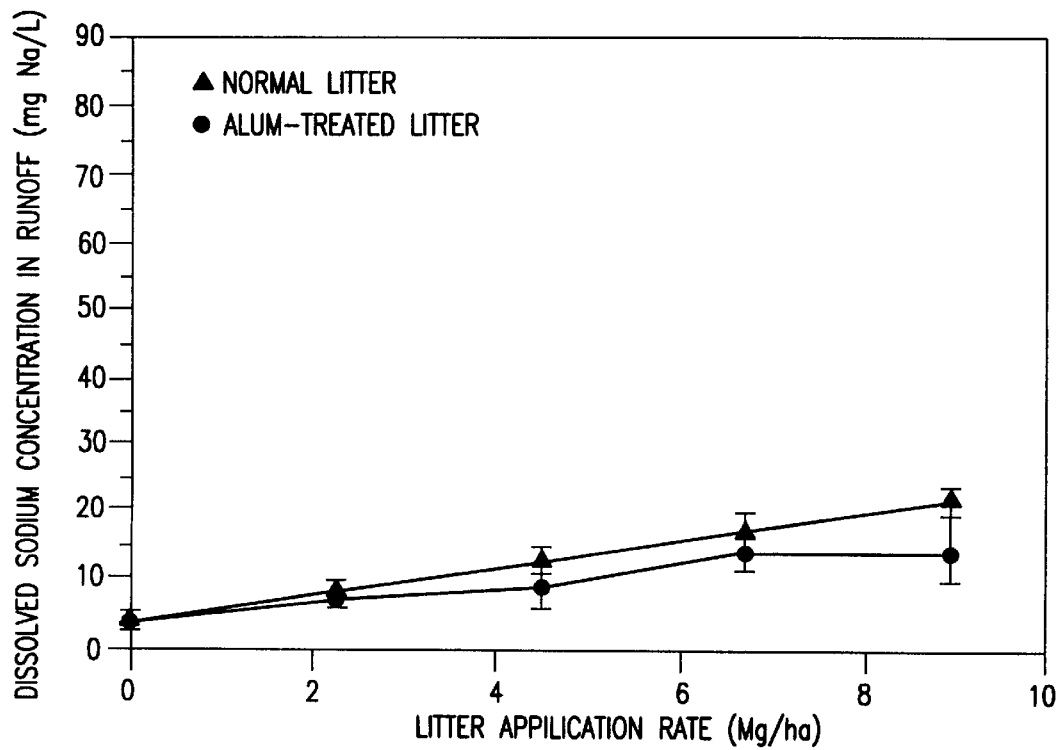


FIG.26B

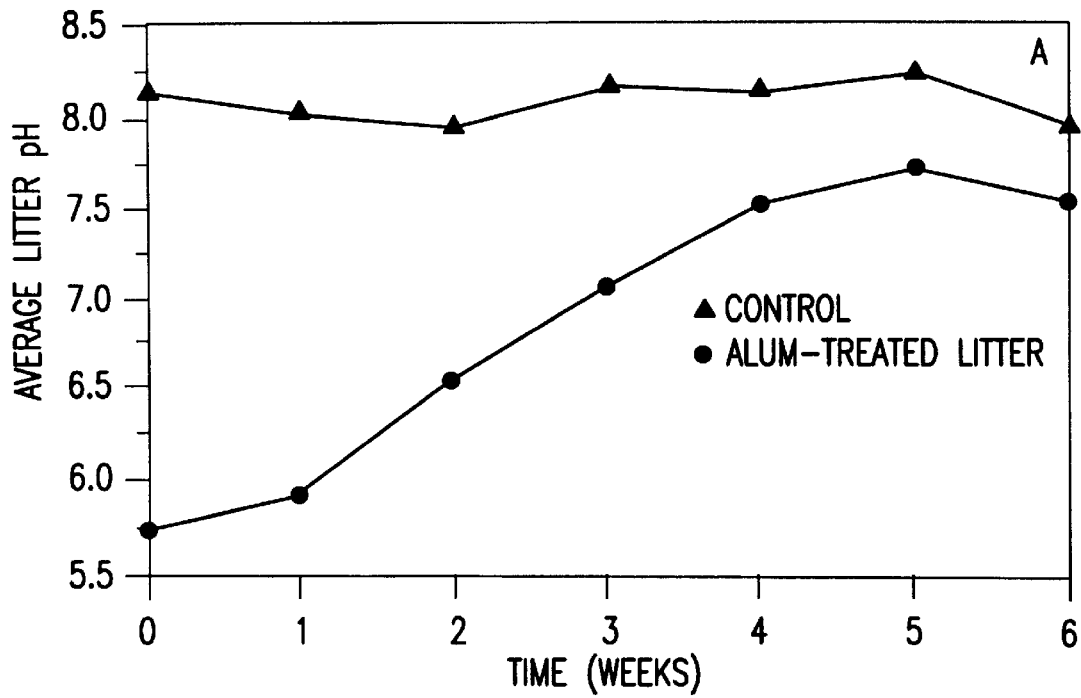


FIG.27

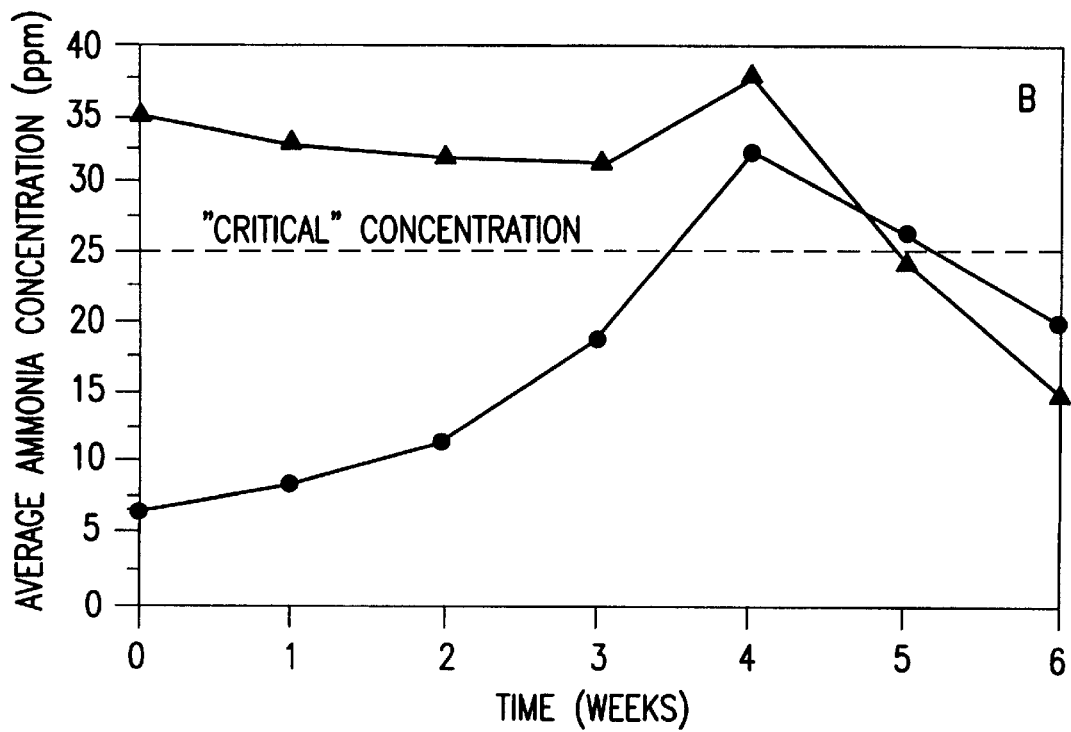


FIG.28

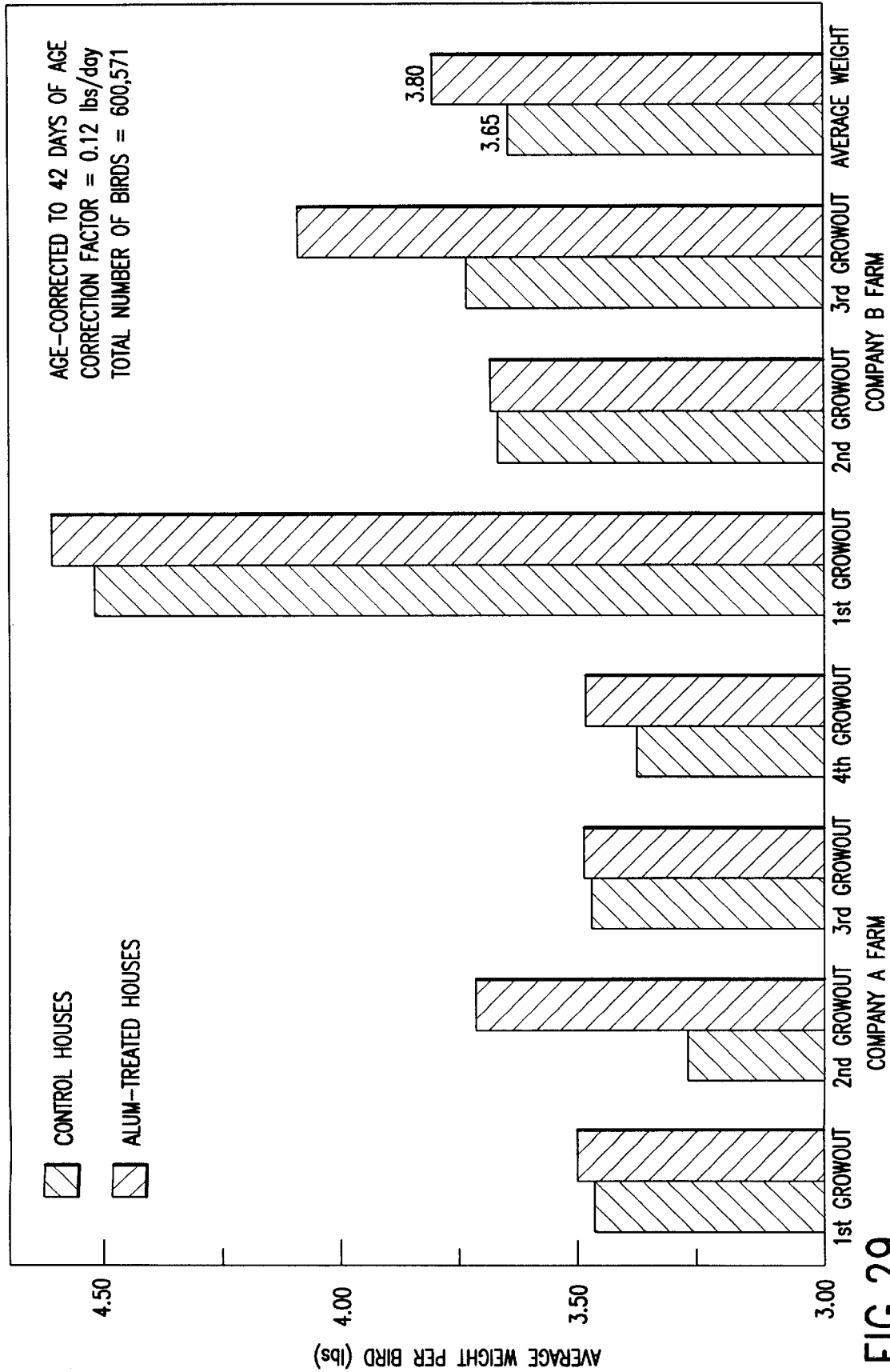


FIG. 29

METHODS FOR DECREASING NON-POINT SOURCE POLLUTION FROM POULTRY MANURE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-in-part of commonly-assigned prior application Ser. No. 08/437,991, filed May 10, 1995, now U.S. Pat. No. 5,622,697, which is a Division of application Ser. No. 05/129,742, filed Sep. 30, 1993, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to a method for inhibiting ammonia volatilization in poultry litter for improving bird weight gain and feed conversion. The present invention further relates to a method for reducing energy costs associated with poultry production and reducing heavy metals runoff from soil fertilized with a poultry manure-containing agricultural fertilizer.

