AN ABSTRACT OF THE THESIS

Zaheer Uddin for the degree of Master of Science in Poultry Science presented on March 14, 1991

Title: Comparison on the Effectiveness of Different Chemical Treatments of Built-Up Broiler Litter on Broiler House Environment and Broiler Performance.

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Dr. Harry S. Nakaue

The objectives in these four experiments were to observe the effectiveness of sodium bisulfate and clinoptilolite and different methods of application of sodium bisulfate, ferrous sulfate heptahydrate and Micro Aid® on atmospheric ammonia level in the broiler house and on broiler performance.

The first experiment was conducted to determine the optimum effective level of the litter application of sodium bisulfate. Atmospheric ammonia at 4 weeks and litter moisture at 3 weeks were significantly lower in sodium bisulfate treated-pens (488 g/m^2) than in the untreated control pens. However, broiler performance was not significantly affected with any treatment. Litter application of sodium bisulfate at 244 g/m^2 and 488 g/m^2 were comparable and better than the 122 g/m^2 and untreated control.

In Experiments 2 and 3 comparisons of litter chemical treatments of liquid Micro Aid® (8.75 ml/L H_2O) applied at 0, 2, 4,and 6 weeks; granular Micro Aid® (0.5 mg/g of feed) fed

continuously throughout the experiment, and litter application of ferrous sulfate (732 g/m^2); clinoptilolite (2443 g/m^2), sodium bisulfate (244 g/m^2) and ferrous sulfate (732 g/m^2) were made for 7 week periods. Ferrous sulfate-treated pens (732 g/m^2) had significantly lower litter pH at 2, 4 and 6 weeks than untreated control and significantly lower atmospheric ammonia levels at 3 and 6 weeks than the clinoptilolite (2443 g/m^2), sodium bisulfate (244 g/m^2) and untreated control in the other experiment.

In the fourth experiment, sodium bisulfate was applied twice (244 g/m^2/application) at 0 and 4 weeks, sodium bisulfate applied once (488 g/m^2) and ferrous sulfate applied once (732 g/m^2) prior to the experiment. At 4 weeks mean body weights and feed conversion were significantly better with one sodium bisulfate application than the untreated control. At 7 weeks feed conversion ($P<0.08$) and male body weights ($P<0.1$) were slightly better in one sodium bisulfate application than in the untreated control while mortality was significantly lower in the untreated control pens. Most mortality occurred after 4 weeks and were due primarily to Sudden Death Syndrome. Atmospheric ammonia levels at 0, 1, 2, 3 and 4, weeks and litter pH levels at 0, 1, 2, 3, and 4 weeks were significantly lower in pens with one application of sodium bisulfate than in pens untreated. Litter application of sodium bisulfate once (488 g/m^2) seemed to be the best litter treatment in reducing atmospheric ammonia.

Comparison on the Effectiveness of Different Chemical Treatments of Built-Up Broiler Litter on Broiler House Environment and Broiler Performance

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CHAPTER I

INTRODUCTION

Presently commercial broilers are reared in enclosed houses with mechanical ventilation and automated waterers and feeders which enable the broiler farmers to rear more broilers than they can in a conventional facility. However, with enclosed housing and concentrated broiler density, the environments within these enclosed houses are altered with more concentrations of dust, feather debris and manure gases, especially ammonia.

With the rising costs of both labor and litter materials in the past few years, a number of farmers are re-using old litter (Caveny _et al_., 1981). Reuse of broiler litter increases the potential for disease (Parkhust _et al_., 1974; Lovett _et al_., 1971 ; Bacon and Burdick, 1977), and the production of unacceptable high levels of atmospheric ammonia (Reece _et al_., 1979).

Ammonia is a colorless, irritant gas produced by the decomposition of the nitrogen fraction of animal wastes (Carlile, 1984). Exposure of poultry for a prolonged period of time to elevated atmospheric ammonia concentrations evolved (>20-25 ppm) from manure has been reported to cause keratoconjunctivitis in chickens (Bullis et al.,1950; Faddoul and Ringrose, 1950; Carnaghan, 1958; Saunders, 1958; Valentine, 1964) and in turkeys (Carnaghan, 1958); weight loss in chickens (Faddoul and Ringrose, 1950; Charles and Payne 1966a); lowered respiratory rate, delayed sexual maturity, lowered feed conversion (Charles and Payne 1966b); lowered egg production (Charles and Payne, 1966a); increased susceptibility to respiratory infection (Anderson, 1970); histopathological changes (Anderson et al., 1966); prolonged *Mycoplasma gallisepticum* infection (Kempf et al., 1988); increased susceptibility to Newcastle disease (Anderson et al., 1964); increased susceptibility to *E.coli* infection (Oyetunde et al., 1978); increased severity of coccidiosis (Quarles and Caveny, 1979); decreased interior egg quality (Cotterill and Nordskog, 1954); increased embryonic mortality (Panigrahi, 1989) and significant increases in yolk and albumen pH (Panigrahi, 1988).

In the last few years, several chemical products have become available for treating built-up broiler litter for the purpose of lowering the evolution of atmospheric ammonia from the built-up litter in enclosed broiler houses. This research is being proposed to compare the efficacy of these chemicals on the treatment of built-up broiler litter on broiler house environment and broiler performance.

CHAPTER II

LITERATURE REVIEW

In the past, different researchers have reported different methods of controlling atmospheric ammonia in the poultry houses. Those suggested methods can be described under the following categories.

A) The use of adequate ventilation control.

B) The control of microflora of the litter.

C) The control of moisture, pH and temperature.

D) The use of antibiotics.

E) The use of different chemical treatments.

A. THE USE OF ADEQUATE VENTILATION CONTROL

Anderson *et al*. (1964) reported that the build-up of ammonia tends to be more severe during winter months due to reduced ventilation. Carr *et al*. (1990) reported that the ventilation rates are reduced by the broiler producers to conserve as much heat as possible during the winter months and to reduce the electricity required to power ventilation fans. The problem with reduced ventilation rate is deterioration of air quality inside the poultry house which can adversely affect the hen's health, production, and egg quality (Charles and Payne, 1966; Quarles and Kling, 1974; Carr and Nicholson, 1980; Reece and *et al*, 1980). Griffin *et al*. (1968) reported that high ammonia concentration in below-normal ventilated enclosed pens resulted in high condemnation rates and low body weight.

Several workers have reported that diluting the aerial ammonia through proper ventilation was an effective means of control (Branigan and McQuitty, 1971; Carlile, 1984; Carr et al., 1990). Leonard et al. (1984) carried out a study to measure concentrations of carbon dioxide, ammonia, hydrogen sulfide and dust particles in broiler barns in Canada under fall-winter conditions. The broiler barns were monitored for 24 hrs. Ventilation range was from 400 to 4332 L/sec. Higher ventilation rates resulted in lower measured gas concentrations.

Over ventilation leads to other problems including excessive fuel use and over dried litter (Carr et al., 1990). The dried litter causes dust particles in the environment and Bundy and Hazen (1975) have shown that dust particles serve as transport mechanism for ammonia. O'Connor et al., (1988) suggested that ammonia control rather than moisture control should be the main criterion on which minimum ventilation rates were based. Roller (1961) observed that good ventilation functions in getting rid of ammonia, moisture and dust. In Arkansas minimum ventilation rates for optimum broiler performance suggested by Ross et al. (1980) were 0.047 L/sec (week 1 and 2), 0.141 L/sec (week 3) and 0.33 L/sec (week 4). Additional ventilation was recommended in the last two weeks of the broiler production. Holleman (1989) suggested that installing commercial ammonia detectors in poultry house which may be tied to the ventilation system to start fans at a preset ammonia levels were helpful in getting rid of excessive atmospheric ammonia in enclosed broiler houses.

