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Estimating Potential Ground and Surface Water Pollution from Land Application of Poultry Litter - II

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Publication No. 137

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Research Project Technical Completion Report

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ABSTRACT

ESTIMATING POTENTIAL GROUND AND SURFACE WATER POLLUTION FROM LAND APPLICATION OF POULTRY LITTER-II

In Arkansas, approximately 1 Tg of poultry (Gallus gallus domesticus) manure and litter is produced annually. These waste products are commonly applied to pastures as a soil amendment or fertilizer, but excessive application rates and poor management practices could result in nutrient contamination of ground and surface water. The purpose of this study was to: (1) assess the nutrient concentrations in poultry manure and (2) evaluate the nitrogen loss from land-applied poultry litter and manure due to ammonia volatilization and denitrification. Analyses for total Kjeldahl nitrogen (TKN), inorganic nitrogen (N_i), phosphorus (P), and potassium (K) were compared in 12 wet and dry hen manure samples. Drying the manure reduced the TKN from 57 to 40 g N/kg on a dry weight basis in wet and dry manure, respectively. The N_i in the manure was in the ammoniacal form with values of 19 and 2 g N/kg for wet and dry manure, respectively. The P and K levels were not influenced by drying the manure and had values of 24 and 21 g/kg, respectively. The results indicate that the nitrogen content of hen manure can be significantly reduced by drying the sample prior to analysis. In a 10-day laboratory study and an 11-day field study to evaluate ammonia volatilization from surface-applied hen manure, results indicated that 37% of the total nitrogen content of the manure was lost. The results indicated that a substantial amount of nitrogen in surface-applied poultry waste can be lost due to ammonia volatilization. Laboratory studies to evaluate denitrification in a Captina silt loam amended with 9 Mg/ha of poultry litter were conducted. When the soil was aerobically incubated for 168 h and then flooded for 66 h, the nitrate-nitrogen level decreased a net of 17 mg N/kg. The results indicated that, if the ammoniacal nitrogen in the litter is oxidized to nitrate under aerobic conditions and then the soil is flooded and available carbon is present, denitrification can occur rapidly. Results from these studies indicate that soil and environmental conditions play a critical role in determining the potential for nitrate pollution of ground and surface water when poultry manure and litter are surface-applied to pastures.

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Keywords -- Nitrogen/Manure Disposal/Water Quality

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INTRODUCTION

Arkansas is a major producer of poultry and poultry products. In 1986, Arkansas produced 788,000,000 broiler chickens (*Gallus gallus domesticus*) and housed approximately 18,000,000 egg-laying hens and a similar number of turkeys (*Meleagris gallopavo*) (Von Steen and Hicks, 1987). These important agricultural industries produce substantial quantities of poultry manure with estimates of approximately 1 Tg of waste on a dry weight basis. To recycle the nutrients and take advantage of the beneficial properties of the waste material, much of the poultry manure is used as a soil amendment or fertilizer on pastures. The manure has been shown to be a valuable source of plant nutrients, but over application or poor management can result in environmental problems and ground and surface water pollution (Liebhardt et al., 1979).

A typical nitrogen content of poultry manure is approximately 4.5%, and if all of the manure was applied to pastures, this would amount to a total nitrogen application of 45 Gg during 1986. Excessive rates of waste application could result in increased nitrate levels in ground and surface water and potential health problems if the drinking water level exceeds the 10 mg NO_3-N/L limit established by the U.S. Public Health Service.

However, not all of the nitrogen in the poultry litter and manure is subject to conversion to nitrate and transport into ground and surface water. In addition to plant uptake, the nitrogen may remain in the soil in stable organic forms, may be lost in the form of ammonia when the waste is applied, and may be denitrified and returned to the atmosphere in the form of N_2, which is a harmless gas. Before we can fully take advantage of the benefits of land application of poultry wastes, we must be able to better understand and manage the transformation reactions which take place in the waste-amended soil. Once such information is available, it will be possible to make better use of the nutrients in the waste and more fully protect our surface and ground water supplies.

A. Purpose and Objectives

The purpose of this study was to quantify two major aspects of the nitrogen cycle which influence the ground and surface water pollution potential of poultry manure and litter in a land-application program and provide better information on the forms of nutrients in the waste materials. The ultimate goal of the research efforts is to provide information for use by producers which will enable them to use poultry litter and manure to optimize forage production while protecting our water supplies from contamination. The specific objectives of the research were to: (1) determine the amount of ammonia volatilization from surface-applied poultry manure and (2) quantitate the proportion of nitrogen denitrified or lost to the atmosphere in the form of dinitrogen gas.

B. Related Research and Activities

Agricultural producers have long recognized the benefits of recycling poultry manure and litter as a fertilizer on pastures. Poultry litter was compared to commercial fertilizer nitrogen sources in studies reported by Hileman (1973), and he found that application of 4.48 and 8.96 Mg/ha of broiler litter resulted in high forage yields and increased soil levels of available phosphorus and potassium. Recently, Huneycutt et al. (1988) reported results from yield trials for three forages. Irrigated and non-irrigated bermudagrass (*Cynodon dactylon* (L.) Pers.), tall fescue (*Festuca arundinacea* Schreb.) and tall fescue-clover (*Trifolium* spp.) were fertilized with six rates of commercial fertilizer and litter rates of 4.48, 8.96, and 13.44 Mg/ha. Six years of dry matter yield data showed that bermudagrass exhibited the greatest yield response to litter addition and the tall fescue-clover mixture was the least responsive. Bermudagrass and fescue exhibited a linear yield response to litter addition over the range of 0 to 13.44 Mg/ha.

One of the major limitations to efficient utilization of poultry waste as a soil amendment is inconsistency in nutrient content of the waste. Over 20 years ago, Hileman (1967) indicated that variability in the nitrogen, phosphorus, and potassium content of broiler litter could be substantial. His research showed that broiler litter contained an average of 4.11% nitrogen, 1.45% phosphorus, and 2.18% potassium on a dry weight basis (Hileman, 1971) Before maximum utilization of nutrients in the poultry litter can be attained, more information is needed on the nutrient content of the waste materials (Chescheir et al., 1985).