One of the major problems encountered in raising chickens, turkeys or laying hens under confined conditions is ammonia volatilization, the production of excessive levels of ammonia gas (NH₃). As volatilization occurs, ammonia levels can reach as high as 100–200 ppm in poultry houses. For over 30 years, researchers have shown that excessive ammonia build-up in poultry rearing facilities adversely affects both poultry and farm workers. Scarborough (*Delaware Agric. Exp. Stn. Prog. Rep.*, NE8, 1957) and Valentine (*Br. Poultry Sci.* 5:149–159, 1964) both observed ammonia levels in the 60 to 70 ppm range in the atmosphere of poultry houses. Ammonia levels reaching as high as 100 ppm in commercial poultry houses have also been reported (Anderson et al., *Poult. Sci.* 43: 305–318 (1964)).

Anderson et al. demonstrated that when chickens, turkeys, guinea pigs, or mice were exposed continuously to 20 ppm ammonia, gross or histopathological signs of damage to the respiratory tract occurred after six weeks (*Avian Dis.* 8:369–379, 1964). They also found that chicks exposed to 20 ppm ammonia for 72 hours were much more susceptible to Newcastle Disease than controls reared in ammonia-free environments. Although all of the chickens had been exposed to the Newcastle Disease virus, only 40% of the chickens in the ammonia-free environment were infected, whereas 100% of the chicks were infected when exposed to ammonia. They indicated that these results may have been due to damage to the mucous lining of the respiratory tract.

High levels of ammonia have been shown to enhance the multiplication of *Mycoplasma gallisepticum* in the respiratory tract of chickens (Sato et al., *Natl. Inst. Anim. Hlth. Qrt.*, Tokyo, 13:45–53, 1973).

Charles et al. (*British Poultry Science* 7:177–187, 1966) found that keratoconjunctivitis developed in hens exposed to 100 ppm ammonia after six weeks, and egg production was depressed. Similarly, Strombaugh et al. found that high levels of ammonia adversely affected feed consumption and weight gain in pigs (*J. Anim. Sci.* 28:844, 1969).

In Europe, COSSH (Control of Substances Hazardous to Health) has set the limit of human exposure to ammonia at 25 ppm for an eight hour day and 35 ppm for a 10 minute exposure (Williams, *Proc. Ark. Nutrition Conference*, Fayetteville, Ark., pp. 14–29, 1992). With current production practices, these levels are often exceeded in broiler houses.

The number one complaint received by state and federal environmental agencies each year against animal producers

involves odor. Since ammonia comprises a large portion of the odor associated with poultry litter, measures to control odor must incorporate strategies that reduce ammonia volatilization.

There are several litter amendments currently on the market which supposedly reduce ammonia volatilization. Among these are MLT (Multi-Purpose Litter Treatment), PLT (Poultry Litter Treatment), De-odorase, and Ammonia Hold. However, there are no published reports based on valid scientific studies in which these products were tested. Most of the products depend on testimonials from individuals for their sales. A need, therefore, exists for reproducible studies comparing these products with other compounds, which based on their chemical or physical properties, would likely reduce volatilization.

In addition to the ammonia volatilization, another major problem commonly associated with poultry litter is the amount of phosphorus (P) runoff which enters the aquatic system from fields receiving poultry litter. Phosphorus runoff is the primary cause for eutrophication in lakes and other freshwater bodies. Tighter controls of point sources of phosphorus, such as municipal waste water treatment plants, have resulted in decreased phosphorus loading from point sources into the aquatic environment in the last few decades. However, improvement of water quality has not always been observed when point source phosphorus loads were reduced. Therefore, attention is currently being focused on non-point sources of phosphorus such as agricultural runoff. One of the major sources of phosphorus runoff from agricultural lands is animal waste.

Several investigators have characterized phosphorus runoff from fields receiving poultry manure (Edwards et al., *J. Environ. Qual.* 22:361–365, 1993; McLeod et al., *J. Environ. Qual.* 13:122–126, 1984; Westerman et al., In (R. J. Smith, ed.) *Livestock waste: A renewable resource. Proc. Fourth Int. Symp. on Livestock Wastes*, 289–292. St. Joseph, MI:ASAE, 1980; and Westerman et al., *Transactions of the ASAE* 26:1070–1078, 1983). These studies have all shown that phosphorus runoff increases as the manure or litter application rate increases and as rainfall intensity increases. Drying time has also been shown to be an important parameter with respect to phosphorus runoff. With longer periods between application and rainfall, phosphorus runoff was greatly reduced (Westerman et al., supra, 1980; Westerman et al., supra, 1983). Recent studies have shown high concentrations of phosphorus (14–76 mg PL⁻¹) in runoff from pastures receiving poultry litter, most of which is dissolved inorganic phosphorus (≈85%), with only small amounts of particulate phosphorus (Edwards et al., supra). Sonzogni et al. found that dissolved inorganic phosphorus is directly available to algae and concluded that best management practices used to decrease phosphorus runoff should consider the bioavailable-phosphorus load, rather than focusing on the total-phosphorus load (*J. Envir. Qual.* 11:555–563, 1982).

Rapid and concentrated growth of the poultry industry, fueled by the demand for low-fat meat, has raised concerns in several states regarding water quality. Arkansas, for example, is the number one poultry producing state in the U.S., with approximately one billion broilers produced per year. Each broiler produces approximately 1.5 kg of poultry litter over a 10-week growing cycle (Perkins et al., *Bull. NS 123*, Georgia Agri. Exp. Station, Athens, Ga., 1964). This litter contains 8–25.8 g P kg⁻¹, with soluble reactive phosphorus levels up to 4.9 g P kg⁻¹ (Edwards et al., *Bioresource Tech.* 41:9–33, 1992). Runoff of phosphorus from fields receiving poultry litter has been speculated to be one of the

primary factors affecting water quality in Northwest Arkansas. High bacterial counts and high biochemical oxygen demands have also been attributed to litter.

Currently, there is a movement to limit the amount of chickens produced in a given area to minimize phosphorus loading into the aquatic system. In the next 5 years, the U.S. Environmental Protection Agency will require all farms that produce in excess of 15,000 birds per year to construct detention ponds capable of holding all the runoff from a 25 year storm. As an alternative, poultry producers could be forced to transport litter to areas with low soil phosphorus and/or build litter storage facilities at a significant cost to poultry producers, and ultimately the consumer. An alternative solution is clearly needed to reduce soluble phosphorus levels in poultry litter.

SUMMARY OF THE INVENTION

The present invention is predicated on the discovery that treatment of poultry litter with the aluminum sulfate compound, alum, dramatically reduces ammonia volatilization from the litter. Results also indicate that alum, ferrous sulfate and calcium hydroxide effectively precipitate soluble phosphorus when added to litter, thereby reducing soluble phosphorus levels. Poultry litter is composed of a mixture of bedding material, manure, spilled food and feathers.

To inhibit ammonia volatilization, alum is applied to poultry litter in an amount sufficient to maintain the litter pH at values low enough to inhibit ammonia volatilization. Since poultry litter is highly variable in composition, the actual quantity of alum needed to inhibit volatilization may vary between approximately 5–25% of the litter weight on a dry weight basis.

To reduce phosphorus solubility in poultry litter in accordance with the present invention, aluminum, iron or calcium amendments were added to the poultry litter in an amount equivalent to a metal to phosphorus mole ratio of approximately 0.5:1 to 2.5:1. The most effective compounds reducing phosphorus solubility in litter include alum, ferrous and ferric sulfate, ferrous and ferric chloride, and calcium hydroxide.

Currently, over half of the nitrogen in poultry litter is lost via ammonia volatilization before it can be taken up by forages. This results in a poorly balanced fertilizer source, because the nitrogen/phosphorus ratio is low. Since forages have much higher requirements for nitrogen than phosphorus, the best fertilizers should reflect this balance. Since the addition of alum acts to reduce volatilization losses, litter treated with alum would function as a higher quality fertilizer than those currently available on the market.

With respect to the environmental impact of these chemical amendments to litter (i.e., toxicity to the land and animals subject to runoff from fields treated with the chemicals), aluminum represents one of the primary components of soils and sediments. Its bio-availability is controlled by pH. Aluminum is non-toxic to plants and fish under normal pH conditions, for example, when soil pH is above about 4.5 and water pH is above pH 5.5.

In one embodiment for the treatment of litter, alum is applied to litter in an amount equivalent to approximately 5–25% of the litter weight on a dry weight basis.

In another embodiment, litter is treated with alum prior to field application.

Additional features and advantages of the present invention will become apparent from the following Detailed Description taken in conjunction with the Drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates cumulative ammonia volatilization (g nitrogen (N)/kg litter) from poultry litter with and without MLT amendments as a function of time (days). Plot A represents 10 g MLT. Plot B represents 20 g MLT. Plot C represents the control or unamended litter.

FIG. 2 illustrates cumulative ammonia volatilization (g N/kg litter) from poultry litter with and without calcium hydroxide amendments as a function of time (days). Plot A represents 50 g Ca(OH)_2 . Plot B represents 25 g Ca(OH)_2 . Plot C represents the control or unamended litter.

FIG. 3 illustrates cumulative ammonia volatilization (g N/kg litter) from poultry litter with and without ferrous sulfate amendments as a function of time (days). Plot A represents 200 g FeSO_4 . Plot B represents 100 g FeSO_4 . Plot C represents the control or unamended litter.

FIG. 4 illustrates cumulative ammonia volatilization (g N/kg litter) from poultry litter with and without aluminum sulfate amendments as a function of time (days). Plot A represents 200 g alum. Plot B represents 200 g alum+ CaCO_3 . Plot C represents 100 g alum. Plot D represents 100 g alum+ CaCO_3 . Plot E represents the control or unamended litter.

FIG. 5 illustrates total N content of the litter after 42 days of incubation as a function of the cumulative ammonia volatilization (g N/kg) from the various treatments in Experiment 1. Point A represents the control or unamended litter. Point B represents the total N content of the 200 g alum kg^{-1} treatment. R is the regression coefficient with a value of 0.94. $y = -1.17x + 41.7$.

FIG. 6 illustrates cumulative ammonia volatilization (g N/kg) from poultry litter with and without various chemical amendments as a function of time (days). Plot A represents alum. Plot B represents ferrous sulfate. Plot C represents ammonia hold. Plot D represents PLT. Plot E represents the control. Plot F represents MLT. Plot G represents Deodorase.

FIG. 7 illustrates cumulative ammonia volatilization (g N/kg) from poultry litter with and without various waste products as a function of time (days). Plot A represents red mud. Plot B represents FBC (fluidized bed combustion material). Plot C represents brown mud. Plot D represents the control. Plot E represents acid mine soil.

FIG. 8A illustrates total N content of the litter after 42 days of incubation as a function of the cumulative ammonia volatilization (g N/kg) from the various treatments in Experiment 2. Point A represents the control. Point B represents the alum treated litter. The original nitrogen content is 41.8 g/kg. R is the regression coefficient with a value of 0.84. $y = -0.96x + 44.1$.

FIG. 8B illustrates the amount of alum added to poultry litter for inhibition of ammonia volatilization as a function of litter pH. Plot A represents litter from low ventilation environmental chambers. Plot B represents litter from eight commercial broiler houses.

FIG. 9 illustrates the effective calcium amendments to poultry litter on water soluble reactive phosphorus. Plot A represents gypsum. Plot B represents calcium hydroxide. Plot C represents calcium oxide.

FIG. 10 illustrates the effect of poultry litter pH on soluble organic carbon.

FIG. 11 illustrates the effect of aluminum amendments to poultry litter on water soluble reactive phosphorus. Plot A represents alum. Plot B represents sodium aluminate. Plot C represents alum plus calcite.

FIG. 12 illustrates the effect of iron amendments to poultry litter on water soluble reactive phosphorus. Plot A represents ferric chloride. Plot B represents ferrous chloride. Plot C represents ferric sulfate. Plot D represents ferrous sulfate.

FIG. 13A illustrates the treatment effects on soluble reactive phosphorus concentrations in a first runoff event based on a simulated rainfall event. Plot A represents litter alone. Plot B represents litter plus ferrous sulfate. Plot C represents litter plus alum. Plot D represents the control.