B. THE CONTROL OF MICROFLORA OF THE LITTER

Production of ammonia from poultry litter was attributed to microbial decomposition of uric acid in the poultry manure (Burnett and Dondero, 1969; Bacharah, 1957; Schefferle, 1965a,b). Chang and Flint (1976) reported that ammonia release begins immediately after excretion. The role of micro-organisms in ammonia release is well documented by Kitai and Arakawa (1979). Sterilized broiler excreta at 121 ^{0}C for 20 min produced no ammonia release. Reduced incubation temperature to 33 ^{0}C for 24 hrs produced little ammonia gas. Schefferle (1965b) reported that high atmospheric ammonia concentration in windowless broiler houses seemed to be primarily due to the aerobic or anaerobic action of some microbes on the uric acid of the droppings. Ammonia is produced after the degradation of nitrogenous compounds in droppings in a two step process with urea as the intermediate product.

The microbes, which convert uric acid to urea and ammonia thrive most favorably at alkaline (7 to 9 pH) conditions. Baum *et al.*, (1956) found that the rate of uric acid disappearance was maximum at pH 9.00 and decreased in a nearly linear fashion for more acidic or alkaline values. Conceicao *et al.*, (1989) reported that the rise in ammonia concentration was caused by an increase in the generation rates from the major sources (birds and the litter) which acted as a nutritive reservoir for the microorganisms. Lovett *et al.*, (1971) suggested that litter age was the only factor affecting microbial densities while Giddens and Rao (1975) reported that microbial (fungal) population was inversely proportional to the pH which was directly proportional to ammonia production. Schefferele (1965b) reported that unused litter was strongly acidic and contained few uricolytic organisms while used litter was alkaline and had higher numbers of uric acid decomposers. The uric acid decomposing bacteria may comprise as much as a quarter of the total bacterial population in used litter. Schefferle (1965b) and Burnett and Dondero (1969) reported that aerobic bacteria are more significant as uric acid decomposers in poultry litter. Schefferle (1965b) reported that the organisms decomposing uric acid usually comprised about one quarter of the total bacterial population. They were strains of *Corynebacterium* and less frequent strains of *Nocardia*, *Streptomyces*, *Alcaligenes* and *Achromobacter*. Uric acid was converted to ammonia by some of the organisms and to urea by a majority of the strains. Hydrolysis of urea to ammonia could be brought about by strains of Corynebacterium, Micrococcus, Alcaligenes, Achromobacter and Cytopaga which had no action on uric acid. From the built-up litter, three strains of Nocardia and one of Streptomyces and occasionally strains of Alcaligenes and Achromobacter were isolated. These microbes were able to decompose uric acid. The proportion of Coryneform bacteria to decompose uric acid varied from 10 to 53 percent (Schefferle 1965b). In poultry droppings coryneform bacteria were abundant and about 48 percent of the isolates decomposed uric acid.

The control of the above mentioned microflora of the built-up litter can control atmospheric ammonia production.

C. THE CONTROL OF pH, TEMPERATURE AND MOISTURE

Xin et al. (1987) suggested that ammonia concentration is dependant on factors such as temperature, humidity, animal density, and ventilation rates. Elliott and Collins (1982) observed a level of 200-300 ppm ammonia on reused litter in the broiler house during the first week. They observed that the factors, in the order of importance in influencing ammonia volatilization were: litter pH, temperature and moisture content. A decrease in ammonia concentration at high litter moisture levels has been reported by Valentine, (1964) and Schefferle (1965a). At high moisture levels, the litter becomes anaerobic thus suppressing ammonia release

(Schefferle, 1965a). Carr et al. (1990) reported an increase in ammonia concentration with increased pH, temperature, and litter moisture. An increase in litter moisture above 30 percent caused a large increase in ammonia concentration. Their results suggested that at higher litter moisture levels (>30-50 percent) the capillary action in the litter was greater, which would increase the diffusion rate of ammonia resulting in higher atmospheric concentrations. However at very high litter moisture, there was a decrease in atmospheric ammonia. North and Bell (1990) and Carr et al. (1990) recommended litter moisture in a production house below 25 and 30 percent, respectively for proper atmospheric ammonia control.

The pH has been shown to be an important variable in the control of atmospheric ammonia release from broiler litter by several research workers (Reece et al., 1979; Elliott and Collins, 1982; Carr and Nicholson, 1980). Reece et al. (1979) reported pH 8 and higher results in high ammonia levels, whereas lower pH values (<7) depress ammonia production. Gidden and Rao, (1975) reported that soil pH was directly proportional to the ammonia levels (i.e. the higher the pH the higher will be the ammonia level). Wahhab et al., (1960) found that the loss of ammonia from urea at neutral pH was about half the rate observed at pH 8.5.

D. THE USE OF ANTIBIOTICS

There is little work done on this aspect of ammonia control. Antibiotics reduced the ureolytic activity and the ammonia concentration of the gut of poultry (Alvares _et al._, 1964). Kitai and Arakawa (1979) observed _in vitro_ that thiopeptin at the rate of 100 mg/kg fresh poultry droppings decreased the ammonia release significantly. Similar results were observed with the incorporation of 100 mg of thiopeptin or zinc bacitracin per kg of the feed.

E. THE USE OF DIFFERENT CHEMICAL TREATMENTS

The use of paraformaldehyde as a fumigant to disinfect hatching eggs and incubators and its anti-microbial effect was well documented by Lancaster and Crab (1953) and Lancaster _et al_. (1954). Seltzer _et al_. (1969) treated litter with paraformaldehyde at the rate of 4.5 kg/26 m^2 of the litter and observed that it helped to prevent ammonia production. However, Swenberg _et al_. (1980) questioned the general safety of paraformaldehyde, which they reported as a potential carcinogen in rats.

Carr _et al_. (1988) reported that chlorination of broiler drinking water with household bleach (5.25% NaOCl) to achieve a chlorine level of 2 mg/L of water, reduced water consumption by 15%, slightly improved live performance, produced drier litter, with less caking and lower ammonia levels.

Nakaue _et al_. (1982) used Mount St. Helen s' volcanic ash for litter application and observed its effect on broiler performance , health, and house environment. No significant differences were observed in mean body weight, feed conversion, atmospheric ammonia levels in the pens, percent mortality and carcass quality with litter application of the volcanic ash.

Nakaue (1983) carried out an experiment with litter application of hydrated lime on built-up broiler litter at the rates of 0.454, 9.1 and 18.2 kg/m^2 of floor space. Lime was applied on the surface of litter and stirred into litter before placing the broiler chicks. No significant differences were observed in ammonia levels, litter moisture, respiratory dust level, mean body weight, feed conversion, foot burns and litter score among the treatments.

Parkhurst et al. (1974) reported that use of volatile fatty acids (acetic acid, 60 percent and propionic acid, 40 percent) at the rate of 1 percent and 3 percent (w/w) significantly reduced the bacterial count and litter pH while mean body weights, feed conversion, mortality, moisture contents of the litter, temperature and final nitrogen contents were not affected significantly.

The use of feed additives such as DSS40® (40 % yucca saponin) and Micro Aid® (a formulated product of yucca extract which contains a potent urease inhibitor) reduced aerial ammonia concentration in some studies (Berg, 1977 and Rowland et al., 1976). Malone et al. (1985) fed Micro Aid® at the rate of 63 ppm in one trial and 31, 63 and 125 ppm in another.

Atmospheric ammonia levels were numerically reduced. Goodall et al. (1988) reported that ammonia production from decomposing chick excreta was reduced significantly by adding Micro Aid® to the laying hens diet at the rate of 62 ppm. Micro Aid® was also fed to broilers for 7 weeks at the rates of 62 and 124 ppm and broiler chickens excreata was incubated 7, 14 or 24 hrs. Ammonia readings were taken in vitro.

The 21.7 percent reduction in ammonia production in vitro was similar to the 24.8 percent reduction in aerial ammonia concentration achieved in a field study by adding the same amount of Micro Aid® (62 ppm) to a laying-hen diet. The aerial ammonia concentration in a poultry facility is directly related to the rate of ammonia production from decomposing excreta (all other factors, such as ventilation rate being the same) and as such, aerial ammonia has the potential of being mitigated by agents such as Micro Aid®, which slow the rate of ammonia production from excreta. The addition of Micro Aid® at higher levels (i.e. 124 ppm) in the diet would be even more efficient in reducing ammonia levels in a poultry facility. Smith (1980) working with turkeys also observed a similar reduction in atmospheric ammonia levels when they were fed a ration containing 40 percent yucca saponin. Johnston et al., (1981) added yucca saponin at a rate of 63 ppm to broiler ration and observed that at 28 days of age broilers receiving yucca saponin were significantly heavier than the control and the ammonia levels in the pens were not significantly different among the treatments.