Generally, the most critical nutrient element supplied by the poultry manure to the forage system is nitrogen. If waste application rate is to be determined by nitrogen supplied to the crop, the waste application rate for a given soil should be determined by the quantity of nitrogen which becomes available or is mineralized (Gilmour and Gale, 1986; Mathers and Goss, 1979; and Pratt et al., 1973;). Poultry manure and litter contain various nitrogen forms which are mineralized at different rates (Fig. 1). The nitrogen mineralization rate is also controlled by such factors as soil temperature, moisture, and carbon mineralization (Gale and Gilmour, 1986; Sims, 1986). researchers reported that the mineralization process consists of rapid, intermediate, and slow phases. Research from several laboratories has shown that the amount of nitrogen mineralized in the rapid phase of poultry litter decomposition is generally 20 40% (Castellanos and Pratt, 1981; Gale and Gilmour, 1986; Hadas et al., 1983; and Pratt and Castellanos, 1981). In field and

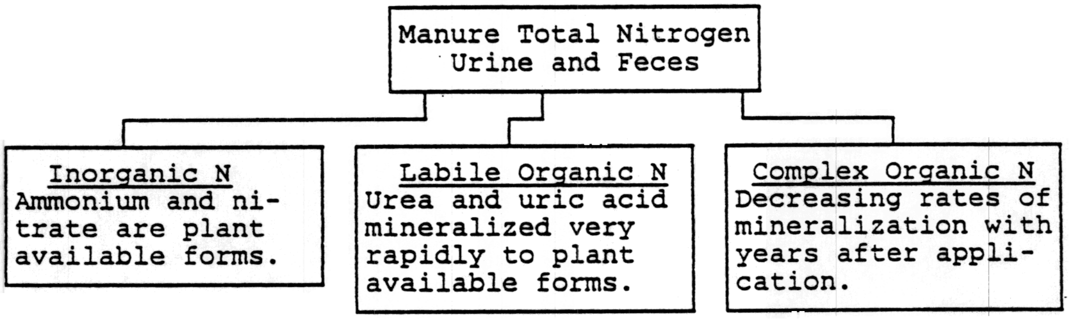

Fig 1 Forms of nitrogen in poultry manure and litter and relative mineralization rates.

laboratory studies to determine nitrogen availability in poultry manure incorporated into the soil, Bitzer and Sims (1988) reported that 66% of the organic nitrogen from 20 manure samples was mineralized and resulted in large amounts of available nitrogen in the soil within 2 weeks.

An important avenue of nitrogen loss from waste-amended soils is ammonia volatilization when the poultry manure or litter is surface applied. Giddens and Rao (1975) showed that air drying of fresh poultry manure resulted in an approximate decrease of 50% in the total nitrogen content of the waste which was due to ammonia volatilization. Surface-applied dairy manure was shown to have total losses of from 61 to 99% of the ammoniacal nitrogen content of the manure in a field study (Lauer et al., 1976) Laboratory studies with poultry manure have shown significant reductions in the inorganic nitrogen content during the first 14 days of incubation, and the losses were attributed to ammonia volatilization and denitrification (Chescheir et al., 1986). In the equation used by Bitzer and Sims (1988) to predict available nitrogen, they assumed a 20% loss of the inorganic nitrogen in poultry manure due to ammonia volatilization.

A second avenue of nitrogen loss from soil amended with poultry manure or litter is denitrification. Before denitrification can occur, the soil must be anaerobic and there must be a supply of nitrate and available carbon (Alexander, 1977).

Reddy et al. (1980) showed that the application of beef, swine and poultry manure increased the denitrification potential Norfolk sandy loam. The denitrification potential was greatest when the manures had undergone a 30-day decomposition. At poultry manure rates of 0 to 184 Mg/ha, Cooper et al. (1984) reported increased denitrification losses with increased manure application. At the highest manure rate, 60% of the applied nitrogen was not recovered either in the soil profile or in the harvested crop, and this incomplete recovery led the researchers to postulate that the major avenue of loss was denitrification

METHODS AND PROCEDURES

A. Nutrient Variability

During August, fresh hen manure samples were collected from 12 separate truck loads from an 850,000 hen, caged-layer operation Each load was sampled by collecting ten subsamples, each weighing approximately 200 g. Each subsample was also divided into two separate samples and all samples were frozen in polyethylene bags and transported to the laboratory. A total of 24 samples were collected, 12 to be analyzed in the moist condition and 12 to be analyzed after the samples had been dried

When the samples arrived at the laboratory, they were thawed, mixed for 10 min with a commercial mixer, and split into two equal portions One portion of the sample was dried constant weight at 65°C in a forced-draft oven, ground in a Wiley mill to pass a 0.85-mm screen, and stored in a desiccator. The other portion was analyzed in the existing moist state

Percentage solids were determined on four replications of each of the 12 samples by drying subsamples to a constant weight at 65^{o}C in a forced-draft oven. Samples had a mean solids content of 340 g/kg. The pH values were determined potentiometrically using 1:10 ratio of manure to distilled water. An induction furnace combustion procedure was used to determine percentage C on dried samples (Nelson and Sommers, 1982). A 1-g manure sample was extracted with 20 mL of 2M KCl, and the ammonium and nitrite plus nitrate nitrogen were determined for two replicates of both wet and dry samples following the method described by Keeney and Nelson (1982). The total nitrogen content of the wet and dry samples was determined by semimicro-Kjeldahl digestion and steam distillation procedures (Bremner and Mulvaney, 1982) using four replications per sample. Additionally, the total nitrogen content of the dried samples was determined from a H_2SO_4-H_2O_2 digestion procedure

The phosphorus, potassium, calcium, magnesium, and sulfur levels were also determined on two replicates of both wet and dry manure samples following H_2SO_4-H_2O_2 digestion The analyses were conducted with an inductively coupled plasma emission spectrometer. Analysis of variance procedures were used to determine significant differences ($\underline{P}<0.05$) in the parameters measured in a randomized complete block design.

B. Ammonia Volatilization

A Bowie fine sandy loam (fine-loamy, siliceous, thermic Fragic Paleudult) and a Captina silt loam (fine-silty, mixed mesic Typic Fragiudult) were utilized in the ammonia volatilization studies (Table 1).

For the laboratory studies, cylindrica volatilization chambers, 13 cm in diameter and 6 cm high, were used to contain the soil and manure (Fig. 2) Air was input through ports equally spaced around the cylinder and output through a central port on the top of the cylinder. Soil was placed on a porous ceramic plate attached to a water reservoir that allowed a continuous supply of water at a constant potential of -34 kPa which enabled evaporation to occur without altering the moisture content of the soil. Fresh hen manure at rates of 0 and 6.8 Mg/ha (dry weight) was surface-applied or incorporated into the soil Table 2)

Immediately after itter application, the chambers were closed and passage of air across the soil surface was initiated. Air flow was regulated at two chamber volume exchanges per minute and temperature maintained at 23 $\pm 2^{o}$C. Air entering the system was initially prescrubbed to remove NH_3 and maintained at approximately 30% relative humidity by scrubbing through 8.1 $\underline{M}$

Table 1 Physical and chemical properties of the soils used in the ammonia volatilization and denitrification studies.