FIG. 13B illustrates treatment effects on soluble reactive phosphorus concentrations in a second runoff based on a simulated rainfall event. Plot A represents litter alone. Plot B represents litter plus ferrous sulfate. Plot C represents litter plus alum. Plot D represents the control.

FIG. 14 illustrates the treatment effects on total phosphorus load from 3 runoff events. For runoff event 1, plot A represents the control. Plot B represents litter plus alum. Plot C represents litter plus ferrous sulfate. Plot D represents litter alone. For runoff event 2, plot E represents the control. Plot F represents litter plus alum. Plot G represents litter plus ferrous sulfate. Plot H represents litter alone. For runoff event 3, plot I represents the control. Plot J represents litter plus alum. Plot K represents litter plus ferrous sulfate. Plot L represents litter alone.

FIG. 15A is a plot showing dissolved Cu concentrations in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure on the day of application as a function of poultry manure application rate in Mg/ha.

FIG. 15B is a plot similar to FIG. 15A showing dissolved Cu concentrations in runoff water as a function of poultry manure application rate taken seven days after application.

FIG. 16 is a plot showing dissolved Cu concentrations in runoff water as a function of the concentration of soluble organic carbon in runoff water.

FIG. 17 is a plot showing the concentration of soluble Cu as a function of total Cu concentration in runoff water.

FIG. 18A is a plot showing concentration of dissolved Zn in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken on the day of application.

FIG. 18B is a plot similar to FIG. 18A taken seven days after application.

FIG. 19A is a plot showing concentration of dissolved As in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken on the day of application.

FIG. 19B is a plot similar to FIG. 19A taken seven days after application.

FIG. 20A is a plot showing concentration of dissolved Fe in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken the day of application.

FIG. 20B is a plot similar to FIG. 20A taken seven days after application.

FIG. 21A is a plot showing concentration of dissolved Al in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken the day of application.

FIG. 21B is a plot similar to FIG. 21A taken seven days after application.

FIG. 22 is a plot showing the concentration of soluble Al as a function of total Al concentration in runoff water.

FIG. 23A is a plot showing concentration of dissolved Ca in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken the day of application.

FIG. 23B is a plot similar to FIG. 23A taken seven days after application.

FIG. 24A is a plot showing concentration of dissolved Mg in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken the day of application.

FIG. 24B is a plot similar to FIG. 24A taken seven days after application.

FIG. 25A is a plot showing concentration of dissolved K in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken the day of application.

FIG. 25B is a plot similar to FIG. 25A taken seven days after application.

FIG. 26A is a plot showing concentration of dissolved Na in runoff water from fescue plots fertilized with normal poultry manure and alum-treated poultry manure as a function of manure application rate in Mg/ha taken the day of application.

FIG. 26B is a plot similar to FIG. 26A taken seven days after application.

FIG. 27 is a plot showing the average from five flocks of poultry manure pH for control manure versus alum-treated manure as a function of time in weeks.

FIG. 28 is a plot showing the average from five flocks of ammonia concentrations in poultry houses containing control poultry manure versus alum-treated poultry manure as a function of time in weeks; and

FIG. 29 is a graphical plot showing average bird weight for birds grown in poultry houses containing control manure versus alum-treated manure for Company A, Company B and showing the overall average.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a method for treating poultry litter, which inhibits ammonia volatilization from the litter and reduces soluble phosphorus levels in the litter. The method involves the addition of alum to poultry litter. Alum is an aluminum sulfate compound having the composition $Al_2(SO_4)_3 \cdot nH_2O$, with n varying from approximately 14–18 molecules of water due to the varying degree of hydration in alum. Since poultry litter is highly variable in composition, the quantity of alum needed to arrest volatilization also varies. However, the amount of alum necessary to inhibit the buildup of atmospheric ammonia in poultry rearing facilities is the amount sufficient to maintain the litter pH at values low enough to inhibit ammonia volatilization. In this regard, alum is applied to the litter in an amount equivalent to approximately 5–25% of the litter weight on a dry weight basis. For example, 130 grams of alum would be applied per kilogram of litter. During a normal growout, 20,000 chickens will generate 20 tons of moist litter (16 tons dry). Therefore, 2 tons of alum would be required per poultry house after each growout.

Preferably, alum should be applied to the top of the litter and thoroughly mixed in with a mechanical mixer such as a

power-tiller. Alum applications to litter also greatly reduced nitrogen loss in the litter, thereby further enhancing the value of this treated poultry litter as a fertilizer source. Ferrous sulfate was also found to dramatically reduce ammonia volatilization in litter.

Studies revealed that in addition to aluminum compounds like alum, calcium and iron compounds when added to poultry litter, precipitate the phosphorus in the litter, resulting in a reduction of water soluble phosphorus levels by as much as 99%. In this regard, water soluble phosphorus levels in poultry litter were reduced from over 2,000 mg phosphorus kg^{-1} litter to less than 1 mg phosphorus kg^{-1} litter with the addition of alum, quick lime, slaked lime, ferrous chloride, ferric chloride, ferrous sulfate and ferric sulfate under favorable pH conditions. To achieve a reduction in the soluble phosphorus levels in litter, alum, calcium, and iron compounds were applied to litter in an amount equivalent to having a mole ratio of the metal to phosphorus of approximately 0.5:1 to 2.5:1. These results along with actual field application studies suggest that treating litter prior to field application with these compounds could significantly reduce the amount of soluble phosphorus in runoff from litter-amended pastures and increase forage yields.

Although the methods of the present invention for treating litter focuses on poultry litter, it is contemplated that the addition of various compounds described herein would be applicable to other types of animal manures.

By way of example, and not limitation, the following examples serve to further illustrate the present invention in its preferred embodiments.

EXAMPLE 1

Experiment 1

(A) Methods and Materials

A laboratory study was conducted to determine if ammonia volatilization could be inhibited with chemical amendments. 92 g of fresh poultry litter (50 grams dry weight equivalent) was weighed into 44 air-tight plastic containers. 11 treatments were utilized in this study. The treatments were as follows:

1. control—litter alone
2. 25 g $\text{Ca}(\text{OH})_2$ per kg litter
3. 50 g $\text{Ca}(\text{OH})_2$ per kg litter
4. 100 g $\text{Al}_2\text{SO}_4 \cdot 18\text{H}_2\text{O}$ per kg litter
5. 200 g $\text{Al}_2\text{SO}_4 \cdot 18\text{H}_2\text{O}$ per kg litter
6. 100 g $\text{Al}_2\text{SO}_4 \cdot 18\text{H}_2\text{O} + 50\text{ g CaCO}_3$ per kg litter
7. 200 g $\text{Al}_2\text{SO}_4 \cdot 18\text{H}_2\text{O} + 50\text{ g CaCO}_3$ per kg litter
8. 100 g $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ per kg litter
9. 200 g $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ per kg litter
10. 10 g MLT per kg litter
11. 20 g MLT per kg litter

There were 4 replications per treatment. The treatments were mixed into the litter. The containers were equipped with air inlets and outflows. Ammonia-free air was passed through each chamber and any ammonia volatilized from the litter was trapped in 30 ml of boric acid solution. At each sampling period, the boric acid was removed and titrated with 0.10 N HCl to determine the ammonia content. After the titration, the flasks were replaced with fresh boric acid solutions. Samples were titrated daily for the first 19 days and every other day thereafter. The study was carried out for 42 days.

At this time, a 20 gram sub-sample of the litter was extracted with 200 ml of deionized water for two hours. The

samples were centrifuged at 6,000 RPM and aliquots were taken for pH, electrical conductivity (EC), alkalinity, ammonium, nitrate, soluble reactive phosphorus (SRP) and metals. Samples for EC, pH and alkalinity were unfiltered and were analyzed immediately. Samples for ammonium and nitrate were filtered through 0.45 μm filter and frozen. Metal and SRP samples were filtered (0.45 μm), acidified to pH 2.0 with ultrapure HNO_3 , and frozen. Total dissolved phosphorus and metals were determined by ICAP (inductively coupled argon plasma emission spectrometer). Soluble reactive phosphorus was determined using an auto-analyzer. After the water extract, the litter was extracted with 1 N KCl for 2 hours for exchangeable ammonium. After centrifuging, these samples were filtered and analyzed for ammonium. 10 gram sub-samples were taken from each container for water content and TKN (total kjeldahl nitrogen) analysis. Total nitrogen was determined by kjeldahl distillation. Fecal coliform counts were made on litter samples taken at this time and were analyzed by the Arkansas Water Resources Laboratory using the most probably number method. All samples tested negative for fecal coliform.

(B) Results

As shown in FIG. 1, an average of 13.2 g N kg^{-1} litter was lost from the controls (unamended litter) during the 42 day incubation period. This corresponds to an NH_3 volatilization rate of 314 mg N kg^{-1} day $^{-1}$. Applications of MLT actually increased NH_3 volatilization. The recommended rate (10 g MLT kg^{-1}) resulted in 31% more N loss via volatilization than the controls. At 2 times the recommended rate (20 g MLT kg^{-1}), volatilization was 15% higher than the controls. These results are not surprising, since the pH of MLT and water is around 10. Increases in litter pH shift the NH_3/NH_4 equilibrium towards NH_3 , resulting in higher volatilization.

As shown in FIG. 2, ammonia volatilization from litter treated with $\text{Ca}(\text{OH})_2$ was not significantly different from that in the controls. During the first three days of the experiment, the rate of NH_3 loss from the 50 g $\text{Ca}(\text{OH})_2$ kg^{-1} treatment was much faster than the controls, which was probably due to increases in pH. However, $\text{Ca}(\text{OH})_2$ was probably converted to CaCO_3 with time, resulting in lower pHs. The pHs of the $\text{Ca}(\text{OH})_2$ treatments were not significantly different from the controls after 42 days of incubation. Applications of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ decreased NH_3 volatilization. This is illustrated in FIG. 3. Cumulative NH_3 losses were 12 and 58% lower than the controls for the 100 and 200 g $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ kg^{-1} treatments, respectively. This is probably due to a decrease in litter pH, since $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ is an acid forming compound.

As shown in FIG. 4, alum applications, both with and without CaCO_3 , greatly reduced NH_3 volatilization. Nitrogen losses with alum in combination with 100 g CaCO_3 were 24 and 57% lower than the controls at the 100 and 200 g alum kg^{-1} rates, respectively. When alum was applied alone, the N loss was greatly reduced, with cumulative NH_3 losses 38 and 99% lower than the controls for the 100 and 200 g alum kg^{-1} treatment, respectively. In fact, only 0.2 g N kg^{-1} were lost due to NH_3 volatilization at the high rate of alum, and this occurred in the last week of the study. Prior to that time, NH_3 loss from the 200 g alum kg^{-1} treatment had been zero.

In FIG. 5, the total N content of the litter after 42 days of incubation is plotted as a function of the cumulative NH_3 volatilization for the various treatments. Treatments with higher volatilization had lower total N contents at the end of the study as would be expected. The total N content of the 200 g alum kg^{-1} treatment was 43 g N kg^{-1} . This is

somewhat higher than the original N content (41.8 g N kg⁻¹). If the amount of alum present had been taken into account, then the N content would be 52.3 g N kg⁻¹. Higher total N contents as compared to the original N content are due to losses in carbon via CO₂ evolution from microbial decomposition. The controls contained 25.5 g N kg⁻¹ at the conclusion of the study. Therefore, the addition of alum at the higher rate resulted in a doubling of the N content in the litter. This would greatly increase the value of poultry litter as a fertilizer source.

EXAMPLE 2

Experiment 2

(A) Methods and Materials

In order to determine the relative effectiveness of the products currently being sold as NH₃ volatilization inhibitors, as well as ferrous sulfate and alum, a second study was conducted.

50 g (dry weight equivalent) of fresh poultry litter was weighed into 44 plastic containers. Different products were compared and rates of each were as follows:

Relative Costs of Various Poultry Litter Amendments			
Product	Recommended rate	Metric rate	Cost/House
1. Control	0	0	0
2. Acid Mine Soil	50 lb/100 ft ₂	200 g/kg	?
3. Aluminum Sulfate	50 lb/100 ft ₂	200 g/kg	\$880
4. Ammonia Hold	1 lb/100 ft ₂	4 g/kg	\$288
5. Brown Mud	50 lb/100 ft ₂	200 g/kg	?
6. De-odorase	4 oz/100 ft ₂	0.52 mL/kg	?
7. Ferrous Sulfate	50 lb/100 ft ₂	200 g/kg	\$420
8. FBC	30 lb/100 ft ₂	120 g/kg	?
9. MLT	1 gal/480 ft ₂	6.95 mL/kg	?
10. PLT	5 lb/100 ft ₂	20 g/kg	\$280
11. Red Mud	50 lb/100 ft ₂	200 g/kg	?