Reece et al. (1979) reported that phosphoric acid at 0.4 kg/m^2 level was more effective in controlling atmospheric ammonia and reducing litter pH than super phosphate at 0.4 kg/m^2 level.

Mumpton and Fishman, (1977) reported that zeolites were used extensively in Japan for many years for purifying fish hatchery waters in aquaculture, reducing intestinal diseases in young pigs and ruminants and controlling moisture and ammonia in manure. The addition of about 10 percent clinoptilolite to the diets of chickens and pigs appear to increase feed efficiency by as much as 25 percent.

Nakaue et al. (1978) reported that feeding increasing levels of zeolite (clinoptilolite) from 0, 2.5, 5 to 10 percent to laying chickens numerically decreased fecal moisture levels as the zeolite (clinoptilolite) levels increased in the feed. The application of clinoptilolite on broiler litter at levels of 0, 2.5, and 5 kg/m^2 decreased atmospheric ammonia and litter moisture levels with increasing levels of clinoptilolite application. Olver (1989) fed clinoptilolite at the rate of 50 gm/kg of diet to the laying hens. No significant dietary effects between treatments with respect to body weight at first egg, egg weight, Haugh scores or feed intake/hen were observed. Significant dietary effects in favor of clinoptilolite were noticed with higher number of eggs laid per hen, better shell thickness, better feed efficiency (g egg/g feed), lower fecal moisture contents and lower mortality.

Nakaue and Koelliker (1981a) fed laying rations containing 0, 2.5, 5, and 10 percent clinoptilolite for six 28 days periods to 240 10-month old dwarf Single Comb White Leghorn layers. Significantly lower egg production was observed in layers fed rations with 2.5 and 5 percent of clinoptilolite. However increases in daily feed consumed per layer and feed conversion were noted with increases in clinoptilolite in feed. The 10 percent clinoptilolite-fed layers had significantly poorer feed conversion than the layers fed rations containing 0 and 2.5 percent clinoptilolite. Significantly lower fecal moisture levels were observed for manure from pullets fed 10 percent clinoptilolite. A fishy odor from fecal samples from layers fed 10 percent clinoptilolite was also detected. Nakaue et al. (1981b) carried out a series of experiments on broilers to determine the effects of various methods of using clinoptilolite on house environment and broiler performance. Neither application (2.5 kg or 5 kg/m^2)of clinoptilolite on clean or reused wood shavings litter and clinoptilolite as sole source of litter in the most frequented areas of the pens nor feeding 10 percent clinoptilolite significantly affected broiler performance. The surface application of clinoptilolite on clean wood shavings litter at the rate of 5 kg/m^2 was more effective in reducing ammonia at 28 days of production than at 21 days. Litter application of clinoptilolite reduced litter moisture contents and incidence of foot pad burns. Koelliker et al. (1980) devised a small, simple air scrubber packed with clinoptilolite. The device removed 15-45 percent of atmospheric ammonia from air within a poultry laying building even though air contact time through the system was less than one second.

Iheanacho (1984) conducted three experiments to determine the optimal rate and the best method of ferrous sulfate heptahydrate application on used litter to control atmospheric ammonia and subsequent broiler performance. In the first experiment, litter application of ferrous sulfate heptahydrate at the rates of 0.38 kg/m^2, 0.76 kg/m^2 and 1.52 kg/m^2 of floor space were compared. Ferrous sulfate heptahydrate at the rate of 0.76 kg/m^2 was suggested as the optimal level to control atmospheric ammonia from three to five weeks of age. Litter application of ferrous sulfate heptahydrate at the rate of 0.76 kg/m^2 was compared with clinoptilolite at the rate of 7.6 kg/m^2 in the second experiment. Ferrous sulfate was a better litter treatment to control atmospheric ammonia than the application of clinoptilolite. Different methods of ferrous sulfate application were studied in the third experiment. The hanging box method showed significantly less atmospheric ammonia than the direct litter application of ferrous sulfate (at 0.76 kg/m^2) and spraying litter with ferrous sulfate solution (at 0.38 kg/m^2).

CHAPTER III

COMPARISON ON THE EFFECTIVENESS OF DIFFERENT CHEMICAL TREATMENTS OF BUILT-UP BROILER LITTER ON BROILER HOUSE ENVIRONMENT AND BROILER PERFORMANCE

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INTRODUCTION

Present day commercial broilers are reared extensively in large enclosed buildings. Caveny et al. (1981) observed that with the rising costs of both labor and litter materials in the past few years, a number of farmers were reusing litter in the enclosed broiler building. Reece et al. (1979) reported that reuse of broiler litter increases potential for the production of unacceptably high levels of ammonia. Nakaue et al. (1980) reported accumulation of atmospheric ammonia levels up to 39 parts per million during the spring season in commercial poultry houses in Arkansas and Texas. High levels of ammonia (>20-25 ppm) are dangerous for the well being of birds as well as for human health (Holleman, 1989). Therefore, considerable effort has been devoted to finding different methods of controlling ammonia evolution from the litter.

Chemicals applied on the broiler litter can serve as antimicrobial agents, $NH^{+}4/NH3$ complexants, or strong oxidizing agents (Elliott and Collins, 1982). In the last few years, several chemical products have become available for prevention of evolution of atmospheric ammonia from the litter in broiler houses. These chemicals have been reported with varying degrees of success. Ferrous sulfate has been reported to lower atmospheric ammonia levels in broiler pens (Huff et al 1980: Elliott and Collins, 1982; Iheanacho, 1984) and subsequently improve body weights (Huff et al., 1980). Some other chemicals such as Micro Aid® (Goodall et al., 1988), clinoptilolite (Nakaue et al. 1978, 1981a, 1981b; Koelliker et al., 1981), phosphoric acid (Reece et al., 1979), chlorination of broiler drinking water (Carr et al., 1988) were also reported to reduce atmospheric ammonia.

The studies reported here were carried out to compare the efficacy and the methods of application of sodium bisulfate, ferrous sulfate heptahydrate, Micro Aid® and clinoptilolite on the effect of atmospheric ammonia evolution from the litter level in the broiler house and on subsequent broiler performance in a mechanically ventilated enclosed broiler house.

MATERIALS AND METHODS

Four experiments were conducted in the same enclosed mechanically ventilated house with eight floor pens (3.1 m x 4.3 m) during different seasons of the year. Built-up broiler wood shavings litter was used as bedding material. Standard brooding and rearing practices were followed as outlined by Dorminey and Nakaue (1977) and North and Bell (1990) for all experiments. Fan ventilation was regulated by time clocks with the duration of mechanical ventilation shorter or longer depending on the ammonia levels in the pens. Twenty four hours of light were provided in all the experiments from day-old to 7 weeks of age (market age).

The broilers were fed a 23 percent crude protein starter mash from day one to three weeks of age and a 21 percent crude protein grower/finisher mash from three to seven weeks of age for all experiments. Feed and water were provided ad libitum throughout the experiments.

Mortality was recorded daily. Atmospheric ammonia levels were determined at weekly intervals with Gastec[1] and Kitagawa detector tubes[2] and pump[3]. Fans were turned off for at least

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[1]Sensidyne Gastec analyzer tube cat. No. 3L., Gastec Corporation Tokyo, Japan.

[2]Kitagawa precision gas detector tubes model 42 CFR 84., Matheson Safety Products, East Rutherford, N.J.

[3]Kitagawa aspirating pump model 400, Matheson Safety Products, East Rutherford, N.J.

four hours prior to taking ammonia readings. The broilers (by sexes) and feed for each pen were weighed at four and seven weeks of age during each experiment. Mean body weights and feed conversion were calculated from these data. Litter moisture and pH were determined at weekly intervals in the laboratory by the methods described by Modhish (1987).