Soil	Texture			pH	Organic	
	sand	silt	clay		C	N
	--------%--------			(1:1)	-----%----	
Bowie fine sandy loam	62	27	11	5.9	0.78	0.08
Captina silt loam	27	63	10	6.1	0.52	0.05

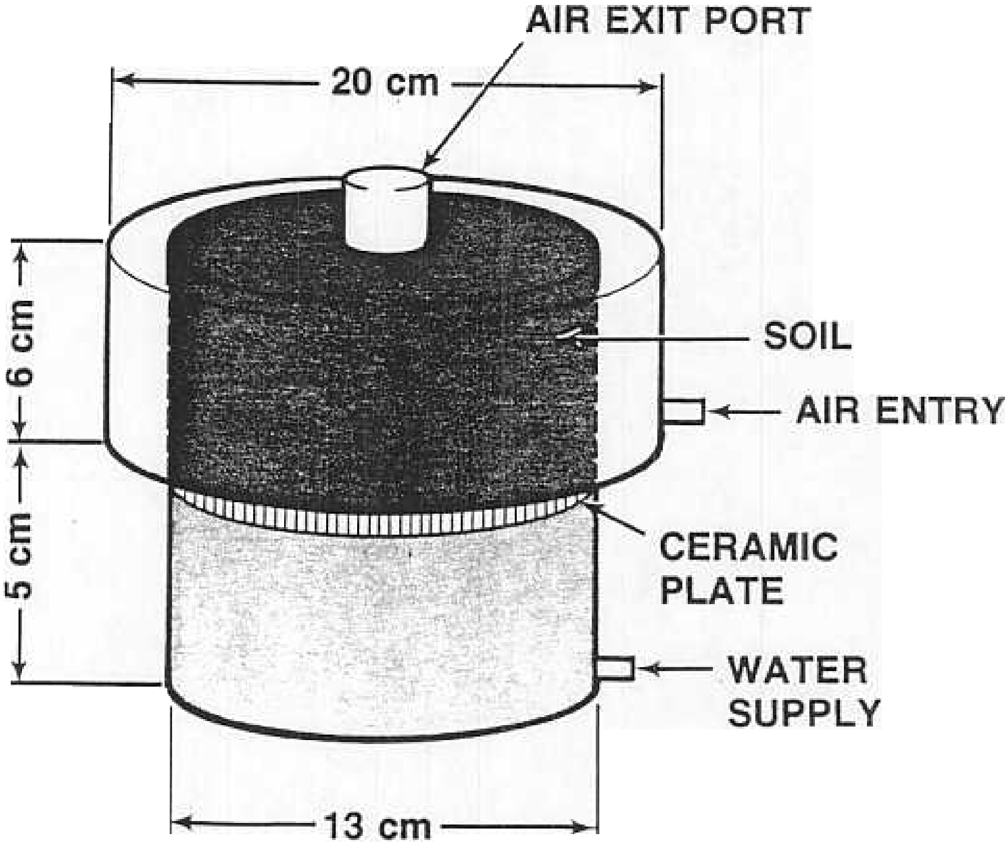

Fig. 2. Flow-through chamber used in the laboratory study to assess ammonia volatilization from poultry manure.

Table 2. Properties of the hen manure used in the ammonia volatilization studies.

Study	% Solids	pH	NH_4	NO_3	Total
			g N/kg dry manure		
Laboratory	35	8.1	17	0	64
Field	38	7.6	4	0	54

H_2SO_4. After flowing through the chambers, the air passed through a test tube which contained 20 ml of 1.0 M H_2SO_4 The tubes on the trap were changed at approximately 12-h intervals, and an aliquot was removed for NH_3 determination by steam distillation (Keeney and Nelson, 1982). The incubation was conducted for 10 days

After incubation, the soils were removed from the chamber, thoroughly mixed, and portions extracted with 2 M Inorganic-N was determined from these extracts following the methods described by Keeney and Nelson 1982). Two replications of each treatment were made

Static chambers were used in the field study (Fig. 3) and have been described in detail by Reynolds and Wolf (1988). In the study, hen manure application rates were 0, 3.4, and 6.8 Mg/ha on a dry weight basis. The study was conducted for 11 days at 32 $\pm 10^{o}$C. The soil moisture potential was -15 kPa

C Denitrification

The soi used was a Captina silt loam, and samples were obtained at a depth of 0 to 15 cm from a bermudagrass (*Cynodon dactylon* L. pasture. The soil was passed through a 2-mm sieve and was stored at field moisture levels at 2^{o}C in sealed polyethylene bags until used Twenty-gram samples of soil were placed in 50-ml Erlenmeyer flasks and amended with poultry litter at rates of 0 or 9 Mg/ha Analysis of the litter has been