Rates were based on a house size of 16,000 ft², containing 20 tons litter. There were 4 replications per treatment in a completely randomized design. The containers were equipped with air inflows and outflows. Ammonia-free air was passed through each chamber and any ammonia volatilized from the litter was trapped in two 50 ml volumetric flasks containing 30 ml of boric acid solution. At each sampling period, the boric acid was removed and titrated with 0.10 N HCl to determine the ammonia content. After the titration, the flasks were replaced with fresh boric acid solutions. Sampling times were daily for the first 21 days and every 2 days thereafter. After 42 days, a 20 gram sub-sample of the litter was extracted with 200 ml of deionized water for 2 hours. The samples were centrifuged at 6,000 RPM and aliquots were taken for pH, EC, alkalinity, ammonium, nitrate, SRP and metals. Analyses were conducted as described above in Experiment 1.

(B) Results

As shown in FIG. 6, ammonia volatilization from litter treated with MLT was 8% higher than the controls. These results confirm those found in Experiment 1 and indicate that this product, which is currently being sold in several states, increases rather than decreases NH₃ volatilization. De-odorase, a product made from yucca plant extract, also increased volatilization (9% more N loss than the controls).

The only two commercial products that appeared to work at all were Ammonia Hold and PLT, which reduced N losses by 29 and 23%, respectively, as compared to the controls. However, reduction in NH₃ volatilization was much greater with ferrous sulfate and alum, which resulted in 65 and 85%

less N loss, respectively. These data indicate that these two treatments are far better than what is currently available commercially.

In Table 1 below, the cost of treating an average poultry house for one growout with these amendments is provided. In order to make a proper comparison, the products' effectiveness must be taken into account. This was done by calculating the cost to treat an average house (20 tons of litter) and dividing that by the amount of N conserved by each treatment. These data indicate that alum and ferrous sulfate are much more cost effective than the best commercial product that was found to inhibit volatilization.

TABLE 1

Cost and Cost-effectiveness of various poultry litter amendments based on recommended rates for one growout in a 16,000 ft² house

Amendment	Cost/house	Amount N Conserved* (lbs. N/house)	Cost/lb N Held
Ferrous Sulfate	\$420	957	\$0.44
Alum	\$880	1112	\$0.79
Ammonia Hold	\$288	28	\$10.15
PLT	\$280	42	\$6.63
MLT	—	Increases NH ₃ Volatilization	—
De-odorase	—	Increases NH ₃ Volatilization	—

*Amount N conserved was calculated based on the increase in nitrogen content of the litter above that observed in the control samples, assuming 40,000 lbs. litter are produced per growout.

It should be noted that alum and ferrous sulfate would be more desirable than Ammonia Hold and PLT from an environmental point of view, since they would immobilize soluble phosphorus in the litter. On the other hand, phosphoric acid is used to produce Ammonia Hold. This would result in higher phosphorus loading onto the land, resulting in higher phosphorus runoff. Poultry litter treater (PLT) is composed of NaHSO₄. This compound reduces litter pH (which solubilizes calcium phosphates), without providing a phosphate binding agent, like Al, Ca and/or Fe.

As shown in FIG. 7, cumulative NH₃ volatilization from litter amended with acid mine soil was roughly equivalent of that of the controls. Brown mud and red mud, two clay wastes from aluminum processing in Arkansas reduced volatilization by 15 and 20%, respectively. Similarly, fluidized bed combustion material (FBC), a waste product from coal-fired power plants, reduced volatilization by 16%. All of these waste products should theoretically reduce soluble phosphorus levels in poultry litter. Future studies will also be conducted to determine if increasing rates of these amendments will decrease volatilization.

Total kjelkdahl N (TKN) in the litter at the conclusion of Experiment 2 is plotted as a function of cumulative ammonia volatilization in FIG. 8. Decreases in TKN were observed in samples that had higher volatilization rates, while TKN increased in the alum and ferrous sulfate treated litter. The reasons for this increase are the same as those noted for Experiment 1.

The rate of ammonia volatilization is dependent on pH, moisture content, wind speed, ammonium concentration and temperature. Volatilization increases with increases in any of these variables. The pH of litter is very important because it determines the ratio of NH₃/NH₄. As pH increases, this ratio increases, causing volatilization to increase and vice versa. Therefore, acid forming compounds, like alum and ferrous

sulfate, reduce volatilization, whereas basic compounds like MLT (which has a pH of 10) increases volatilization.

Results from this study indicate that alum and ferrous sulfate greatly reduce ammonia volatilization from poultry litter. By decreasing nitrogen losses from volatilization, the use of these products results in a higher total nitrogen content in poultry litter, thus increasing the value of the litter as a fertilizer. These compounds, which have also been shown to immobilize phosphorus in litter, are cheaper and more effective than any commercial products currently available. Since high ammonia levels in poultry houses cause major economic losses to producers, the use of these compounds should result in increased profitability to producers, while simultaneously decreasing the negative environmental impact from land application of poultry litter.

EXAMPLE 3

Determination of Alum Requirement in Poultry Litter for Inhibition of Ammonia Volatilization

The objective of this study was to determine the amount of alum needed to inhibit volatilization from litter. Rather than measure ammonia volatilization, litter pH was used as an indicator of whether or not volatilization would occur. Based on the two previous studies, it was determined that the target pH to inhibit volatilization was approximately 5.75 for the methods being used to determine pH.

Broiler litter was obtained from 3 low ventilation environmental chambers and 8 commercial broiler houses, all of which had at least 2 growouts on the litter. The litter from the 3 chambers was composited and 20 grams moist litter from each source was weighed into 250-ml polycarbonate centrifuge tubes. There were 6 treatments: 0, 1, 2, 3, 4, and 5 g alum/20 g moist litter. After adding the alum to the litter, 200 ml of deionized water was added to each tube, which was then shaken for 2 hours. The pH of the supernatant was then determined. Water content was determined on each litter source in order to convert rates to a dry weight basis.

As shown in FIG. 8B, alum additions resulted in decreases in pH of the litter from both the commercial houses and environmental chambers. However, the amount of alum needed to reach pH 5.75, or inhibit ammonia volatilization, was much lower in litter from commercial houses as compared to the litter from the environmental chambers (130 versus 200 g/kg dry litter). There is approximately 20 tons of moist litter produced in a growout (16 tons dry). Therefore, the alum requirement for a commercial house would be approximately 2 tons per growout. Assuming alum can be purchased for \$220/ton, the cost of treating a commercial broiler house is approximately \$440.

EXAMPLE 4

(A) Methods and Materials

The objective of this study was to determine if soluble phosphorus levels could be reduced in poultry litter with aluminum (Al), calcium (Ca), and/or iron (Fe) amendments.

To this end, 26 grams of fresh poultry litter (20 grams dry weight equivalent) were weighed into glass bottles. The litter had been forced through a 10 mesh sieve to break up large clumps and mixed in a portable cement mixer for 2 hours to insure homogeneity. The bedding of this litter was rice hulls. The litter had not been stacked or composited. The initial pH (1:1) and electrical conductivity (1:10, litter:water extract) was 8.2 and 8970 $\mu\text{S cm}^{-1}$, respectively. Total N, P, and Potassium (K) were 42.8, 18.1, and 27.3 g kg^{-1} , respectively. Total Kjeldahl N was determined on the fresh poultry litter according to the method of Bremner et al. In

(A. L. Page, R. H. Miller and D. R. Keeney eds.) *Methods of Soil Analysis, Part 2, Second Edition*. Amer. Soc. Agron. Publ. Madison, Wis., 1982). Total phosphorus and potassium were determined on fresh litter using the method of Huang et al. (*Commun. in Soil Sci. Plant Anal.* 16:943-958, 1985).

The litter was amended with aluminum, calcium, and iron compounds to reduce phosphorus solubility. Materials tested included alum, sodium aluminate, quick lime, slaked lime, calcitic limestone, dolomitic limestone, gypsum, ferrous chloride, ferric chloride, ferrous sulfate and ferric sulfate. All amendments were reagent grade materials. After the amendments had been added, the mixtures were stirred with a spatula for approximately 1 minute. The calcium treatments were tested with and without CaF_2 additions as a secondary amendment in an attempt to precipitate fluorapatite. Calcium carbonate was added as a secondary amendment in cases where the primary amendment was believed to be an acid forming compound.

As shown below in Table 2, there were 20 different chemical treatments tested, with 5 rates of each treatment (total number of treatments equalled 100 plus control) and 3 replications. The lowest rate of the iron and aluminum amendments was equal to the amount needed to achieve a 1:1 metal:phosphorus mole ratio, assuming the phosphorus content of the litter was 10 mg kg^{-1} . The lowest rate of the calcium amendments was based on a calcium:phosphorus ratio of 1.5:1. It should be noted that while the rates were based on the assumption that the phosphorus content of litter was 10 mg phosphorus kg^{-1} , the actual phosphorus content was found to be 18.1 mg phosphorus kg^{-1} . Therefore, the lowest rate of aluminum and iron was equivalent to 1:1.8 mole ratio, etc. In view of these studies and based on the differences noted with the use of each of the aluminum, calcium, and iron compounds, the amount of each compound sufficient to reduce soluble phosphorus levels in poultry litter is equivalent to a metal to phosphorus mole ratio of approximately 0.5:1 to 2.5:1.

TABLE 2

Treatment	Rates of Chemical Amendments Utilized in this Study					Rate of Secondary Amendment in g/kg litter
	Rate of Primary Amendment in g/kg litter					
1. CaO	30	60	90	120	150	0
2. CaO + CaF_2	30	60	90	120	150	5
3. $\text{Ca}(\text{OH})_2$	40	80	120	160	200	0
4. $\text{Ca}(\text{OH})_2$ + CaF_2	40	80	120	160	200	5
5. CaCO_3	50	100	150	200	250	0
6. CaCO_3 + CaF_2	50	100	150	200	250	5
7. $\text{CaMg}(\text{CO}_3)_2$	100	200	300	400	500	0
8. $\text{CaMg}(\text{CO}_3)_2$ + CaF_2	100	200	300	400	500	5
9. $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	100	200	300	400	500	0
10. $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ + CaF_2	100	200	300	400	500	5
11. $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$	100	200	300	400	500	0
12. $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ + CaCO_3	100	200	300	400	500	100
13. $\text{Na}_2\text{Al}_2\text{O}_4$	25	50	75	100	125	0
14. $\text{Na}_2\text{Al}_2\text{O}_4$ + CaCO_3	25	50	75	100	125	100
15. $\text{Fe}_2(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$	60	120	180	240	300	0
16. FeCl_3	50	100	150	200	250	0
17. $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	90	180	270	360	450	0
18. $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + CaCO_3	90	180	270	360	450	100

TABLE 2-continued

Treatment	Rates of Chemical Amendments Utilized in this Study					Rate of Secondary Amendment in g/kg litter
	Rate of Primary Amendment in g/kg litter					
19. FeCl ₂ ·4H ₂ O	60	120	180	240	300	0
20. FeCl ₂ ·4H ₂ O + CaCO ₃	60	120	180	240	300	100

After amendments were added to the litter, deionized water was added to achieve a water content of 20% by volume. The amended litter was then incubated in the dark at 25° C. for one week. A one week equilibration time was utilized for this study because this is usually the time scale between the removal of broilers from the houses after the final growout before litter removal and land application of the litter. At the end of this period, the litter was transferred to polycarbonate centrifuge tubes, shaken for 2 hours with 200 mL of deionized water, and centrifuged at 4066 g for 20 min. Unfiltered samples were collected for measurement of pH, alkalinity, and electrical conductivity (EC). Alkalinity was determined by titration, according to APHA method 2320 B (*American Public Health Association (APHA), Standard Methods for the Examination of Water and Wastewater*, 18 Ed. Amer. Publ. Health Assoc., Wash., D.C. pp. 1268, 1992). Filtered samples (0.45 μm millipore filters) were collected for measurement of soluble reactive phosphorus (SRP), water soluble metals (Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S, Zn), soluble organic carbon (SOC), SO₄, and Cl. The metal and SRP samples were acidified to pH 2.0 with nitric acid to prevent precipitation. Chloride, SOC, and SO₄ samples were not acidified. Soluble reactive phosphorus was determined using an ascorbic acid technique, according to APHA method 424-G (APHA, supra). Metals were analyzed using an inductively coupled argon plasma emission spectrometer (ICP), according to APHA method 3120 B (APHA, supra). Soluble organic carbon was determined as the difference between total organic carbon and inorganic carbon as measured on a Rosemont DC-190 organic carbon Analyzer, using the combustion-infrared method according to APHA method 5310 B (APHA, supra). Sulfate was determined using the turbidimetric method, according to APHA method 4500-SO₄²⁻ E (APHA, supra). Chloride was determined using the potentiometric method with a chloridometer, according to APHA method 4500-Cl⁻ D (APHA, supra).