Each litter treatment was replicated twice and assigned randomly. The data for each parameter from the experiment were analyzed by one way analysis of variance and significant treatment means were separated by lesat significant method (LSD)as outlined by Snedecor and Cochran (1980) at $P<0.05$ with the statgraphic program (Statgraphics, 1989).

EXPERIMENT 1

This experiment was conducted during October and November. The cold winter rains began in October and continued in November. Mean weekly outside and inside temperatures during this period ranged from 4.9 to 19.3 C and from 17.4 to 28.3 C, respectively. One thousand four hundred eighty straight run Hubbard x Indian River broiler strain cross chicks were distributed equally in eight pens. The bird density was 0.072 m^2/chick. The treatments were untreated litter (control), and sodium bisulfate[4] application rates of

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[4]Jones-Hamilton Company, Agricultural Chemical Division, 8400 Enterprise Drive, P. O. Box 464, Newark, CA.

122 g/m^2, 244 g/m^2 and 488 g/m^2. The chemicals were applied on the litter prior to placing chickens with a fertilizer drop spreader[5].

The fan ventilation were for 15 min on/4 hrs off, recycled from days 21 to 24; for 15 min on/2 hrs off, recycled for days 25 and 26 and for 15 min on/15 min off, recycled from days 27 to 49 (end of experiment).

EXPERIMENT 2.

This experiment was conducted during April and May. The spring rains were intermittent and there were cool evenings. Mean weekly outside and inside temperatures ranged from 10 to 26 C and 17 to 29 C, respectively. One thousand four hundred eighty straight run Vantress X Hubbard broiler strain cross chicks were distributed equally in eight pens. The bird density was 0.072 m^2/chick. The litter treatments were untreated litter (control), Micro Aid®[6] granules (0.5 mg/g of feed) fed throughout the experiment, liquid Micro Aid®[6] (8.75 ml/L of water) sprayed on the litter with a pump[7] at 0, 2, 4 and 6 weeks of the experiment and ferrous sulfate heptahydrate[8] (732 g/m^2 of floor space) spread on the litter

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[5]Scott Lawn fertilizer drop spreader.

[6]Distributors Processing, Inc., Porterville, CA.

[7]Spray Doc Pump, model 261 P, Gilmour Somerset, PA.

[8]Crown Chemical Company Inc., Indianapolis, Indiana.

with a fertilizer drop spreader[5] prior to placing the chicks.

Litter moisture levels for each pen were measured at 6 weeks of the experiment. The fan ventilation were for 15 min on/4 hrs off, recycled from days 16 to 25; for 15 min on/15 min off, recycled during the afternoon from days 26 to 30; for 15 min on/ 15 min off, recycled from days 31 to 49 (end of the experiment).

EXPERIMENT 3.

This experiment was conducted during July and August. The weather was warm and dry during this period. Mean weekly outside and inside temperatures ranged from 13 to 27 C and 16 to 31 C, respectively. One thousand five hundred twenty straight run Peterson x Arbor Acres broiler strain cross chicks were distributed equally in eight pens. The bird density was 0.07 m^2/bird. The treatments were untreated litter (control) and the application of clinoptilolite[9] (2443 g/m^2), ferrous sulfate heptahydrate (732 g/m^2) and sodium bisulfate (244 g/m^2) on the litter with a fertilizer drop spreader[5] prior to placing the chicks on the litter.

Litter moisture levels for each pen were measured at the 6 week of the experiment. The fan ventilation were for 30 min in the morning, 15 min at noon and 15 min in the evening,

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[9]Teague Mineral Products. Rt.2 Box 35C, Adrian, OR.

recycled from days 16 to 20; for 15 min on/2 hrs off, recycled from days 21 to 29; for 15 min on/hr off, recycled from days 30 to 49 (end of experiment).

EXPERIMENT 4.

This experiment was conducted during January and February. During this period, the weather was rainy and the evenings were cool and moist. The mean weekly outside and inside temperatures ranged from -1 to 13 C and 12 to 19 C, respectively. One thousand five hundred forty four straight run Peterson x Arbor Acres broiler strain cross chicks were distributed equally in eight pens. The bird density 0.069 m^2/chick. The treatments were untreated litter (control), the application of sodium bisulfate (244 g/m^2) on the litter twice, prior to placing chicks on the litter and again at four weeks of the experiment and one application each of sodium bisulfate (488 g/m^2), and ferrous sulfate heptahydrate (732 g/m^2) on the litter prior to placing the chicks. All chemicals were applied on the litter by a fertilizer drop spreader[5]

Litter moisture levels for each pen were measured at 2, 4 and 6 weeks of the experiment. The fan ventilation were for 15 min on/4 hrs off, recycled from days 17 to 20; for 15 min on/2 hrs off, recycled from days 21 to 30; for 15 min on/hr off, recycled from day 31 to 43, and for 15 min on/15 min off recycled from days 44 to 49 (end of experiment).

RESULTS AND DISCUSSION

EXPERIMENT 1

Sodium bisulfate is a product which is used as a commercial fertilizer, for controlling pH of urea and free ammonia and as a dry acid.

No significant differences among the litter treatments (0, 122, 244 and 488 g of sodium bisulfate per m^2 of the floor space) were observed in mean body weights, feed conversion and mortality at both four and seven weeks of age (Tables III.1).

No atmospheric ammonia were detected during the first three weeks of the experiment; therefore, the data were not presented. Atmospheric ammonia levels (Table III.2) at four weeks were significantly lower in the pens treated with 488 g than in the untreated pens. No statistical differences in the ammonia levels were observed between the untreated, 122 and 244 g sodium bisulfate treated pens at 4 weeks. At 5, 6 and 7 weeks no significant differences in atmospheric ammonia levels were observed among the treatments. Although no statistical differences were observed at 5 weeks, there was an approximately 50 percent reduction in atmospheric ammonia levels in the pens treated with 488 than in the untreated control pens. At 6 weeks similar reduction in the atmospheric ammonia levels in the pens treated with 244 g and 488 g sodium bisulfate were observed when compared to the untreated control pens. However, the data were not statistically significant. The nonsignificant differences may be due to the number of replicates per treatment. The low atmospheric ammonia levels at four weeks may be attributed to the ammonia neutralizing ability of the sodium bisulfate.

One factor that influences ammonia evolution from broiler litter is litter pH. Litter pH's were significantly lower with the highest level of sodium bisulfate (488 g/m^2) application than with the untreated and 122 and 244 g levels of sodium bisulfate at the end of the first week (Table III.3). No significant differences in litter pH were observed at 2, 3, 4, 5, 6 and 7 weeks (Table III.2 and III.3) among the three levels of sodium bisulfate and untreated control pens. There was a gradual increase in the litter pH from 2 to 7 weeks of age. Sodium bisulfate is also called sodium acid sulfate since it readily produces sulfuric acid when dissolved in water. Parkhurst et al. (1974) reported that 60 percent acetic acid and 40 percent propionic acid applied on the litter significantly reduced litter pH. Reece et al. (1979) also observed similar reduction in litter pH with phosphoric acid which was more effective in reducing ammonia evolution than superphosphate probably due to its acidic nature. The low pH observed during this experiment may be due to the high acidic nature of the sodium bisulfate. Baum et al. (1956) reported a maximum uric acid degradation at pH 9 and a decrease in the reaction in a linear fashion for more acidic pH. Uric acid is the main nitrogenous compound responsible for atmospheric ammonia production from the chick manure.

Another factor that influences ammonia evolution is litter moisture. Carr et al. (1990) reported an increase in litter moisture above 30 percent causes large increases in ammonia concentration. Litter moisture (Table III.4) at the end of third week was significantly lower in the highest sodium bisulfate-treated pens than in the untreated control pens or in the treated with the lowest level of sodium bisulfate. No significant differences in litter moisture levels were observed at 0, 1, 2, 4, 5, 6 and 7 weeks among the treatments (Table III.4). There was an increasing level of litter moisture as the experiment progressed.