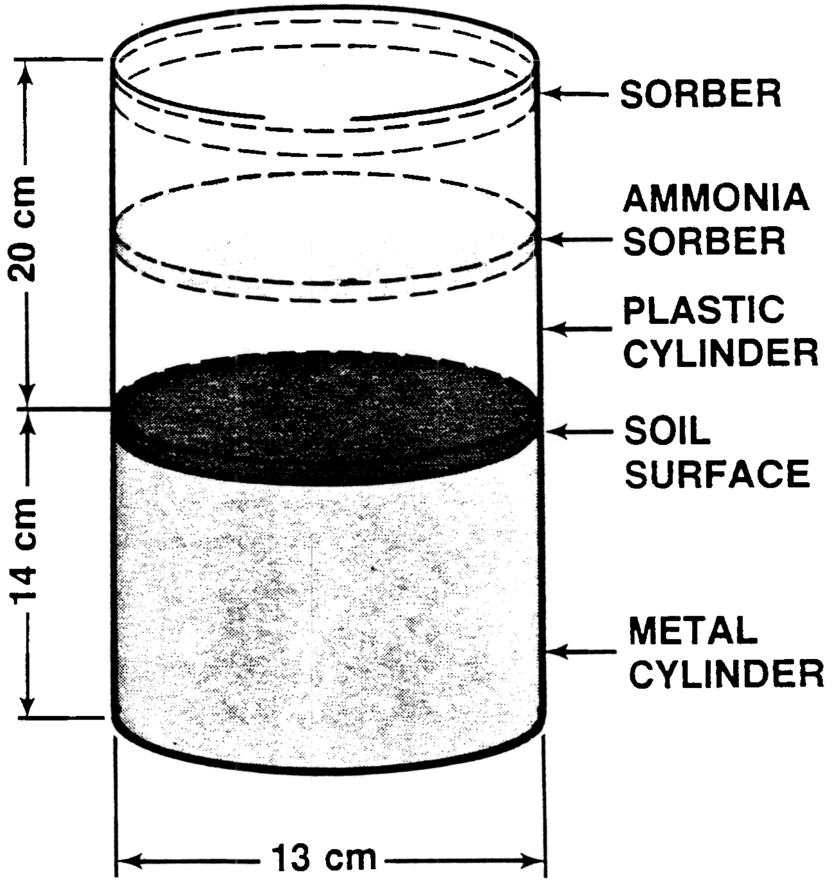

Fig. 3. Static chamber used in the field study to assess ammonia volatilization from poultry manure.

previously reported by Gale and Gilmour 1986) and is given in Table 3. Distilled water was added to adjust the moisture content of the soil to a moisture potential of -30 kPa which corresponded to 18% by weight (Thiesse, 1984). The flasks were incubated under aerobic conditions for 0, 72, 120, and 168 h. After each aerobic incubation interval, 5 ml of distilled water was added to achieve flooded or anaerobic soil conditions and the flasks were incubated for an additional 48 or 66 h. All incubations were conducted at 21°C in the dark. After the appropriate incubation time, flasks were analyzed for pH, total soluble organic carbon TOC), NH_4-N, and NO_2+NO_3-N. The pH was measured in a 1:1 soil to solution ratio. The TOC was measured with a PHOTOchem Organic Carbon Analyzer. Samples were prepared by adding water to obtain a 1:1 ratio, shaking for 1 h, centrifuging the extract for 10 min at 4,000 RPM, and filtering the extract through a 0.22-um membrane filter. Exchangeable NH_4-N and NO_3-N were determined by extraction of the soil with 2N KCl and steam distillation using MgO and Devarda's alloy (Keeney and Nelson, 1982).

PRINCIPAL FINDINGS AND SIGNIFICANCE

A. Nutrient Variability

The percentage solids of the 12 samples had a mean value of 340 g/kg with a standard deviation of ±2.5% which agrees with the 35.8% reported by Chescheir et al. 1986) for caged layers. The

Table 3. Chemical characterization of the poultry litter used in the denitrification study (Gale and Gilmour, 1986).

Property	Units
	g/kg
Total C	404
Organic N	45
NH_4-N	6
NO_3-N	0

pH values of the wet and dry manure were 7.6 and 6.3, respectively. The total C of the dried manure was 321 g/kg.

As determined by the sample analytical procedure, the total N content of the wet manure significantly decreased when the samples were dried prior to analysis with values of 57 and 40 g N/kg, respectively (Fig. 4). On the dried manure samples using the H_2SO_4-H_2O_2 digestion procedure, the total N content was 36 g/kg which was not significantly different from the 40 g N/kg value determined by the procedure of Bremner and Mulvaney (1982). The H_2SO_4-H_2O_2 digestion procedure increased the variability of the total N determinations in the dry manure Fig. 5)

The inorganic N in the manure was in the ammoniacal form with the NO_2+NO_3-N levels in all samples < 1 g N/kg. The NH_4-N content in the wet manure varied from 8 to 30 g N/kg with a mean of 19 g N/kg (Fig. 6). When the manure was dried, the NH_4-N level decreased to a mean value of 2 g N/kg which indicated a substantial N loss due to ammonia volatilization. Giddens and Rao (1975) reported that fresh poultry manure lost 47.6% of the total N content when the manure was air dried for 10 days and 23.6% when dried in a boiling water bath.

Chescheir et al (1986) reported that NH_4-N was 23% of the total N in fresh poultry manure and the value increased to 36% after 3.5 days. Bitzer and Sims 1988) recently pointed out the