(B) Results

(1) Calcium Amendments

As shown in FIG. 11, calcium oxide decreased the water soluble phosphorus levels in the litter from >2000 mg phosphorus/kg to <1 mg phosphorus/kg when an equivalent of 43 g calcium was added per kg of litter. It is not known whether this was due to precipitation or adsorption. Whatever the mechanism, the data suggest that soluble phosphorus runoff from fields receiving poultry litter could be decreased significantly if the litter were pretreated with CaO. The pH of the litter increased from 7.2 (control) to approximately 12 at the higher rates of CaO as shown in Table 3.

TABLE 3

Treatment	Effect of Al, Ca and Fe compounds on pH of poultry litter					
	Amendment Level	pH				
		1x	2x	3x	4x	5x
Control		7.30				
10 CaO		9.82	11.76	12.29	12.41	12.44
CaO + CaF ₂		9.71	11.38	12.24	12.40	12.45
Ca(OH) ₂		9.12	11.06	12.23	12.32	12.33
Ca(OH) ₂ + CaF ₂		9.51	11.43	12.21	12.30	12.34
CaCO ₃		7.87	8.10	7.87	7.37	7.27
CaCO ₃ + CaF ₂		6.88	7.64	7.75	7.56	7.65
15 CaMg(CO ₃) ₂		7.69	7.35	7.84	8.24	7.98
CaMg(CO ₃) ₂ + CaF ₂		8.21	8.05	7.52	7.65	8.18
CaSO ₄ ·2H ₂ O		7.41	7.57	7.36	7.68	7.32
CaSO ₄ ·2H ₂ O + CaF ₂		7.36	7.14	7.43	7.61	7.32
Al ₂ (SO ₄) ₃ ·18H ₂ O		5.73	4.26	3.81	3.59	3.50
Al ₂ (SO ₄) ₃ ·18H ₂ O + CaCO ₃		7.56	6.75	6.46	5.37	4.18
20 Na ₂ Al ₂ O ₄		7.78	8.97	9.88	10.55	11.01
Na ₂ Al ₂ O ₄ + CaCO ₃		7.97	9.31	13.31	10.56	11.18
Fe ₂ (SO ₄) ₃ ·2H ₂ O		7.21	4.86	2.77	2.45	2.33
FeCl ₃		5.33	3.52	2.21	1.97	1.88
FeSO ₄ ·7H ₂ O		7.13	5.67	4.39	4.28	5.15
FeSO ₄ ·7H ₂ O + CaCO ₃		6.76	6.17	6.03	6.14	5.21
25 FeCl ₂ ·4H ₂ O		7.19	4.85	4.42	4.09	3.95
FeCl ₂ ·4H ₂ O + CaCO ₃		7.32	6.23	6.05	5.83	5.34

(LSD.05 = 30)

A reduction in pH of the litter treated with CaO would be expected with time, due to equilibration with atmospheric CO₂. This gradual reduction in pH may result in increased phosphorus solubility, since the solubility of calcium phosphates is extremely pH dependent. However, even if the pH drops to about 7.3, the equilibrium concentration of the most soluble calcium phosphate minerals, such as brushite (CaHPO₄·2H₂O), would be about 10⁻⁴ M or 3 mg P L⁻¹ (Lindsay, *Chemical Equilibria in Soils*, 449 pp. John Wiley & Sons, N.Y.). This would still be roughly 2 orders of magnitude lower than soluble phosphorus levels determined for the litter used (200 mg P L⁻¹).

Recently, it has been determined that the majority of phosphorus runoff from land application of poultry manure occurs during the first runoff event (Edwards et al., *J. Environ. Qual.* 22:361-365, 1993). If soluble phosphorus levels could be decreased for at least a few weeks following land application, then there would be time for precipitation and adsorption by soils to occur, as well as uptake by plants and microorganism. Therefore, if the solubility of phosphorus was lowered for only a short period of time, it would be beneficial from both an environmental and an agronomic viewpoint.

Calcium hydroxide decreased phosphorus solubility in poultry litter in the same manner as CaO. This is shown in FIG. 9. Since Ca(OH)₂ is less caustic, this treatment would be preferable to CaO, which can cause severe burns upon skin contact.

Calcitic and dolomitic limestone on phosphorus solubility in poultry litter had very little effect on SRP concentrations. There are several possible reasons why these amendments did not work. One possibility is that the experiment was not carried out for a sufficient period of time. Normally, it takes months for limestone to completely react and neutralize soil acidity. Our incubation period was one week, which may have been an insufficient time period for solubilization and precipitation reactions. Phosphorus adsorption by calcite should have occurred, since this is an extremely fast reaction.

The pH of the unamended litter was initially 8.2, which decreased to 7.2 after one week. Both calcite and dolomite are relatively insoluble at this pH, which may have led to inadequate amounts of Ca^{2+} in solution to precipitate the phosphorus. However, even if the Ca^{2+} concentrations in solution were low, phosphorus adsorption onto the calcite surface should have removed phosphorus from solution based on research previously done in this area.

Phosphorus accumulation onto calcite surfaces is characterized as a three step process: (1) chemisorption of phosphate onto the surface causing the formation of amorphous calcium phosphate nuclei; (2) a slow transformation of the nuclei into crystalline apatite; and (3) crystal growth of apatite. In our study, this process may have been inhibited by the high SOC levels in these treatments. High soluble carbon levels were measured in the extracts of samples which had relatively high pHs. This is shown in FIG. 10.

Our studies further revealed that gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) decreased SRP from over 2000 mg phosphorus kg^{-1} to approximately 700 mg phosphorus kg^{-1} at the 100 g kg^{-1} rate as shown in FIG. 9. It should be noted that the lowest rate of gypsum used in this study was high enough to exceed the solubility product of gypsum (2.4 g L^{-1}). This helps to explain why increasing rates of this compound did not influence phosphorus, which is that water soluble calcium levels will not be expected to increase after the solubility has been exceeded. If the reduction in SRP noted with the gypsum treatment was due to the formation of calcium phosphate mineral(s), phosphorus removal could be enhanced with this amendment if the pH were increased to about 7.3 or higher. If adsorption of phosphorus by gypsum was the dominant mechanism of phosphorus removal with this amendment, then concentrations of phosphorus should have decreased with increasing rates of gypsum. However, this was not observed.

The addition of CaF_2 did not increase phosphorus removal in the calcium treatments, suggesting that fluorapatite formation did not occur. This could have been due to the presence of organic acids, Mg and HCO_3^- , both of which are known to inhibit apatite formation. Mineral equilibria studies have shown also that when calcium phosphates are forming, the solubility is intermediate between octacalcium phosphate ($\text{Ca}_8\text{H}(\text{PO}_4)_6 \cdot 2.5 \text{ H}_2\text{O}$) and beta tricalcium phosphate ($\beta\text{-Ca}_3(\text{PO}_4)_2$).

(2) Aluminum and Iron Amendments

Alum additions greatly decreased water soluble phosphorus as illustrated in FIG. 11. Without CaCO_3 to buffer the pH, water soluble phosphorus increased at the highest alum rates. This was believed to be due to the acidity created by the alum, which may have caused: (1) dissolution of inorganic calcium phosphates; (2) acid hydrolysis of organic phosphorus; and/or (3) dissolution of $\text{Al}(\text{OH})_3$, which would result in phosphorus release if adsorption had been the primary mechanism of removal. The pH of the alum treated litter dropped to 3.5 at the highest rate. This is shown in Table 3. Calcium phosphate minerals are highly soluble at this pH and could release enough phosphorus to achieve the phosphorus concentrations noted at the higher rates. Dicalcium phosphate is added to poultry feed to help insure proper bone development, since most of the phosphorus in soybean and corn is phytate phosphorus, which is unavailable to chickens since they lack the phytase enzyme.

As further illustrated in FIG. 11, when CaCO_3 was added with the alum to buffer the pH, virtually 100% of the soluble phosphorus was removed from solution. The optimum pH range for removal by Al has been shown to be from 5.5 to 8.0. Under acidic conditions ($\text{pH} < 6$), AlPO_4 forms, while at

pH 6 to 8, an $\text{Al}(\text{OH})_3$ floc forms, which removes phosphorus from solution by sorption of inorganic phosphate and entrapment of organic particles containing phosphorus.

Other positive aspects anticipated with this invention include decreasing soluble organic carbon (SOC) levels in runoff water from litter-amended fields. As shown in FIG. 10, soluble organic carbon levels were relatively low under acidic conditions, whereas they tended to be high in the controls and in treatments which increased the pH of the litter. Decreases in SOC concentrations and associated reductions in biological oxygen demand of wastewaters are one of the primary functions of flocculents used in waste water treatment. Decreases in SOC runoff should also improve water quality by decreasing O_2 demand in lakes and rivers receiving runoff from pastures amended with poultry litter treated with acid forming products. Addition of metal flocculents also decreased the solubility of Cu and Zn, which occur in high concentrations in poultry litter. Minimum solubility of both of these metals occurred at approximately pH 6.

Sodium aluminate decreased SRP levels to around 600 mg phosphorus kg^{-1} litter at the lowest rate. This is shown in FIG. 11. Increasing rates of sodium aluminate did not decrease water soluble phosphorus, which was probably due to elevated pH at the higher rates. Further, calcitic limestone, as an additive to the sodium aluminate treatment, did not decrease soluble phosphorus.

FIG. 12 illustrates the effect of iron amendments to poultry litter on water soluble reactive phosphorus. Additions of ferric iron as $\text{Fe}_2(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$ or FeCl_3 greatly decreased phosphorus solubility at the lower rates, but increased the solubility at the higher rates. Increases in SRP at the higher rates may have been due to: (1) dissolution of calcium phosphates; (2) acid hydrolysis of organic phosphorus; and/or (3) a decrease in adsorption of phosphorus by iron compounds due to dissolution of iron oxides and hydroxides at low pH. The pH of these two treatments approached 2 at the higher rates, which is shown in Table 3. These values are well below the optimum pH range (4.7 to 7.1) for phosphorus removal by iron reported previously in the literature. Therefore, removal with these compounds would have been enhanced if the pH of the litter had been maintained at a higher value.

The results from the study further indicate that pH adjustment is also necessary for Fe(III) systems which contain SO_4 , such as the $\text{Fe}_2(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$ treatment, because when extremely acid conditions occur, water soluble phosphorus levels increase dramatically.

As further illustrated in FIG. 12, ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) additions greatly decreased the solubility of phosphorus in poultry litter. Water soluble phosphorus concentrations were not significantly different in the FeSO_4 treatment amended with CaCO_3 , indicating that phosphorus removal with this compound is less pH dependent than for some of the other iron compounds. Additions of ferrous chloride greatly decreased phosphorus solubility. Additions of calcitic limestone in conjunction with ferrous chloride resulted in more efficient phosphorus removal at lower rates than ferrous chloride alone.