At 2 and 3 weeks litter moisture levels ranged from 23.3 to 26.6 percent and from 33.8 to 38 percent, respectively. Several workers have suggested that controlling litter moisture levels under certain limits will control ammonia and improve poultry house environment (e.g. optimum moisture levels suggested by North and Bell (1990) and Carr et al. (1990) were <25 and <30 percent, repectively).

Litter moisture levels at 3 weeks were high but still sodium bisulfate-treated pens with 244 and 488 g showed lower atmospheric ammonia levels. This indicates the potential of sodium bisulfate (244 and 488 g levels) to reduce atmospheric ammonia levels because of its acidic property.

Under the conditions of this experiment, the application of sodium bisulfate at the rate of 244 g and 488 g/m^2 of floor space on the litter seems to be better than the 122 g level and the untreated control in controlling atmospheric ammonia for the first four weeks. Broiler house environment was improved, and broiler performance was not affected by the litter application of sodium bisulfate.

EXPERIMENT 2

No significant differences were observed in the mean body weights, feed conversion and mortality of the birds among the litter treatments (Table III.5) at 4 and 6 weeks of age. The performance data for the litter application of ferrous sulfate (732 g/m^2) are in agreement with the results obtained by Iheanacho (1984) and Elliott and Collins (1982). However, the results on body weight disagree with Huff _et_ _al_. (1980). Litter Aid® (main ingredient of which is ferrous sulfate) when applied on the litter at 760 g/m^2 significantly increased mean body weight.

Atmospheric ammonia levels (Table III.6) seemed to be lower in ferrous sulfate treated pens at 2 and 6 weeks but the differences were not statistically significant from the Micro Aid® treatments or the untreated control pens. However, there were 53.8 and 63.6 percent reductions in atmospheric ammonia levels for the ferrous sulfate application at 2 and 6 weeks, respectively. Usually atmospheric ammonia tends to increase rapidly after 3 weeks. Atmospheric ammonia levels at 6 weeks of the experiment were not as high as compared to Experiment 1 and ranged between 6 ppm to 16.5 ppm. The lower atmospheric ammonia levels throughout the 6 weeks may be attributed to the higher outside and inside temperatures during this experiment and drier litter (i.e. about 24 to 26 percent moisture at 6 weeks). The experiment was carried out during April and May when rainfall was low and day time temperatures were 9.67 to 25.7 C and 16.7 to 28.6 C, respectively.

Litter pH's (Table III.6) at 2, 4 and 6 weeks were significantly lower in ferrous sulfate treated pens than the untreated (control) pens. Iheanacho (1984) reported a similar decrease in litter pH in the ferrous sulfate treated pens at 1, 2 and 4 weeks than in either the untreated (control) or clinoptilolite treated pens. Since ferrous sulfate is acidic, the lower pH in ferrous sulfate treated litter may be attributed to the acidic characteristic of ferrous sulfate

There is a gradual increase in the atmospheric ammonia levels with the increase in the litter pH levels in the pens. Several workers (Carr and Nicholson, 1980; Elliott and Collins, 1982; Reece et al., 1979; Wahhab et al., 1960) reported pH as an important variable in the control of atmospheric ammonia. The lower the litter pH the lower the ammonia production.

The application of ferrous sulfate heptahydrate on the built-up broiler litter at the rate of 732 g/m^2 was apparently more effective in significantly reducing litter pH levels than the untreated control. Subsequently, atmospheric ammonia levels in the pens were lower.

EXPERIMENT 3

No significant differences in mean body weights, feed conversion and mortality at 4 and 7 weeks were observed among the litter treatments (Table III.7). The results with clinoptilolite are in agreement with Nakaue et al (1981b) where different methods and application rates of clinoptilolite were examined. Clinoptilolite did not influence bird performance. The ferrous sulfate data are in agreement with Elliott and Collins (1982) where the ferrous sulfate application (0.72 kg/m^2) had no significant effect on mean body weights, feed conversion and mortality. Iheanacho (1984) also reported similar results.

Atmospheric ammonia levels were measured prior to the chemical applications and weekly thereafter until 7 weeks of the experiment (Tables III.8 and Table III.9). Atmospheric ammonia levels were significantly lower in ferrous sulfate treated pens than in the clinoptilolite and sodium bisulfate treated pens at 3 and 6 weeks (Tables III.8 and III.9). Atmospheric ammonia levels at 1 and 2 weeks in ferrous sulfate treated pens were about 36 and 57 percent lower than in the untreated control pens. Atmospheric ammonia levels in this experiment started raising rapidly from the third week. Elliott and Collins (1982) reported that ferrous sulfate can reduce atmospheric ammonia up to 35 days. Iheanacho (1984) also reported a significant decrease in the atmospheric ammonia levels in ferrous sulfate treated pens (0.76 kg/m2) for the first 35 days. The levels of atmospheric ammonia were not as high as in the Experiment 1. This experiment was conducted during July and August when mean weekly outside and inside temperature ranged from 13 to 27 C and 16 to 31 C, respectively. Relative humidity ranged from 53 to 77 percent, and the litter looked drier than in the first experiment. The drier litter (<25 percent) reduces ammonia production (Carr et al., 1990 and Xin et al., 1987).

Litter pH's were not significantly different among the treatments throughout the seven week study (Tables III.8 and III.9). Chemical treatments lowered the litter pH for the first two weeks after application but the differences were not significant. Iheanacho (1984) observed significantly lower pH levels at 1, 2 and 4 weeks in ferrous sulfate (0.76 kg/m^2) treated pens than in the clinoptilolite-treated and the untreated control pens.

A steady increase in the weekly litter pH levels was observed as the experiment progressed. Atmospheric ammonia also followed a similar trend. Reece et al (1979) reported that litter pH of 8 and higher results in high atmospheric ammonia levels, whereas lower pH values (<7) depress atmospheric ammonia levels. While working with different empirical models to determine ammonia concentrations from broiler litter, Carr et al. (1990) observed that atmospheric ammonia concentration increased with the increase in litter pH levels.

Ferrous sulfate application (732 g/m^2) on the built-up broiler litter seems to be the most effective chemical litter treatment in the reduction of atmospheric ammonia than either clinoptilolite or sodium bisulfate applications.

EXPERIMENT 4

Significant differences in mean body weights and feed conversion were observed among the treatments at 4 weeks of the experiment (Table III.10). Mean body weights of males, females and combined sexes and feed conversion were better with the sodium bisulfate applied once (488 g/m^2) than with the sodium bisulfate applied twice (244 g/m^2) at 0 and 4 weeks, ferrous sulfate (732 g/m^2) application and the untreated control pens. At 7 weeks, male broilers were slightly heavier ($P<0.1$) and feed conversion was slightly better ($P<0.08$) in the 488 g/m^2 sodium bisulfate-treated pens than in the untreated control pens. However, no significant differences in mean body weights and feed conversion at 7 weeks were observed among the chemical treatments. At 7 weeks, mortality was significantly higher in the 488 g sodium bisulfate-treated pens than in the untreated control pens. More than 50 percent of the total mortality in 488 g sodium bisulfate-treated pens were due to Sudden Death Syndrome. Most of the mortality were well-fed males.

Atmospheric ammonia levels were significantly lower at 0, 1, 3, 4, 5 and 6 weeks in the pens treated sodium bisulfate once (488 g) than in the untreated control pens (Table III.11 and III.12). The ammonia levels in pens treated with the chemicals were not significantly different throughout the experiment. At 2 weeks all the chemically treated pens were from 41 to 66 percent lower in atmospheric ammonia levels than in the untreated control. This experiment was conducted during January and February when the weather outside is wet and cold. Mean weekly outside and inside temperature ranged from -1 to 13 C and from 12 to 19 C, respectively. Atmospheric ammonia levels were relatively lower throughout this experiment than what was observrd in the first experiment. The lower atmospheric ammonia levels in this experiment may be attributed to the lower temperature range during this experiment. Temperature is an important factor in atmospheric ammonia production as has been reported by several workers (Carr et al., 1990; Elliott and Collins, 1982 and Xin et al., 1987). Higher ventilation rates were required especially from 3 to 7 weeks to reduce ammonia. Higher relative humidity levels (63.5 to 88 percent) were also found.