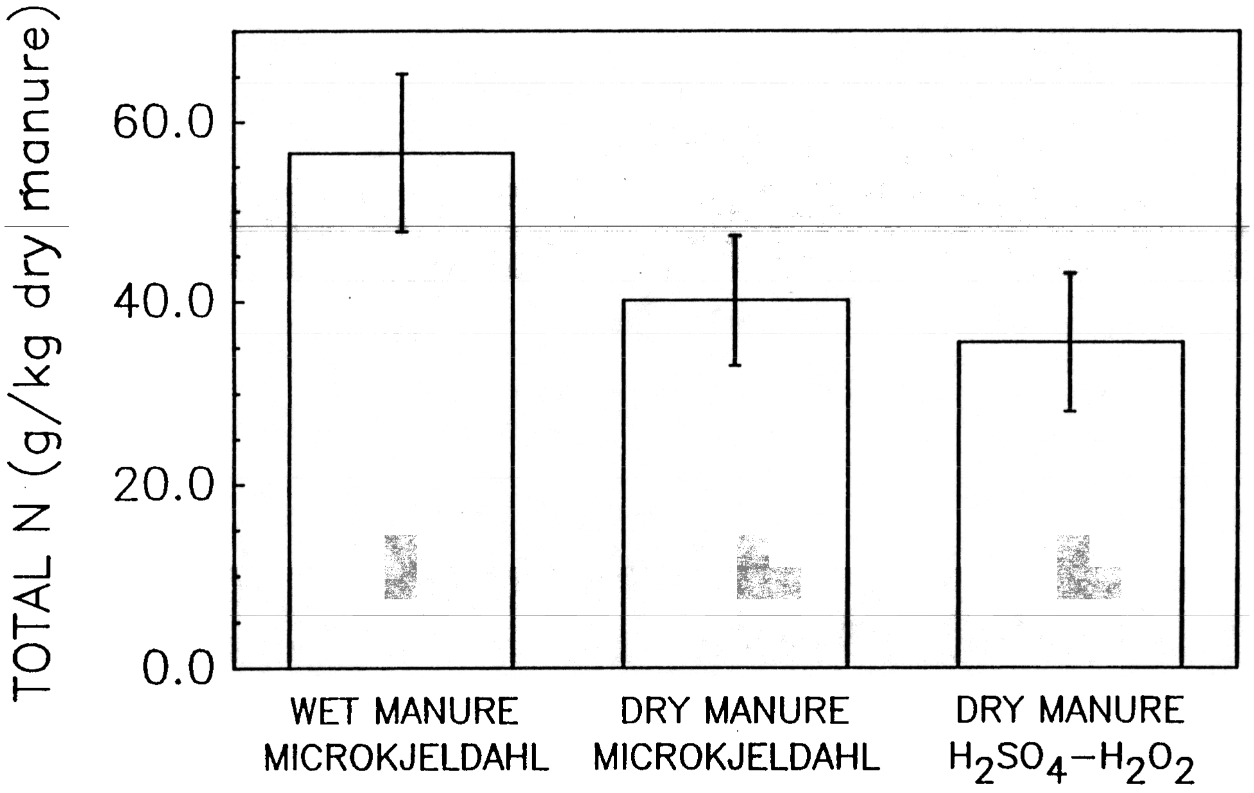

Fig. 4. Influence of method of digestion on the total N content of manure

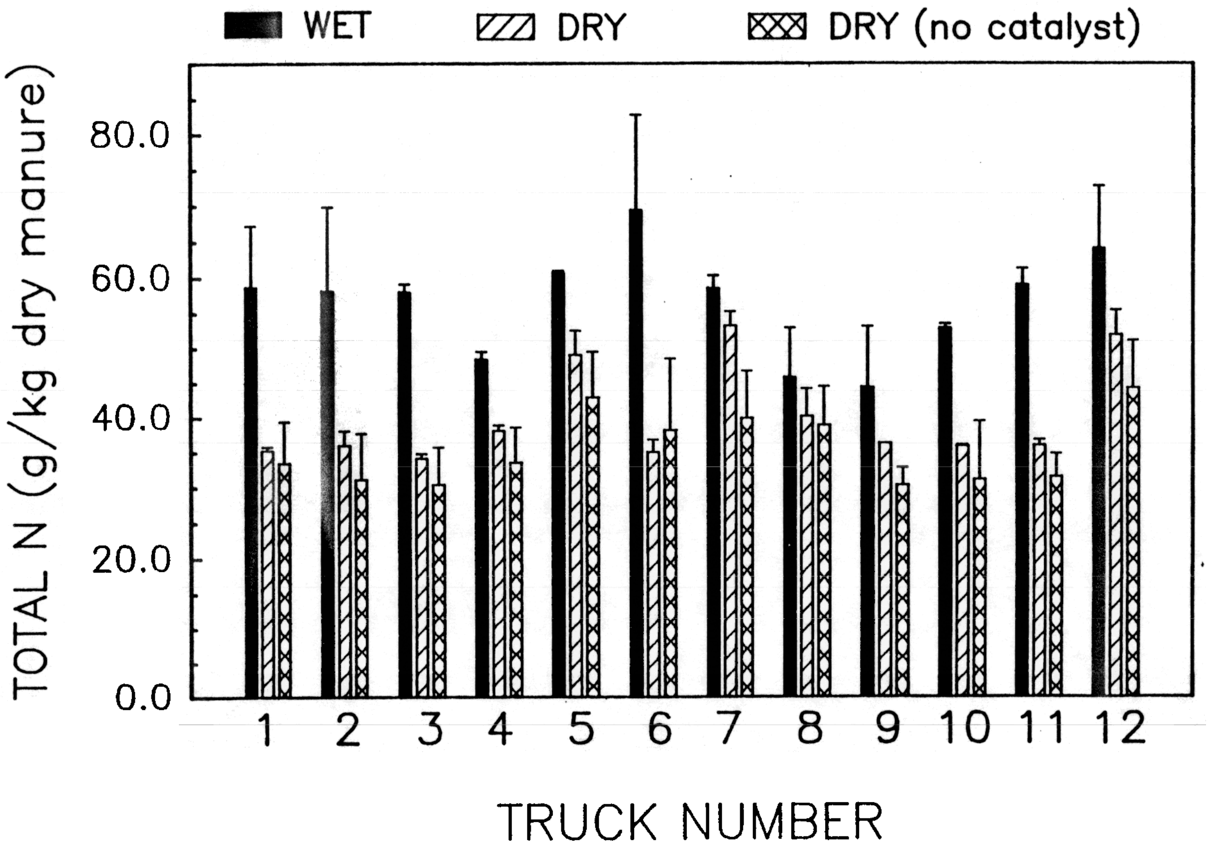

Fig. 5. Influence of method of digestion on the total N analysis of 12 wet and dry manure samples.