(C) Litter Management

Recently, there has been increasing emphasis on decreasing runoff of bioavailable phosphorus, rather than particulate phosphorus, since it is more available for use by algae that are responsible for eutrophication. Water soluble phosphorus is by far the most available form of phosphorus to algae and bacteria. Drastic reductions in soluble phosphorus levels running off agricultural lands receiving poultry litter should help improve the water quality of adjacent lakes and rivers.

It should be noted that alum and lime are relatively inexpensive and readily available. Calcium compounds, such as CaO or Ca(OH)₂, cost approximately \$55 per metric ton. Results from the present invention indicate that 50 kg of Ca(OH)₂ per metric ton of litter may be adequate to immobilize most of the litter phosphorus. Since there are 20 metric tons of litter produced per poultry house per growout (each house contains 15,000 to 20,000 birds), one ton of Ca(OH)₂ (slaked lime) is needed per house per growout. Assuming five growouts per year, the annual cost of slaked lime for one house would be \$275. Gross incomes per house normally exceed \$25,000 per year. Therefore, the cost of slaked lime needed for phosphorus immobilization would be around 1% of the gross income, which should be economically feasible. However, before a valid economic analysis of this process can be made, on-farm experiments need to be conducted to determine if treatment levels found in this study are adequate.

Although alum and ferrous sulfate are more expensive than Ca(OH)₂, the benefits of using these compounds should far exceed that of the calcium compounds. Lowering the pH of the litter will decrease NH₃ volatilization. High levels of NH₃ in poultry houses increase the incidence of ascites in poultry (water belly) and other respiratory related maladies, such as New Castle Disease and airsacculitis. Since the amount of NH₃ volatilization is a function of the ratio of NH₃/NH₄ in the litter, which is controlled by pH, reducing the pH of the litter to around 6.0 will cause nitrogen losses via this mechanism to cease. This should result in increased weight gains in the birds, as well as decreased incidence of respiratory problems.

Currently, the number one complaint received by federal and state regulatory agencies concerning poultry production concerns odors arising from land application of litter. Ammonia is one of the primary agents responsible for the odor. It is estimated that 37% of the nitrogen is lost from litter during the first 11 days of application. If these losses were combined with those that occur in the poultry houses, the total loss by volatilization would probably exceed 50% of the total nitrogen. Therefore, volatilization losses not only result in air pollution, but in losses of valuable fertilizer nitrogen. Decreasing NH₃ volatilization will result in higher nitrogen/phosphorus ratios in poultry litter. Currently, the nitrogen/phosphorus ratio in litter is often as low as 2, whereas this ratio in the feed is near 8. The difference is mainly due to nitrogen loss via volatilization. Since application rates of litter are based on the nitrogen requirement of the crop, less litter could be applied per acre if the nitrogen content were higher.

EXAMPLE 5

Reduction of Phosphorus in Runoff From Field-Applied Poultry Litter Using Chemical Amendments

(A) Methods and Materials

The use of poultry manure or poultry litter as a source of crop nutrients has been well established. The University of Arkansas Cooperation Extension Service recommends an annual maximum application rate of 11.2 Mg/ha, with no more than 5.6 Mg/ha in a single application. This recommendation is based on meeting the nitrogen requirements of forage, a common approach in animal waste application programs. Recommendations, however, based on forage nitrogen requirements do not consider other possible limiting factors in land application of poultry litter, such as phosphorus or heavy metal content. Field application of poultry litter at rates to meet forage nitrogen requirements

normally results in an over-application of phosphorus. This study was conducted to determine the effects of two chemical amendments, alum and ferrous sulfate, on phosphorus concentrations and load in runoff and to evaluate the effects of amended litter on forage production.

The study was conducted on 1.5 m by 6.0 m (long axis oriented up- and down-slope) plots constructed at the Main Agricultural Experiment Station on a Captina silt loam (fine-silty, mixed, mesic Typic Fragiudult). Plots were graded to a uniform 5% slope and have rust-proofed metal borders (0.1 m below ground and 0.1 m above ground) to isolate runoff. An aluminum gutter attached to a 0.1-m horizontal approach plate was installed at the down-slope end of plots to facilitate collection of runoff. The soil-gutter interface was stabilized by means of a 0.1 m lip normal to the approach plate pushed vertically into the soil. Separation distance between plots are 0.75 m side to side and 3.0 m end to end. A stand of fescue grass (*Festuca arundinacea* Schreb.) was established on the plots by seeding at approximately 500 kg/ha.

Soil samples were taken from the surface 15 cm of each plot, and available PO₄-P (Mehlich III) was determined. The experimental design was a modified randomized complete block design with 3 replications of 4 treatments consisting of a control (no litter), poultry litter alone, poultry litter plus alum, and poultry litter plus ferrous sulfate. Treatments were randomized among plots in each block such that mean soil test phosphorus levels were approximately equal between treatments as shown below in Table 4.

TABLE 4

Treatment	Mean Soil Test P Levels in Plots of the Various Treatments	
	Soil Test P. in mg/kg	
	Mean	S.D.
Litter + Alum	143	30
Litter + Ferrous Sulfate	143	19
Litter Alone	144	16
Control	142	40

Litter was broadcast at the rate of 11.2 Mg/ha (dry weight basis). Chemical amendments were incorporated into litter prior to broadcasting at a 1:5 (w/w) ratio. Plots received 1.0 cm of precipitation from rainfall simulators 24 hours after litter was broadcast. Plots were covered during naturally-occurring rainstorms to prevent runoff.

Rainfall simulators (Edwards et al., *Arkansas Farm Research* 42(2):13-14, 1992) were used to provide 5 cm/hr precipitation events 2, 9, and 16 days after litter application. Runoff was collected during each event at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 minutes after continuous runoff was observed. Time to runoff was recorded for each plot, and collection time and volume were recorded for each runoff sample. Total runoff volume and runoff rate were then calculated from these parameters.

A portion of each sample was filtered through a 0.45 μm membrane and acidified to pH 2 with concentrated HCl. Soluble reactive phosphorous concentrations were determined calorimetrically in the filtered, acidified samples. Phosphorus load from each plot was calculated from phosphorus concentration and runoff rate.

Plots were harvested 2 weeks and 4 weeks after the last precipitation event by mowing the entire plot to a 10 cm height and weighing all forage. Samples were retained from each prior plot for determination of moisture and nutrient content.

(B) Results

Runoff phosphorus concentrations for the first and second runoff events are presented in FIGS. 13A and 13B, respectively. Amending poultry litter with alum resulted in an 87% reduction in phosphorus runoff concentration compared to litter alone for the first runoff event and a 63% reduction for the second runoff event. Poultry litter amended with ferrous sulfate also displayed a decrease in phosphorous runoff concentration (77% and 48% for the first and second runoff events, respectively). By the third runoff event, no differences were observed among the litter treatments.

Alum and ferrous sulfate were successful in reducing total phosphorus load from the first runoff event, showing no difference from the control plots which had not received litter as shown in FIG. 14. No differences in total phosphorus load were observed between treatments after the first runoff event. Since most of the phosphorus load is in the first runoff event, the decreased phosphorus load resulting from chemically amending litter prior to application has important environmental implications.

Forage yield was increased by all litter treatments over the control for both first and second harvests as shown in Table 5 below. Total yield, however, showed a significant response to application of litter amended with alum over all other treatments.

TABLE 5

Treatment	Mean Soil Test P Levels in Plots of the Various Treatments		
	Mean Yield, in kg/ha		
	1st Harvest	2nd Harvest	Total
Litter + Alum	801.7	1556.7	2358.3
Litter + Ferrous Sulfate	681.3	1292.3	1973.7
Litter Alone	735.3	1111.7	1847.0
Control	278.7	454.3	733.0
LSD (0.05)	83.7	297.6	290.0

Alum-amended poultry litter decreased phosphorus concentration in runoff, decreased total phosphorus load, and increased forage yield. Chemically amending poultry litter with alum shows considerable promise as a management tool for limiting phosphorus inputs to surface water while increasing forage yields.

EXAMPLE 6

Reduction in Heavy Metals Runoff

Poultry manure has been shown to have very high concentrations of metals, such as As, Cu and Zn. Several workers have shown that soils receiving applications of poultry manure for many years have high concentrations of these metals, particularly near the soil surface. Although these studies would suggest that metal runoff from fields fertilized with poultry manure may be high, there does not appear to be any published reports on this subject in the literature. Therefore, the objective of this study was to determine the effect of aluminum sulfate additions to poultry manure on metal concentrations and loads in runoff water from plots fertilized with varying rates of manure.

MATERIALS AND METHODS

This study was conducted using 52 small plots (1.52x3.05 m) located at the Main Agricultural Experiment Station of

the University of Arkansas on a Captina silt loam soil (fine-silty, siliceous, mesic Typic Fragiudult), which had been in continuous fescue for the past two years. There was a total of 9 treatments; four rates of alum-treated poultry manure, four rates of normal poultry manure, and one control. Manure application rates were 2,244, 4,488, 6,732, and 8,976 Mg ha⁻¹ (1, 2, 3, and 4 tons acre⁻¹). There were four replications per treatment in a randomized block design.

Soil samples (0–5 cm) were taken from each plot (ten cores/plot) prior to the study and analyzed for Mehlich III P and water soluble P. The treatments were then randomized, based on Mehlich III P values, so that the average soil test P level for each treatment was as close as possible (within 1 mg P kg⁻¹) to the overall average (131 mg P kg⁻¹).

The poultry manure utilized for this study was obtained from six commercial broiler houses located in NW Arkansas which had been part of a study on the effects of alum on ammonia volatilization and poultry production. Alum had been applied to half of the houses at a rate of 1816 kg housed⁻¹ after each growout, except the first when it was applied at 1362 kg lbs/house. The alum was applied and mixed into the manure using a manure “de-caker”. Sub-samples of the manure were analyzed for total N, soluble ammonium, exchangeable ammonium, nitrate, total P, soluble P, total and soluble metals, pH, electrical conductivity (EC), alkalinity, and soluble organic carbon (SOC). Chemical characteristics of the control and alum-treated manure used in this study are given in Table 6, as follows:

TABLE 6

Parameter	Chemical Characteristics of Poultry Litter used for Runoff Study			
	Alum-Treated Manure		Normal Manure	
	Average	S.D.	Average	S.D.
pH	7.59	0.77	8.04	0.18
EC	10833	471	6611	311
	Total Metals, g/kg			
S	33.9	9.8	6.8	0.4
Ca	29.4	3.6	34.1	4.2
K	27.4	2.7	26.4	1.6
P	18.9	1.8	22.4	1.7
Al	18.7	6.0	1.18	0.2
Na	7.55	0.6	7.85	0.6
Mg	5.79	0.7	6.57	0.4
	Total Trace Metals, mg/kg			
Fe	1723	312	1095	155
Mn	893	216	956	134
Cu	679	93	748	102
Zn	598	51	718	69
As	57	15	55	4
B	46	4	51	4
Ti	31	11	44	19
Cr	22	5	8	1
Ni	21	5	15	2
Mo	12	2	7	1
Co	6	2	6	1
Cd	3	0.4	3	0.2

Rainfall simulators (Edwards et al., 1992) were used to provide 5 cm h⁻¹ precipitation events immediately after manure application and 7 days later. Runoff water samples were collected during each event at 2.5, 7.5, 12.5, 17.5, 22.5 and 27.5 min after continuous runoff was observed. Time to runoff was recorded for each plot and collection time and volume of runoff per unit time were recorded for each runoff

sample. The six water samples from each plot were composited into one sample, based on runoff volumes.

A portion of each runoff water sample was filtered through a 0.45- μm membrane, acidified to pH 2 with concentrated HCl and frozen for metal analysis. Metals (Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mo, Mn, Na, Pb, Ni, Se, Ti, and Zn) were determined using a Spectro Model D ICP (Spectro Analytical Instruments, Fitchburg, Mass.). The concentrations of Cd, Co, Cr, Mo, Pb, Se, and Ti were below detection limits and are not reported. Soluble organic carbon was determined on filtered, unacidified samples using a Dohrmann DC-190 High Temperature TOC Analyzer (Rosemount Analytical, Santa Clara, Calif.). Unfiltered samples were used for pH, electrical conductivity (EC), and alkalinity determination.