The litter pH levels were significantly lower in pens treated with sodium bisulfate once (488 g/m^2) than in the pens treated twice (244 g at 0 and 4 weeks) at 1,2 and 3 weeks (Tables III.11 and III.12). Litter pH levels at 5, 6 and 7 weeks were lower in twice treated sodium bisulfate (244 g/m^2 at 0 and 4 weeks) pens than in the untreated and ferrous sulfate treated pens (Table III.12). This sudden reduction of pH levels (and atmospheric ammonia at 5 and 6 weeks) pens treated twice with sodium bisulfate (244 g/m^2) at 0 and 4 weeks was probably due to the second application of sodium bisulfate on the litter at the end of the fourth week.

No significant differences in litter moisture at 2, 4 and 6 weeks were observed (Table III.13). The litter moisture ranged from 27 to 39 percent. The high litter moisture levels and significantly lower atmospheric ammonia levels in sodium bisulfate treated pens indicates that the acidic property of the sodium bisulfate has a great influence on ammonia evolution from the litter than the litter moisture level.

Lower pH produced lower atmospheric ammonia (Carr et al., 1990) and also slightly improved broiler performance in this experiment. Applications of sodium bisulfate once (488 g/m^2) prior to placing chicks and twice (244 g/m^2 at 0 and 4 weeks) were better than the ferrous sulfate and untreated (control) in reducing atmospheric ammonia levels. However, litter application of sodium bisulfate once (488 g/m^2) may be preferred over the twice (244 g/m^2 at 0 and 4 weeks) to save labor cost. Furthermore, broiler performance was also slightly improved with sodium bisulfate applied once (488 g/m^2). The litter application of sodium bisulfaste at 488 g/m^2 seems to be the best among the treatments in reducing atmospheric ammonia levels and improving broiler performance.

Table III.1. The effect of various levels of sodium bisulfate applications on built-up broiler litter on mean body weights, feed conversion and mortality at 4 and 7 weeks (Experiment 1)

Litter treatments		4 weeks[1]				7 weeks[1]				
		Mean body weights			Feed	Mean body weights			Feed	Mort-
Chemical	Appl. Rate	M[2]	F[3]	M+F	Conv.	M[2]	F[3]	M+F	Conv.	ality
	(g/m^2)	--------kg---------				---------kg--------				(%)
None	0	1.16	0.99	1.07	1.59	2.47	1.99	2.23	2.13	3.51
Sodium bisulfate	122	1.13	0.97	1.05	1.59	2.47	2.01	2.22	2.10	3.78
Sodium bisulfate	244	1.13	0.98	1.05	1.58	2.43	1.98	2.25	2.07	4.32
Sodium bisulfate	488	1.14	0.97	1.05	1.58	2.48	2.03	2.25	2.07	4.32
	SE[4]	0.01	0.01	0.01	0.02	0.05	0.05	0.05	0.01	0.62

[1]Mean values in each column are not significantly different among the treatments ($P>0.05$)
[2]M = Males
[3]F = Females
[4]SE = Standard error of the means

Table III.2. The effect of various levels of sodium bisulfate applications on built-up broiler litter on mean weekly atsmospheric ammonia (NH_3) and litter pH from 4 to 7 weeks (Experiment 1)

Litter treatments		Weeks on Test							
		4		5		6		7	
Chemical	Appl. Rate (g/m^2)	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH
None	0	19.5[b]	6.7[a]	61[a]	6.6[a]	63[a]	7.0[a]	65[a]	8.45[a]
Sodium bisulfate	122	13.5[ab]	6.8[a]	43[a]	6.9[a]	44[a]	6.7[a]	74[a]	8.25[a]
Sodium bisulfate	244	12.0[ab]	6.7[a]	40[a]	6.8[a]	33[a]	6.8[a]	93[a]	8.25[a]
Sodium bisulfate	488	9.5[a]	6.6[a]	33[a]	6.8[a]	30[a]	6.6[a]	80[a]	8.20[a]
	SE[3]	1.6	0.01	11	0.1	17	0.1	10	0.02

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$
[2]Parts per million
[3]Standard error of the means

Table III.3. The effect of various levels of sodium bisulfate applications on built-up broiler litter on mean weekly litter pH (Experiment 1)

Litter treatments			Weeks on Test[1]			
Chemical	Appl. Rate		0[2]	1	2	3
	(g/m^2)					
None	0		8.20[a]	7.85[c]	6.15[a]	6.55[a]
Sodium bisulfate	122		7.15[a]	7.20[bc]	6.45[a]	6.50[a]
Sodium bisulfate	244		7.55[a]	6.60[ab]	6.05[a]	6.35[a]
Sodium bisulfate	488		6.85[a]	5.60[a]	5.70[a]	6.20[a]
		SE[3]	0.54	0.19	0.13	0.08

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$
[2]Measurements were taken immediately after application and prior to placing the broiler chicks on the litter
[3]Standard error of the means

Table III.4. The effect of various levels of sodium bisulfate applications on built-up broiler litter on weekly litter moisture (Experiment 1)

Litter treatments: Chemical	Appl. Rate		Litter Moisture[1]: Weeks of Sampling 0	1	2	3	4	5	6	7
	(g/m^2)		(%)							
None	0		14.3^{a}	17.4^{a}	26.5^{a}	38.0^{b}	43.3^{a}	35.9^{a}	41.0^{a}	46.8^{a}
Sodium bisulfate	122		14.3^{a}	15.6^{a}	23.3^{a}	38.0^{b}	38.6^{a}	45.9^{a}	42.8^{a}	44.7^{a}
Sodium bisulfate	244		14.9^{a}	16.0^{a}	25.2^{a}	34.4^{ab}	42.3^{a}	37.0^{a}	36.0^{a}	42.8^{a}
Sodium bisulfate	488		13.4^{a}	16.6^{a}	26.8^{a}	33.8^{a}	39.7^{a}	44.9^{a}	39.8^{a}	47.0^{a}
		SE[2]	0.6	0.7	2.9	1.9	1.3	2.3	2.2	4.6

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$

[2]Standard error of the means

Table III.5. The effect of Micro Aid® and ferrous sulfate applications on built-up broiler litter on mean body weights, feed conversion and mortality at 4 and 6 weeks (Experiment 2)

Litter treatments		4 weeks[1]				6 weeks[1]				
		Mean body weights			Feed	Mean body weights			Feed	Mort-
Chemical	Appl. Rate	M[2]	F[3]	M+F	Conv.	M[2]	F[3]	M+F	Conv.	ality
		--------kg--------				--------kg--------				(%)
None	0	1.12	0.96	1.05	1.68	2.22	1.82	2.01	2.03	3.48
Micro Aid (solution)	8.75 ml/L H_2O	1.09	0.93	1.00	1.71	2.22	1.82	2.01	2.02	1.37
Micro Aid (granules)	0.5 mg/g of feed	1.11	0.95	1.03	1.71	2.19	1.87	2.02	2.03	3.48
Ferrous Sulfate	732 g/m^2	1.14	0.99	1.07	1.68	2.30	1.88	2.08	2.02	2.16
	SE[4]	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.04	0.88

[1]Mean values in each column are not significantly different among the treatments (P>0.05)
[2]M = Males
[3]F = Females
[4]Standard error of the means

Table III.6. The effect of Micro Aid® and ferrous sulfate applications on built-up broiler litter on litter pH and atmospheric ammonia (NH_3) levels in broiler pens at 2, 4 and 6 weeks (Experiment 2)

Litter treatments		Weeks on Test[1]					
		2		4		6	
Chemical	Appl. Rate	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH
None	0	6.5[a]	9.0[b]	8.5[a]	9.1[b]	16.5[a]	9.1[b]
Micro Aid (solution)	8.75 ml/L H_2O	8.5[a]	8.6[ab]	12.0[a]	8.7[ab]	13.0[a]	8.8[ab]
Micro Aid (granules)	0.5 mg/g of feed	6.5[a]	8.7[b]	11.0[a]	8.7[ab]	11.5[a]	8.8[ab]
Ferrous sulfate	732 g/m^2	3.0[a]	8.3[a]	10.5[a]	8.4[a]	6.0[a]	8.6[a]
	SE[3]	1.2	0.1	0.9	0.1	2.1	0.1