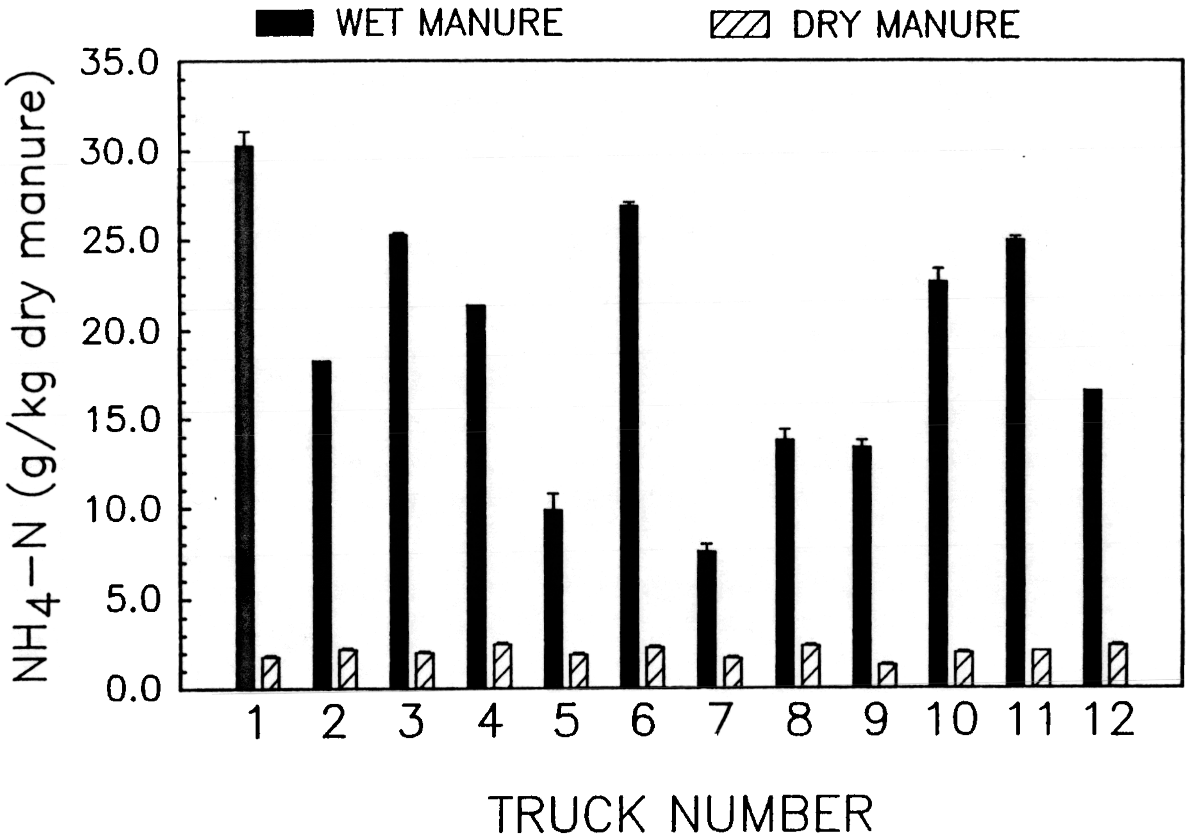

Fig. 6. Variation in the NH_4-N content of 12 wet and dry manure samples.

difficulties in accurately estimating the levels of inorganic N in poultry manure Substantial N losses have been reported for other animal wastes Dairy manure has been shown to lose from 40 to 60% of the total N content at 25°C largely through ammonia volatilization (Adriano et al., 1974; Muck and Richards, 1983).

The mean P contents of the manures were 23.8 and 24.5 g/kg for the wet and dry samples, respectively, and were not significantly different (Fig. 7). The variation in the P level was significantly less in the dry compared to the wet samples. The levels are similar to data reported by Bitzer and Sims 1988) who analyzed 20 poultry manure samples which contained litter and reported a mean P content of 20.9 g/kg for oven-dried samples

The K levels of the wet and dry manure were 19.4 and 21.7 g/kg, respectively, and were not significantly different (Fig 7 The variation in K content was significantly less for the dry compared to the wet samples.

The concentrations of Ca were not significantly different between the wet and dry samples at 92.6 and 85.7 g/kg, respectively, and had very similar variances (Fig. 7). The Mg levels for wet and dry manure samples were 5.4 and 5.7 g/kg, respectively, and were not significantly different. The wet manures had a mean S content of 5.1 g/kg, which was not significantly different from the 5.2 g/kg found in the dry samples, and both samples had similar variances (Fig 7)

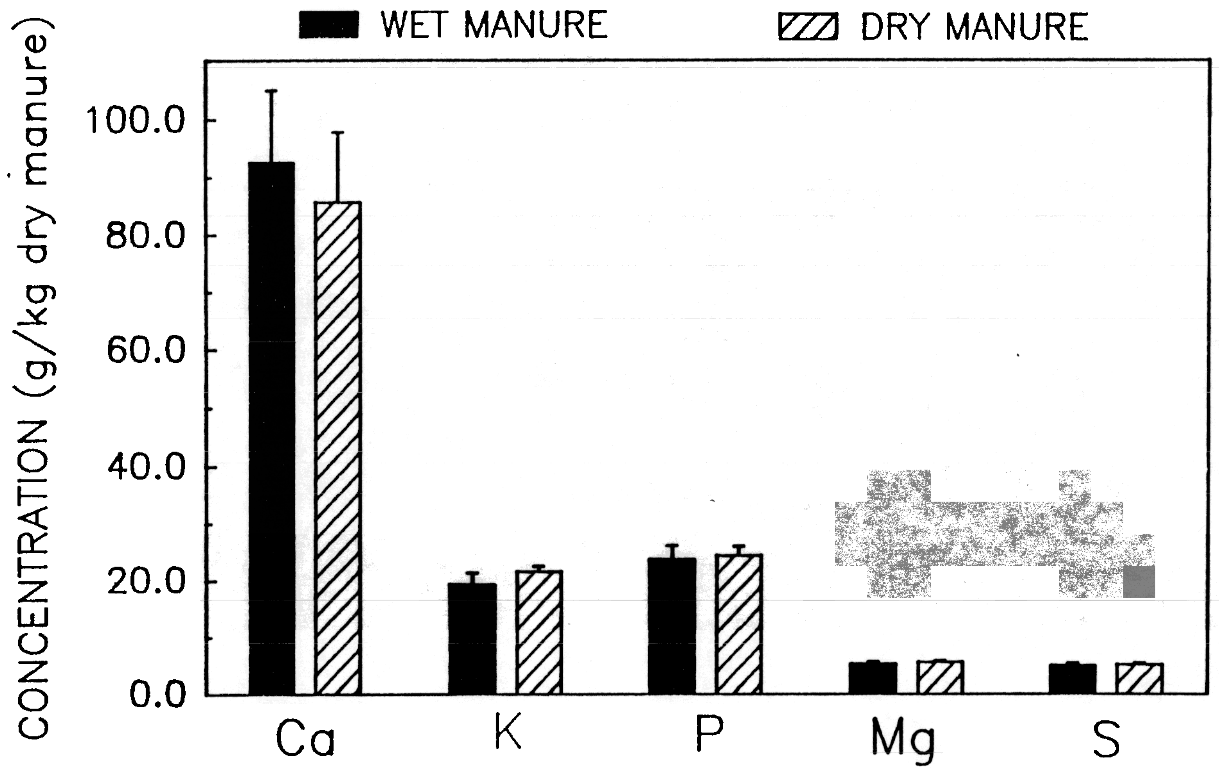

Fig. 7 The Ca, K, P, Mg, and S concentrations of wet and dry manure samples.

B. Ammonia Volatilization

In the laboratory study, the percentage of N applied which was volatilized as NH_3 from the surface-applied manure was maximal from day 3 to 8 of the incubation (Fig. 8). Total N loss as accounted for 37% of the N applied. When manure was incorporated, the N loss as NH_3 was 8%. Following the study, analysis of the surface-applied manure indicated that the pH decreased from 8.1 to 7.7, solids increased from 35 to 55%, and total N decreased from 64 to 27 g N/kg dry manure as compared to initial values (Table 2).