RESULTS AND DISCUSSION

Manure Characteristics

Chemical characteristics of the alum-treated manure were similar to normal manure, except for total Al and total S, which were both much higher in the alum-treated manure (Table 6). The alum-treated manure also had a slightly lower pH than normal manure (7.59 vs 8.04) and a higher electrical conductivity (10,833 uS/cm vs 6,611 uS/cm).

Trace Metal Runoff

Trace metal runoff results are summarized in Table 7 as follows:

Example	A	B	1	C	2	D	3	E	4
Control	X	—	—	—	—	—	—	—	—
Normal Manure, Mg/ha	—	2,244	—	4,488	—	6,732	—	8,976	—
Alum-Treated Manure, Mg/ha	—	—	2,244	—	4,488	—	6,732	—	8,976
Run-Off Composition, g/ha									
Al-1st	22.0	28.5	21.7	31.1	5.5	36.5	31.8	40.4	35.7
-2nd	23.1	28.2	26.0	30.2	120.4	26.1	24.3	33.5	32.6
As-1st	4.8	14.2	6.1	20.0	11.4	33.3	13.2	35.7	15.5
-2nd	5.3	20.2	6.8	10.6	5.3	11.7	7.9	14.3	10.3
Ca-1st	3858	4091	5,545	3970	7460	4338	9016	3418	10464
-2nd	3348	3407	3824	3102	3233	2964	3762	2505	3359
Cu-1st	1.7	48.4	19.9	78.1	46.70	129	68.8	151	83.0
-2nd	2.3	13.2	7.5	25.2	12.1	33.6	18.7	44.1	20.5
Fe-1st	3.7	33.7	15.1	48.0	26.7	75.0	33.9	94.2	37.8
-2nd	2.3	9.0	6.4	17.4	7.1	20.6	10.7	31.1	12.1
K-1st	1623	12559	10909	18014	24923	29147	35323	35511	44127
-2nd	1327	3379	2763	5532	3917	7497	6498	9406	6220
Mg-1st	693	849	1143	930	1455	1037	1864	989	2578
-2nd	531	806	823	863	834	887	1074	1012	1157
Na-1st	782	4017	3906	5762	7164	9130	10163	10997	12823
-2nd	706	1572	1311	2299	1636	2989	2493	3577	2402
Zn-1st	8.0	27.1	19.1	37.8	32.3	62.1	36.7	70.2	38.3
-2nd	7.3	12.1	8.3	25.8	7.7	13.8	9.5	15.4	12.6

Copper Runoff

Soluble Cu concentrations in the runoff water of the unfertilized control plots averaged 0.010 mg Cu L⁻¹ for the first runoff event and 0.014 mg Cu L⁻¹ for the second event one week later (FIGS. 15A and 15B). These values are near the average (0.015 mg Cu L⁻¹) of that for natural waters in the U.S. The amount of soluble Cu in the runoff water increased linearly with manure application rate, regardless of manure type. However, Cu concentrations in runoff from normal manure was much higher than that from alum-treated manure. At the highest manure application rate, the average soluble Cu concentration in the runoff water from normal manure was 78 times higher than the control (0.93 mg Cu L⁻¹), while the average Cu level for the same rate of alum-treated manure was 43 times higher than the control (0.52 mg Cu L⁻¹). One week later, the average Cu concen-

tration had decreased to 0.13 and 0.25 mg Cu L⁻¹, respectively, for the high rates of alum-treated and normal manure.

The U.S. Public Health Service (1962) limit for Cu in drinking water is 1.0 mg Cu L⁻¹, which was exceeded by some of the samples in this study. Although it is unlikely that Cu would cause human health problems at this level, it is extremely toxic to algae at moderate levels and thus may pose a threat to the aquatic environment. The highest value of Cu observed in an assessment of the waters of the U.S. was 0.280 mg Cu L⁻¹, which was exceeded in this study.

Soluble Cu concentrations in the runoff were highly correlated with soluble organic carbon (SOC) levels, indicating that the Cu was probably complexed with organics (FIG. 16). This supports the findings of others, who showed that Cu concentrations in soil solutions were more affected by SOC than any other soil parameters. The data in FIG. 2 also indicate that the SOC from the alum-treated manure had less of an affinity for Cu, than the SOC from normal manure. The slope of the Cu-SOC relationship for the alum-treated manure was 0.0017, compared to 0.0028 for normal manure. These data showed soluble Cu levels were lower in alum-treated manure and were highly correlated to SOC.

It is possible that the dissolved humic materials of the alum-treated manure (pH 7.59) had less Cu adsorbed to than that of normal manure (pH 8.04) because of competitive proton sorption or pH-dependent metal complexation. Other investigators have indicated that equilibrium constant for

fulvic acid (FA) complexation of Cu had a linear dependence on pH. Another possible mechanism to explain this behavior would be sorption of Cu onto Al(OH)₃ which forms in the manure as a result of alum application.

Water soluble Cu was highly correlated (R=0.999) to total Cu in the runoff water (FIG. 17). Approximately 95% of the total Cu was in the water soluble form, indicating that there was very manure particulate Cu runoff. This was the case for all the metals investigated in this study, with the exception of Al and Fe.

Soluble Cu loads from alum-treated and normal manure followed the same patterns as Cu concentrations, as shown in Table 7. Copper loads from the controls were approximately 2 g Cu ha⁻¹ for both runoff events. At the highest rate of manure application, Cu loads were 151 g Cu ha⁻¹ for normal manure and 83 g Cu ha⁻¹ for the alum-treated

manure for the first runoff event. It should be kept in mind that the results from this study represent a worse-case scenario, since the manure was applied immediately prior to a heavy rainfall.

Zinc Runoff

Soluble Zn concentrations in the runoff water from control plots were 0.047 and 0.043 mg Zn L⁻¹ for the first and second runoff event, respectively (FIGS. 4A and 4B). These values are slightly below the average (0.064 mg Cu L⁻¹) of that for natural waters in the U.S. As with Cu, the Zn concentrations of the runoff water increased with the manure application rate for both types of manure on the first runoff event. Zinc concentrations were an average of 56% higher in runoff water from normal manure, compared to alum-treated manure, for the first runoff event. At the highest manure application rate, the Zn concentrations were 0.44 and 0.24 mg Zn L⁻¹, respectively, for normal and alum-treated manure (FIG. 4A).

Soluble Zn concentrations were much lower in runoff from both types of manure one week after manure application, with the highest manure rate resulting in Zn concentrations of 0.077 and 0.097 mg Zn L⁻¹ (FIG. 18B). It is unclear why Zn concentrations in runoff from plots receiving manure decreased to levels approaching background (0.04 mg Zn L⁻¹), while Cu runoff concentrations remained over an order of magnitude higher than the Cu concentrations observed in runoff from control plots. Zinc concentrations were highly correlated to SOC levels, as was Cu (data not shown).

The U.S. Public Health Service (1962) limit on Zn in drinking water is 5.0 mg Zn L⁻¹, which indicates that it is relatively harmless to animal life. Others have indicated that the average Zn concentration in natural waters of the U.S. with detectable Zn was 0.064 mg Zn L⁻¹. This is very near the concentrations in runoff water one week after manure application, which indicates that these levels probably do not pose a problem.

Soluble Zn loads from alum-treated and normal manure followed the same patterns as Zn concentrations, as shown in Table 7. Zinc loads from the control plots were 8.0 and 7.3 g ha⁻¹, respectively, for the first and second runoff event. At the highest manure application rate, Zn loads were 38.3 and 70.2 g ha⁻¹, respectively, for alum-treated and normal manure.

Arsenic Runoff

Soluble As concentrations in the runoff water from the unfertilized control plots were 0.028 and 0.031 mg As L⁻¹ for the first and second runoff event, respectively (FIGS. 19A and 19B). Arsenic levels increased with increases in manure rates for the first runoff event, with the highest manure application rate resulting in mean As values of 0.097 and 0.224 mg As L⁻¹ for the alum-treated and normal poultry manure. On average, the As concentration in the runoff water of the plots fertilized with normal poultry manure was 123% higher than the plots fertilized with alum-treated manure during the first runoff event (FIG. 19A). Arsenic concentrations were highly correlated to SOC, as was Cu and Zn (data not shown).

Soluble As concentrations were much lower during the second runoff event, than the first (FIG. 19B). In general there were no significant effects due to the type of manure, but the normal manure tended to result in higher concentrations than alum-treated manure. The mean concentrations for the highest rates of manure were 0.091 and 0.066 mg As L⁻¹ for normal and alum-treated manure during the second runoff event.

The U.S. Public Health Service (1962) limit on As in drinking water is 0.05 mg As L⁻¹, which indicates that it is

relatively toxic to animals. Some research has indicated that As may be carcinogenic. Therefore, the levels of As observed in this study could potentially cause problems with water quality.

Soluble As loads from alum-treated and normal manure followed the same patterns as As concentrations, as shown in Table 7. Arsenic loads from the controls were approximately 5 g As ha⁻¹ for both runoff events. At the highest rate of manure application, As loads were 35 g As ha⁻¹ for normal manure and 16 g As ha⁻¹ for the alum-treated manure for the first runoff event and 10 and 14 g As ha⁻¹ for the second runoff event.

Iron Runoff

Soluble Fe concentrations in the runoff from control plots was 0.022 and 0.014 mg Fe L⁻¹, for the first and second runoff event, respectively (FIGS. 20A and 2B). Soluble Fe increased linearly with manure application rate to 0.24 and 0.58 mg Fe L⁻¹ at the highest manure application rate, for the alum-treated and normal manure, respectively. Both soluble and total Fe was significantly higher in runoff from normal manure. Total Fe concentrations for the same treatment/time were 1.35 and 1.68 mg Fe L⁻¹ for the alum-treated and control plots (data not shown). As mentioned earlier, Fe was one of the few elements where the soluble concentration did comprise the dominant fraction of the total. Soluble and total Fe concentrations in runoff from normal manure were also higher than that from alum-treated manure during the second runoff event.

Aluminum Runoff

Soluble Al concentrations in the runoff from control plots was 0.129 and 0.136 mg Al L⁻¹ for the first and second runoff event, respectively (FIGS. 21A and 21B). Aluminum concentrations increased as manure application rates increased and tended to be higher in runoff from normal manure, although the effects of manure application rate and manure type were not as pronounced on Al concentrations as they were for As, Cu and Zn. The highest manure application rates resulted in Al concentrations of 0.23 and 0.25 mg Al L⁻¹ for the first runoff event.

Unlike most of the other metals studied, water soluble Al only accounted for a small fraction of the total, indicating that most of the Al runoff was associated with particulates which would not pass through 0.45 um membrane filters (FIG. 22). The total Al content of the runoff from alum-treated manure was higher than normal manure for the first runoff event, but the opposite was true for the second event. We suspect that the particulate Al in the runoff water was either amorphous Al(OH)₃ or gibbsite since the pH of the water was above 7.0, although we did not attempt to calculate activity products. Accurate calculation of ion activities in this system was not deemed to be possible, since the concentrations of various organic ligands present were not measured.

Soluble Al loads from the control plots were 22 and 23 g Al ha⁻¹ for the first and second runoff events, respectively (Table 7). At the highest manure application rate the soluble Al loads were 36 and 40 g ha⁻¹, for alum-treated and normal poultry manure, for the first runoff event.

Selenium

Selenium concentrations in the runoff water were all below detection limits (0.075 mg Se L⁻¹) However, we can not speculate as to whether the levels in poultry manure runoff were safe or not, since the Se level needed for chronic toxicity (24 hour average) is 0.035 mg Se L⁻¹. Runoff concentrations of Se were well below that needed for acute toxicity (0.260 mg Se L⁻¹). U.S. Public Health Service (1962) limits the, level of Se in drinking water to 0.010 mg

Se L⁻¹. More research is needed on Se runoff from fields receiving poultry manure to ascertain if the new limits on Se levels in poultry feed (which were imposed based on environmental considerations) are warranted.