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$
[2]Parts per million
[3]Standard error of the means

Table III.7. The effect of clinoptilolite, ferrous sulfate and sodium bisulfate applications on built-up broiler litter on mean body weights, feed conversion and mortality at 4 and 7 weeks of age (Experiment 3)

Litter treatments		4 weeks[1]				6 weeks[1]				
		Mean body weights			Feed	Mean body weights			Feed	Mort-
Chemical	Appl. Rate	M[2]	F[3]	M+F	Conv.	M[2]	F[3]	M+F	Conv.	ality
	(g/m^2)	--------kg--------				--------kg--------				(%)
None	0	1.11	0.96	1.03	1.59	2.38	1.95	2.35	2.08	2.70
Clinopt-ilolite	2443	1.12	0.97	1.04	1.57	2.37	1.93	2.15	2.09	2.43
Ferrous sulfate	732	1.10	0.96	1.02	1.57	2.43	1.95	2.18	2.08	2.97
Sodium bisulfate	244	1.12	0.99	1.05	1.60	2.34	1.95	2.14	2.13	3.78
	SE[4]	0.02	0.02	0.02	0.02	0.04	0.02	0.09	0.01	0.87

[1]Mean values in each column are not significantly different among the treatments (P>0.05)
[2]M = Males
[3]F = Females
[4]Standard error of the means

Table III.8. The effect of clinoptilolite, ferrous sulfate and sodium bisulfate applications on built-up broiler litter on weekly atmospheric ammonia (NH_3) in broiler pens and litter pH from 0 to 3 weeks (Experiment 3)

Litter treatments		Weeks on Test[1]							
		0[4]		1		2		3	
Chemical	Appl. Rate (g/m[2])	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH
None	0	3.5[a]	8.3[a]	7.0[a]	7.5[a]	9.0[a]	7.9[a]	23.0[b]	8.8[a]
Clinoptilolite	2443	3.0[a]	8.3[a]	5.5[a]	6.8[a]	8.5[a]	7.5[a]	15.0[b]	8.6[a]
Ferrous sulfate	732	2.5[a]	8.3[a]	4.5[a]	6.7[a]	4.0[a]	7.5[a]	12.0[a]	8.5[a]
Sodium bisulfate	244	2.0[a]	8.4[a]	6.0[a]	6.8[a]	9.5[a]	7.5[a]	19.0[b]	8.6[a]
	SE[2]	0.4	0.1	0.6	0.2	1.3	0.2	2.2	0.1

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$
[2]Parts per million
[3]Standard error of the means
[4]Measurements were taken before chemicals application

Table III.9. The effect of clinoptilolite, ferrous sulfate and sodium bisulfate applications on built-up broiler litter on weekly atmospheric ammonia (NH_3) in broiler pens and litter pH from 4 to 7 weeks (Experiment 3)

Litter treatments			Weeks on Test[1]							
			4[4]		5		6		7	
Chemical	Appl. Rate (g/m²)		NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH
None	0		25[a]	8.8[a]	28[a]	8.8[a]	38[b]	9.0[a]	39[a]	9.2[a]
Clinoptilolite	2443		18[a]	8.8[a]	18[a]	8.9[a]	37[b]	9.0[a]	30[a]	9.1[a]
Ferrous sulfate	732		21[a]	8.7[a]	24[a]	9.0[a]	28[a]	9.2[a]	31[a]	9.2[a]
Sodium bisulfate	244		21[a]	8.8[a]	22[a]	8.9[a]	39[b]	9.1[a]	37[a]	9.2[a]
		SE[2]	3	0.1	3	0.1	2	0.1	2	0.1

[1]Mean values in each column with different superscripts were significantly different at P<0.05
[2]Parts per million
[3]Standard error of the means
[4]Measurements were taken before chemicals application

Table III.10. The effect of sodium bisulfate and ferrous sulfate applications on built-up broiler litter on mean body weights, feed conversion and mortality at 4 and 7 weeks of age (Experiment 4)

Litter treatments			4 weeks[1]				7 weeks[1]				
			Mean body weights			Feed	Mean body weights			Feed	Mort-
Chemical	Appl. Rate	Time	M[2]	F[3]	M+F	Conv.	M[2]	F[3]	M+F	Conv.	ality
	(g/m²)	(wk)	--------kg--------				--------kg--------				(%)
None	0	0	1.01^{a}	0.90^{a}	0.95^{a}	1.73^{b}	2.44^{a}	2.04^{a}	2.26^{a}	2.15^{a}	2.33^{a}
Sodium	244	0									
bisulfate	244	4	1.02^{a}	0.93^{ab}	0.97^{bc}	1.71^{b}	2.51^{a}	2.09^{a}	2.30^{a}	2.12^{a}	3.63^{ab}
Sodium bisulfate	488	0	1.08^{b}	0.96^{b}	1.02^{c}	1.62^{a}	2.57^{a}	2.13^{a}	2.32^{a}	2.08^{a}	4.93^{b}
Ferrous sulfate	732	0	1.03^{ab}	0.92^{ab}	1.98^{bc}	1.74^{b}	2.47^{a}	2.10^{a}	2.29^{a}	2.14^{a}	4.15^{ab}
		SE[4]	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.01	0.42

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$
[2]Parts per million
[3]Standard error of the means

Table III.11. The effect of sodium bisulfate and ferrous sulfate applications on built-up broiler litter on weekly atmospheric ammonia (NH_3) in broiler pens and litter pH from 0 to 3 weeks (Experiment 4)

Litter treatments: Chemical	Appl. Rate (g/m^2)	Appl. Time (wk)		Weeks on Test[1] 0[4]: NH_3 (ppm[2])	0[4]: pH	1: NH_3 (ppm[2])	1: pH	2: NH_3 (ppm[2])	2: pH	3: NH_3 (ppm[2])	3: pH
None	0	0		18^{b}	8.4^{b}	10^{b}	8.4^{c}	12^{a}	8.4^{c}	22^{b}	8.6^{c}
Sodium bisulfate	244 244	0 4		7^{ab}	6.5^{a}	6^{ab}	6.8^{b}	7^{a}	6.9^{b}	15^{ab}	7.9^{b}
Sodium bisulfate	488	0		4^{a}	6.0^{a}	4^{a}	6.2^{a}	4^{a}	6.4^{a}	7^{a}	7.2^{a}
Ferrous sulfate	732	0		5^{a}	6.5^{a}	4^{a}	6.5^{ab}	5^{a}	6.8^{ab}	9^{ab}	7.7^{ab}
			SE[3]	2	0.1	0.7	0.1	2	0.1	2	0.1

[1]Mean values in each column with different superscripts were significantly differet at $P<0.05$
[2]Parts per million
[3]Standard error of the means
[4]Measurements were taken immendiately after application and prior to placing the broiler chicks on the litter

Table III.12. The effect of the sodium bisulfate and ferrous sulfate applications on built-up broiler litter on weekly atmospheric ammonia (NH_3) in broiler pens and litter pH from 4 to 7 weeks (Experiment 4)

Litter treatments				Weeks on Test[1]							
Chemical	Appl.			4		5		6		7	
	Rate (g/m^2)	Time (wk)		NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH	NH_3 (ppm[2])	pH
None	0	0		22[b]	8.9[b]	24[b]	9.0[b]	25[b]	9.2[b]	27[a]	9.5[b]
Sodium bisulfate	244 244	0 4		18[ab]	8.4[ab]	8[a]	8.0[a]	17[a]	8.4[a]	23[a]	8.8[a]
Sodium bisulfate	488	0		12[a]	8.2[a]	11[a]	8.6[b]	19[a]	8.8[ab]	25[a]	9.2[ab]
Ferrous sulfate	732	0		15[ab]	8.5[ab]	12[ab]	8.7[b]	21[ab]	9.0[b]	25[a]	9.3[b]
			SE[3]	1	0.1	1	0.1	1	0.5	1	0.1

[1]Mean values in each column with different superscrtips were sigificantly different at $P<0.05$
[2]Parts per million
[3]Standard error of the means

Table III.13. The effect of sodium bisulfate and ferrous sulfate applications on built-up broiler litter on litter moisture at 2, 4 and 6 weeks (Experiment 4)

Litter treatments			Litter Moisture[1]		
Chemical	Appl.		Weeks of Sampling		
	Rate	Time	2	4	6
	(g/m^2)	(wk)	(%)		
None	0	0	35	36	39
Sodium bisulfate	244 244	0 4	27	33	37
Sodium bisulfate	488	0	31	34	38
Ferrous sulfate	732	0	32	35	38
		SE[2]	3	1	1

[1]Mean values in each column are not significantly different among treatments at $P<0.05$
[2]Standard error of the means

CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

The objectives of these studies were to compare the efficiency and the methods of application of sodium bisulfate, ferrous sulfate heptahydrate, Micro Aid® and clinoptilolite on the effect of atmospheric ammonia evolution from the built-up litter in the broiler house and on subsequent broiler performance in a mechanically ventilated enclosed broiler house.