Soil analysis after the 10-day laboratory incubation showed 4% of the applied N was recovered as NO_3-N and that NH_4-N accumulation was greater in the incorporated treatment Table 4). The pH values at the soil surface were 5.9, 6.6, and for the control, surface-applied, and incorporated treatments, respectively.

The total net N balance indicated a high recovery of the applied N when the manure was surface applied (Table 4) When manure was incorporated, 40% of the applied N was recovered and denitrification was hypothesized as the mechanism of N loss.

When the manure was surface-applied in the field study at rates of 3.4 and 6.8 Mg/ha, 37% of the total N applied was lost by volatilization at either rate. The loss was most rapid in the 2 days following application (Fig. 9). At both manure addition

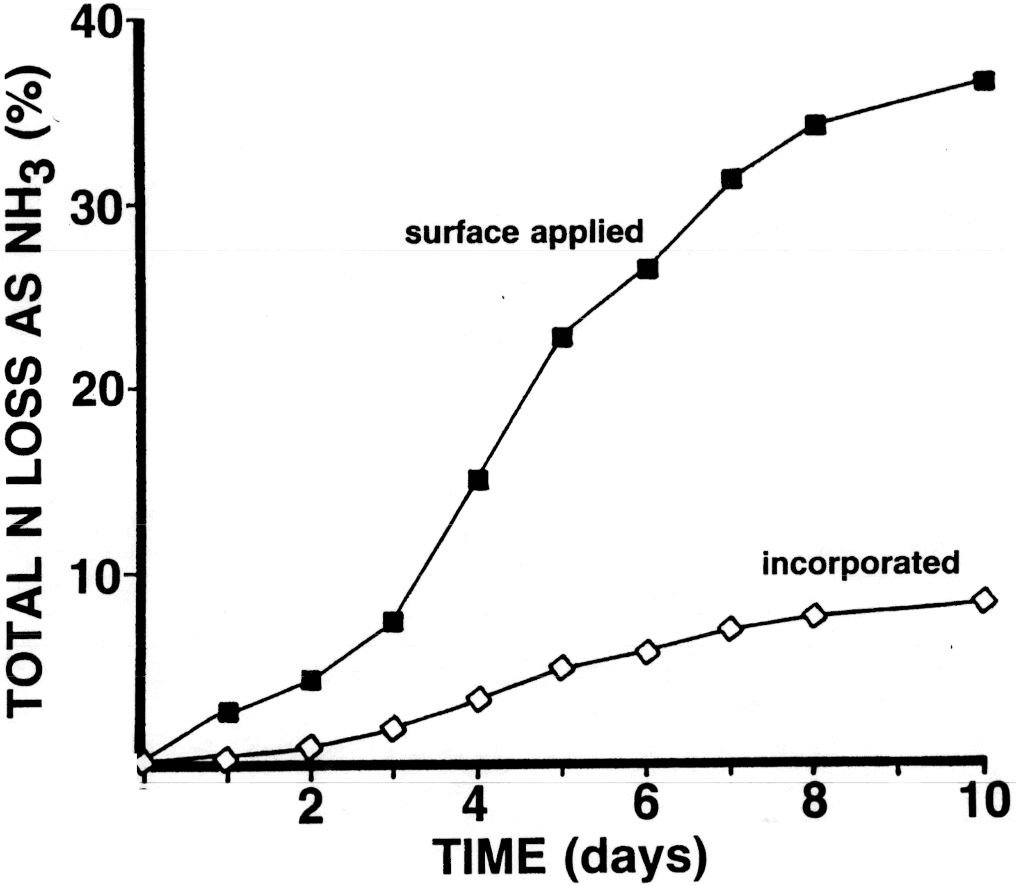

Fig. 8. Percentage of the total N applied which was volatilized as ammonia during a 10-day laboratory study. The manure was surface applied or incorporated at a rate of 6.8 Mg/ha on a dry weight basis.

Table 4. The forms and net nitrogen balance of the manure-amended soil in a laboratory study.

Treatment	N Recovered (%)					
	Soil			Manure	Volat.	Total
	NH_4	NO_3	Total	Total	NH_3	Recov.
Surface-applied	11 b*	4	16 b	42	37 a	95 a
Incorporated	20 a	4	32 a	--	8 b	40 b

* Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

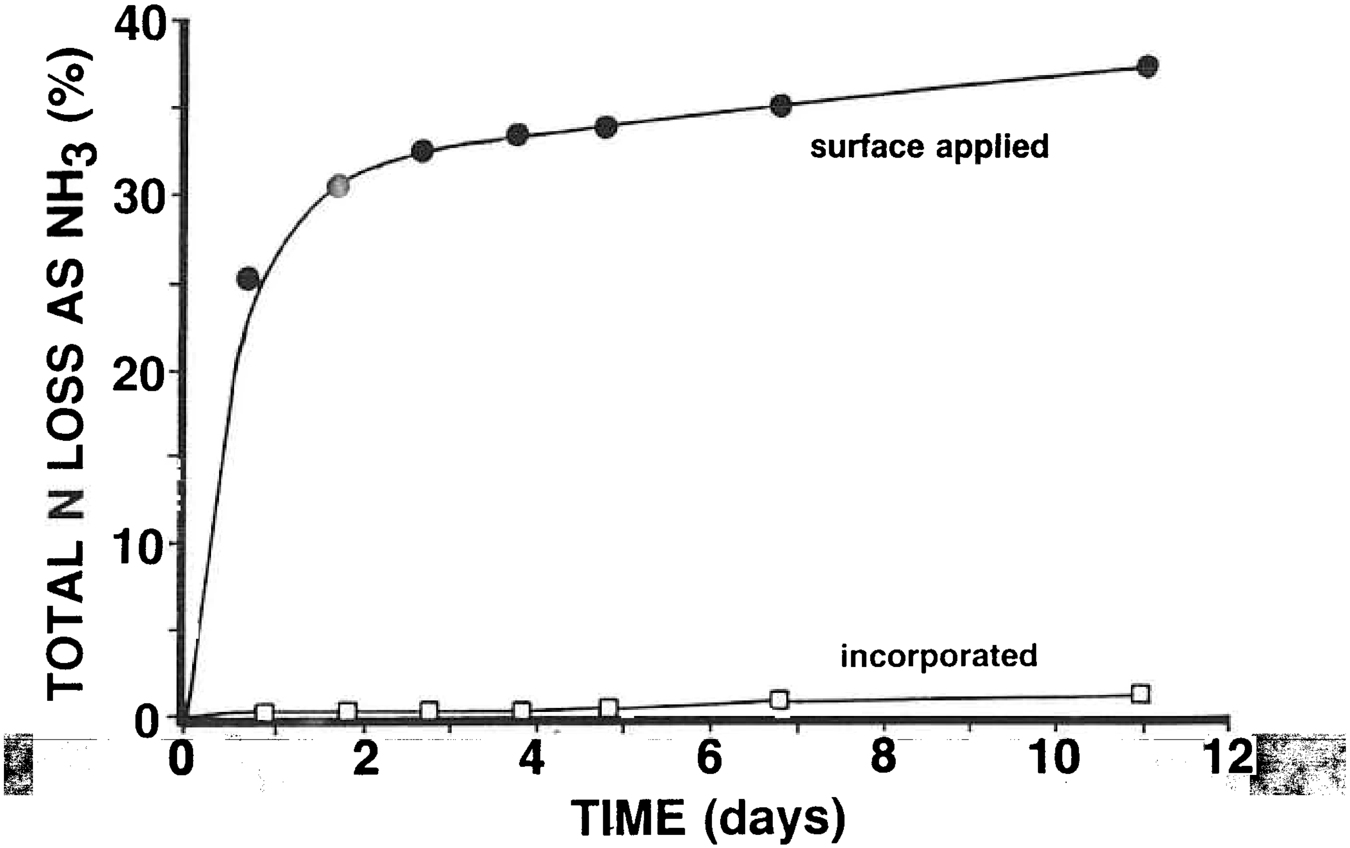

Fig. 9 Percentage of the total N applied which was volatilized as ammonia during an 11-day field study. The manure was surface applied or incorporated at rates of 3.4 and 6.8 Mg/ha.

rates, only 1% of the applied N was lost as NH_3 when the manure was incorporated to a depth of 11 cm. The surface-applied manure dried during the incubation and had a final pH of 7.7

The soil with the incorporated manure contained more than twice as much NH_4-N as the soil with the manure surface-applied Table 5). The total N recovered in the soil ranged from 35 to 52%, and the pH values at the soil surface were 6.0, 6.8, and 6.3 for the control, surface-applied, and incorporated treatments, respectively.

Compared to that of the laboratory study, the total net N balance of the field study indicated that more N was recovered in the soil and slightly less N in the manure (Table 5). The total N recovered was also slightly higher in the field study. When the manure was incorporated, the total N recovered was approximately 50%. This result was in general agreement with that of the laboratory study

C. Denitrification

Results from the denitrification study showed litter addition increased the TOC level substantially throughout the incubation (Table 6) After 168 h of aerobic incubation, litter addition resulted in a net increase of 23 mg NO_3-N/kg soil compared to the control. A subsequent 66 h of flooding or anaerobic conditions resulted in a decrease from 45 to 6 mg/kg in NO_3-N The data show that when litter is added to soil, the NH_4-N must

Table 5. The forms and net nitrogen balance of the manure-amended Bowie fine sandy loam in the field study.

		N Recovered (%)					
Treatment	Rate Mg/ha	Soil			Manure Total	Volat. NH_3	Total Recov.
		NH_4	NO_3	Total			
Surface-applied	3.4	5 b*	13 bc	41	37	37 a	115 a
	6.8	10 b	9 c	35	34	37 a	106 a
Incorporated	3.4	13 b	19 a	52	--	1 b	53 b
	6.8	28 a	16 ab	48	--	1 b	49 b

* Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 6. Influence of incubation time and moisture level on the pH, total soluble organic carbon, and inorganic nitrogen levels in a Captina soil amended with 0 and 9 Mg/ha poultry litter.

Treatment						
Litter Rate	Aerobic Pre-incubation	Flooded Incubation	pH	TOC	NH_4-N	NO_3-N
Mg/ha	-------h--------			-----mg/kg soil----		
0	0	0	6.1	37	3	12
0	0	48	6.3	64	5	2
0	0	66	6.2	61	11	0
9	0	0	6.3	122	36	14
9	0	48	6.6	123	75	0
9	0	66	6.5	103	93	0
0	72	0	6.1	44	2	18
0	72	48	6.0	40	2	16
0	72	66	6.3	42	11	1
9	72	0	6.0	64	45	27
9	72	48	6.3	80	51	6
9	72	66	6.5	73	53	1
0	120	0	6.0	34	3	19
0	120	48	6.1	35	2	15
0	120	66	6.0	36	7	15
9	120	0	6.1	73	40	33
9	120	48	6.2	67	56	23
9	120	66	6.1	52	40	20
0	168	0	6.1	34	1	22
0	168	48	6.1	45	2	18
0	168	66	6.2	21	7	12
9	168	0	6.1	71	40	45
9	168	48	6.4	68	54	13
9	168	66	6.3	77	61	6

be oxidized to NO_3-N under aerobic conditions, and this oxidation must be followed by anaerobic conditions or oxygen depleted microsites and microbially available C must be present if denitrification is to proceed. If the required conditions are present, denitrification can be a rapid process

CONCLUSIONS

Drying fresh hen manure at 65°C resulted in loss of NH_4-N which lowered the TKN an average of 29% compared to that of wet manure. Drying did not affect analyses of P, K, Ca, Mg, and S contents. Variability of nutrient content was much greater in wet compared to dry manure Due to the variable nature of hen manure, representative samples must be thoroughly homogenized and analyzed in the wet state for estimation of N content for efficient land application. In studies with manure, conditions of manure handling and analysis must be carefully evaluated and reported.

In a field study, 37% of the total N in the surface-applied manure was lost as NH_3 after 11 days. In a 10-day laboratory incubation, 37% of the total N was also lost as NH_3-N. When the manure was incorporated, NH_3 losses were 1 and 8% in the field and laboratory studies, respectively. The results indicated that substantial amounts of N in surface-applied hen manure can be lost by NH_3 volatilization, and better management procedures are needed to more efficiently use the manure as a nitrogen fertilizer

When nitrate is formed in litter-amended soils, introduction of anaerobic conditions can result in denitrification activity if C is present in forms available to the soil microbial population conditions do exist and indicate that denitrification may reduce the potential for nitrate to enter ground and surface waters

Understanding the nutrient variability of poultry waste and rate and magnitude of ammonia volatilization and denitrification are important in determining poultry waste application rates which enhance forage production and protect the quality of ground and surface water.

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