Macronutrient Runoff

Calcium Runoff

Calcium concentrations in runoff from the control plots were approximately 22.6 and 19.6 mg Ca L⁻¹, for the first and second runoff event, respectively (FIGS. 23A and 23B). Calcium concentrations in the runoff water increased with manure application rate for the alum-treated manure, whereas they remained relative constant in runoff from normal manure. The average Ca concentration at the highest manure application rate was 64.9 and 21.1 mg Ca L⁻¹, respectively, for alum-treated and normal manure, for the first runoff event. Calcium solubility was probably higher in the alum-treated manure because it had a lower pH than normal manure (7.59 vs 8.04), as stated earlier. This would result in the dissolution of Ca and Mg carbonate minerals, such as calcite and dolomite, releasing Ca and Mg in the process.

Calcium concentrations in runoff water one week after manure application were not affected by manure application rate, as in the first runoff event. In fact, Ca levels in runoff from the highest rate of normal manure tended to be lower than from the control plots (15.5 vs 19.6 mg Ca L⁻¹).

Magnesium Runoff

Magnesium concentrations followed the same trends as Ca (FIGS. 24A and 24B). Magnesium concentrations in the runoff of the control plots was approximately 4 and 3 mg Mg L⁻¹, respectively, for the first and second runoff event. Magnesium concentrations increased with increases in manure rates for alum-treated manure during the first runoff event, with the maximum rate of alum-treated manure resulting in Mg concentrations of 16 mg Mg L⁻¹, whereas there was no effect on Mg runoff from normal manure. As with Ca, we hypothesize that the carbonates in normal poultry manure are less soluble than alum-treated manure, since the pH is higher. Magnesium loads followed the same patterns as did the concentration.

Potassium and Sodium Runoff

Concentrations of K and Na in runoff water followed identical trends (FIGS. 25A, 25B and 26A, 26B). The concentrations of both of these metals increased linearly with manure application rate for, the first runoff event and tended to be higher from plots fertilized with alum-treated manure. Potassium concentrations were in excess of 200 and 250 mg K L⁻¹ in runoff from the highest rate of normal and alum-treated manure during the first event. Sodium concentrations were 65 and 75 mg Na L⁻¹ in runoff from normal and alum-treated manure at this time. One week later the concentrations of both K and Na tended to be lower with alum-treated manure.

CONCLUSIONS

Trace metal (As, Cu, Fe, Zn) concentrations in the runoff water from plots fertilized with poultry manure were increased as manure application rates increased and were higher from normal manure compared to alum-treated manure. The metal of greatest concern in poultry manure is Cu, which was found in extremely high concentrations in the runoff of normal manure (1 mg Cu L⁻¹). Since Cu is extremely toxic to algae, it poses the largest threat of the metals studied to aquatic life. Copper concentrations and loads in runoff were significantly reduced by alum-treatment of manure. This practice has also been shown to increase fescue yields, reduce P runoff, and inhibit NH₃ volatiliza-

tion. Therefore, amending poultry manure with alum appears to be one of the few cost-effective best management practices which both reduces the negative environmental impacts of manure, while increasing agricultural productivity.

EXAMPLE 7

Weight Gains, Feed Conversion and Energy Consumption

The objectives of this study were to evaluate the effects of treating manure in broiler houses with alum on: (1) ammonia levels in the houses, (2) weight gains, feed conversion and mortality in broilers, (3) energy (propane and electric) usage, (4) manure chemistry, and (5) manure microbiology.

MATERIALS AND METHODS

Two broiler farms were chosen for this study; one had six houses, the other four houses. The manure in all of the houses was removed at the beginning of the study and fresh bedding (wood shavings) was placed in each house. After each growout, the manure was de-caked, using a commercial de-caking machine, and two tons of alum (aluminum sulfate) were applied in half of the houses on each farm; the other houses were controls. Ammonia measurements, energy use, manure chemistry and broiler production parameters were evaluated. Ammonia levels were measured weekly using dragger tubes. Electricity and propane use was also evaluated weekly. Broiler weights were determined by the integrator for four growouts from one integrator and two growouts for the other. Feed conversion was determined once. Manure pH, atmospheric ammonia, electricity use and gas use were determined weekly. Manure total N, total P, total metals, soluble P, soluble metals, ammonium, nitrate, pH and alkalinity were measured at the beginning and ending of each growout. At this time, a 20-g subsample of the manure was extracted with 200 mL of deionized water for two hours. The samples were centrifuged at 6,000 rpm and aliquots were taken for pH, electrical conductivity (EC), alkalinity, NH₄, NO₃, and dissolved reactive P (DRP).

Samples for EC, pH and alkalinity were analyzed immediately in an unfiltered state. Samples for NH₄ and NO₃ were filtered through 0.45 μm filter and frozen. Ammonium was determined with the salicylate-nitroprusside technique, according to EPA method 351.2 (USEPA, 1979). Nitrate (+nitrite) was determined using the Cd reduction method, according to Method APHA 418-F (APHA, 1992). Nitrate concentrations were very low (<1% of inorganic N) and are not reported. Dissolved reactive P samples were filtered (0.45 μm), acidified to pH 2.0 with HCl and frozen. Dissolved reactive P was determined using the ascorbic acid technique with an auto-analyzer according to APHA method 424-G (APHA, 1992). After extraction with water, the manure was extracted with 1 N KCl for 2 h, for exchangeable ammonium. After centrifuging, these samples were filtered and analyzed for ammonium as above.

Ten-gram subsamples were taken for water content, total P and total N analysis. Total N was determined by Kjeldahl distillation after using the salicylic acid modification of the Kjeldahl digestion to include NO₃ using moist samples (values were corrected for water content). Moist samples were used, rather than dried, since oven drying resulted in N losses. Total P was determined by digesting oven-dried (60C) manure with HNO₃, and analyzing the digested sample using ICP.

Treatment means were compared for significance (P≤0.05) using Fisher's Protected LSD, which was calcu-

lated after statistical differences were demonstrated using analysis of variance. All statistical analyses were conducted using SAS (1985).

RESULTS AND DISCUSSION

Alum lowered the manure pH for several weeks at the beginning of each growout (FIG. 27). As the amount of manure produced by the birds increased, the pH of the manure increased, until the birds were about four or five weeks old, when the manure pH levelled off at approximately 7.5. The manure pH for the control birds remained relatively constant (above 8) throughout the study.

Reductions in manure pH decreased ammonia volatilization from the manure, which resulted in significant reductions in atmospheric ammonia in the alum-treated houses compared to controls (FIG. 28). The average ammonia concentration in the control houses was above 25 ppm for the first five weeks of the growbut. Decreases in weight gains and poor feed conversion have been demonstrated at this level. Ammonia concentrations in the alum-treated houses were very low the first three to four weeks of the study, which coincides with the stage of growth in birds when they are most sensitive to high ammonia.

Broilers grown on manure treated with aluminum sulfate were significantly heavier ($\alpha=0.05$) than the controls. Average bird weights were 3.75 lbs for control birds and 3.86 lbs for birds grown on alum-treated manure (FIG. 29). The exact reason for this increase in body weight is not known. At present, we hypothesize that it may have been due to either a change in the microbiology in the manure or due to a decrease in atmospheric ammonia in the houses, both of which are related to changes in manure pH.

Mortality was also lower (3.9 vs 4.2%) and feed conversion was better (1.83 vs 1.89) for birds grown on alum-treated manure, compared to controls. These data support the findings of others, who showed that exposure of chicks to relatively low concentrations of ammonia (25 ppm) for the first 28 days reduced body weights by 4%.

Several other benefits of alum-treatment were noticed in this study. Electricity and propane use were lower for alum-treated houses than controls. Higher energy use in the control houses was a result of higher ventilation rates, particularly in the winter, needed to reduce ammonia levels. The control houses used an average of 887 gallons of propane, while the alum treated houses used 798 gallons. Similarly, the electricity used for control houses was higher than alum-treated houses (8330 vs 7320 kilowatt hours). It should be noted that the energy data are for one farm only, since propane receipts were not available for the other farm at the time of this writing.

Decreases in ammonia volatilization also resulted in higher total nitrogen content of the manure in the alum-treated houses, which should result in higher crop yields. Lower manure pH also resulted in lower fecal coliform and *E. coli* bacterial counts in the manure. Recent research has also shown that fecal coliform runoff from plots fertilized with alum-treated manure is lower than plots fertilized with normal poultry manure.

The chemical characteristics of the manure from the houses at the Company A farm is shown in Table above. These data indicate that alum-treated manure is similar to normal manure, except for total Al and total S, which were both much higher in the alum-treated manure (Table 6). The alum-treated manure also had a slightly lower pH than normal manure (7.59 vs 8.04) and a higher electrical conductivity (10,833 uS/cm vs 6,611 uS/cm).

One aspect of high ammonia levels in poultry rearing facilities that is often overlooked is the effect on the grower. Farm workers often spend up to 8 to 10 h per day in poultry houses, particularly when the birds are young. Normally, this period coincides with the highest ammonia levels, at times in excess of 100 ppm. In Europe, COSHH (Control of Substances Hazardous to Health) has set the limit of human exposure to ammonia at 25 ppm for an 8-h day and 35 ppm for a 10-min exposure. The effect on humans of years of chronic exposure to relatively high levels of ammonia warrants investigation.

CONCLUSIONS

Alum applications to manure in commercial broiler houses resulted in lower manure pH, which resulted in significant reductions in atmospheric ammonia. Lower ammonia levels resulted in significantly higher weight gains of the birds grown in houses with alum-treated manure than the controls. Average bird weights were 3.75 lbs for control birds and 3.86 lbs for birds grown on alum-treated manure. Mortality was also lower (3.9 vs 4.2%) and feed conversion was better (1.83 vs 1.89) for birds grown on alum-treated manure, compared to controls. Electricity and propane use in alum-treated houses was also lowered, due to reduced ventilation in cooler months.

From the results of these studies, it was determined that adding about 1 ton of alum per 10,000 birds grown in a commercial growing enclosure is effective to provide improvements in poultry production in terms of increased growth rate, improved feed conversion and reduced mortality. Moreover, the application of alum in an amount of from about 0.15 to about 0.25 pounds of alum per bird to a poultry raising environment, such as an enclosure, provides the above-mentioned improvements in poultry production. In addition, alum treatment of manure provides reduced heavy metal runoff when the treated manure is used as an agricultural fertilizer as compared with untreated manure. Treatment of poultry manure with alum in an amount of about 10% by weight of manure was effective to significantly reduce runoff concentrations of copper, arsenic, iron and zinc as compared to untreated poultry manure when used as an agricultural fertilizer.

It should be understood that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the present invention, and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be covered by the appended claims.

What is claimed is:

1. A method for reducing the amount of metals in agricultural runoff water obtained from soil fertilized with a poultry manure agricultural fertilizer, said method comprising:

treating a poultry manure composition to be used as agricultural fertilizer by admixing said poultry manure with from about 5 to about 20% by weight of alum to provide a treated poultry manure; and

thereafter, applying said treated poultry manure to soil as an agricultural fertilizer.

2. A method as defined in claim 1, wherein the metals are selected from the group consisting of arsenic, copper, iron, phosphorus and zinc.

3. A method as defined in claim 1, wherein in the treating step about 10% by weight of alum is admixed with said poultry manure.

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4. A method as defined in claim 1, wherein said poultry manure composition comprises poultry manure, bedding, spilled food and feathers.

5. A method as defined in claim 1, wherein said poultry manure composition is obtained by raising at least-one generation of poultry in an enclosure to which alum is added in an amount of about 0.75 to about 1.5 tons of alum per ten thousand birds raised per generation in said enclosure.

6. A method as defined in claim 5, wherein alum is added to the enclosure before said at least one generation of poultry is raised and alum is added to the enclosure before each successive generation of poultry is raised in the same enclosure.

7. A method as defined in claim 1, wherein said poultry manure composition is obtained by raising at least one

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generation of birds in an enclosure to which alum is added in an amount of from about 0.15 to about 0.25 pounds of alum per bird.

8. A method as defined in claim 7, wherein said alum is added to the enclosure in a single application.

9. A method as defined in claim 7, wherein said alum is added to the enclosure before a said generation of birds is raised therein.

10. A method as defined in claim 7, wherein said alum is added to the enclosure in a plurality of applications per generation.

11. A method as defined in claim 7, wherein successive generation of birds are raised in the same enclosure and alum is added to the enclosure before each successive generation is raised therein.

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