Ferrous sulfate heptahydrate application (732 g/m^2) was compared with Micro Aid® granules (0.5 mg/g of the feed) fed continuously throughout the experiment; litter application of Micro Aid® solution (8.75 ml/L of H_2O); clinoptilolite (2443 g/m^2) and sodium bisulfate (244 g/m^2). Ferrous sulfate heptahydrate application (732 g/m^2) was apparently better among the chemical treatments to reduce atmospheric ammonia and litter pH levels.

Built-up broiler litter treated with sodium bisulfate (244 and 488 g/m^2) prior to placing the chicks were better than 122 g/m^2 and the untreated control in reducing atmospheric ammonia production. One sodium bisulfate treatment (488 g/m^2) prior to placing chicks was significantly better than the ferrous sulfate application (732 g/m^2) and untreated control and was somewhat comparable to the sodium bisulfate treatment twice (244 g/m^2) at 0 and 4 weeks in reducing atmospheric ammonia production and controlling litter pH levels. It also significantly improved broiler performance at 4 weeks and slightly improved broiler performance feed conversion ($P<0.08$) and males body weights ($P<0.1$).

Litter application of sodium bisulfate (488g/m^2) seems to be better than ferrous sulfate heptahydrate application (732 g/m^2). It is, therefore, wise to use litter application of sodium bisulfate once (488 g/m^2) instead of sodium bisulfate twice (244 g/m^2 at 0 and 4 weeks) to save on labor cost and also to obtain better broiler performance.

Probably another study (under the similar weather conditions) to compare the litter application of sodium bisulfate once at 244, 488 g/m^2 and ferrous sulfate hepta-hydrate applications at 732 g/m^2 prior to placing the broiler chicks, may help to strengthen these results.

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APPENDIX

Table A.1. The effect of Micro Aid® and ferrous sulfate applications on built-up broiler litter on temperature and relative humidity (RH) in broiler pens at 2, 4 and 6 weeks (Experiment 2)

Litter treatments		Weeks on Test[1]					
		2		4		6	
Chemical	Appl. Rate	Temp	RH	Temp	RH	Temp	RH
		(C)	(%)	(C)	(%)	(C)	(%)
None	0	21.9	75	21.4	82	19.7	83
Micro Aid (solution)	8.75 ml/L H_2O	23.9	66	23.9	73	21.4	76
Micro Aid (granules)	0.5 mg/g feed	24.2	68	24.2	73	20.3	76
Ferrous sulfate	732 g/m^2	22.8	74	23.9	76	18.6	74
	SE[2]	1.5	5	1.3	3	1.5	2

[1]Mean values in each column are not significantly different among the treatments (P>0.5)
[2]Standard error of the means

Table A.2. The effect of clinoptilolite, ferrous sulfate and sodium bisulfate applications on built-up broiler litter on weekly temperature and relative humidity (RH) in broiler pens from 1 to 4 weeks (Experiment 3)

Litter treatments			Weeks on Test[1]							
			1		2		3		4	
Chemical	Appl. Rate		Temp (C)	RH (%)	Temp (C)	RH (%)	Temp (C)	RH (%)	Temp (C)	RH (%)
None	0		29.4	56	27.8	70	28.9	74	28.1	63
Clinoptilolite	2443		30.6	53	29.4	66	29.8	77	28.3	72
Ferrous sulfate	732		31.7	57	28.6	61	29.8	72	28.6	70
Sodium bisulfate	244		31.1	53	29.2	69	29.8	76	28.9	70
		SE[2]	1.2	2	2	2	0.7	1	1.5	5

[1]Mean values in each column are not significantly different among the treatments ($P>0.05$)

[2]Standard error of the means

Table A.3. The effect of clinoptilolite, ferrous sulfate and sodium bisulfate applications on built-up broiler litter on weekly temperature and relative humidity (RH) in broiler pens from 5 to 7 weeks (Experiment 3)

Litter treatments			Weeks on Test[1]					
			5		6		7	
Chemical	Appl. Rate (g/m^2)		Temp (C)	RH (%)	Temp (C)	RH (%)	Temp (C)	RH (%)
None	0		28.1	65	29.2	64	29.4	64
Clinopt-ilolite	2443		28.1	76	29.2	71	28.1	81
Ferrous sulfate	732		28.1	63	29.2	74	30.6	75
Sodium bisulfate	244		29.2	70	29.2	69	30.0	70
		SE[2]	1.3	6	0.9	4	1.4	5

[1]Mean values in each column are not significantly different among the treatments (P>0.5)
[2]Standard error of the means

Table A.4. The effect of sodium bisulfate and ferrous sulfate applications on built-up broiler litter on weekly temperature and relative humidity (RH) in broiler pens from 0 to 3 weeks (Experiment 4)

Litter treatments			Weeks on Test[1]							
Chemical	Appl.		0		1		2		3	
	Rate	Time	Temp (C)	RH (%)	Temp (C)	RH (%)	Temp (C)	RH (%)	Temp (C)	RH (%)
None	0	0	19.2[a]	69[a]	19.7[a]	64.5[b]	20.8[a]	74[a]	21.4[a]	74[a]
Sodium bisulfate	244 244	0 4	20.8[a]	59[a]	20.6[a]	65.0[ab]	22.2[a]	71[a]	23.1[a]	70[a]
Sodium bisulfate	488	0	21.1[a]	69[a]	20.6[a]	62.5[a]	22.8[a]	67[a]	23.3[a]	64[a]
Ferrous sulfate	732	0	17.8[a]	74[a]	19.8[a]	69.0[ab]	21.4[a]	74[a]	22.5[a]	71[a]
		SE[2]	2.3	4	0.6	1.8	1.3	4	1.8	4

[1]Mean values in each column with different superscripts were significantly different at $P<0.05$
[2]Standard error of the means

Table A.5. The effect of sodium bisulfate and ferrous sulfate applications on built -up broiler litter on weekly temperature and relative humidity (RH) in broiler pens from 4 to 7 weeks (Experiment 4)

Litter treatments			Weeks on Test[1]							
Chemical	Appl.		4		5		6		7	
	Rate	Time	Temp	RH	Temp	RH	Temp	RH	Temp	RH
			(C)	(%)	(C)	(%)	(C)	(%)	(C)	(%)
None	0	0	18.3[a]	87[a]	15.3[a]	88[b]	15.9[a]	88[b]	22.5[a]	79[b]
Sodium bisulfate	244 244	0 4	18.1[a]	87[a]	15.0[a]	86[ab]	15.9[a]	81[ab]	21.9[a]	77[ab]
Sodium bisulfate	488	0	18.6[a]	87[a]	15.3[a]	76[a]	15.9[a]	79[a]	22.5[a]	70[a]
Ferrous sulfate	732	0	18.1[a]	86[a]	15.0[a]	81[ab]	15.6[a]	84[ab]	22.2[a]	74[b]
		SE[2]	0.4	3	0.4	2	0.66	1	0.4	2

[1]Mean values in each column with different superscripts were significantly differet at $P<0.05$

[2]Standard error of the means