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ABSTRACT

Quantification of nutrient and mass loss during composting is needed to understand the composting process, to implement methods for nutrient conservation, and to reduce potential adverse environmental impact. Beef cattle feedlot manure was composted in a windrow on an open concrete area in 1992, 1993, and 1994 to determine the amounts of nutrient, C, and mass loss during composting. The area was enclosed on all sides with a 0.2 m high metal sheet to direct runoff to a fiberglass tank (4000 L) during rainfall. Nutrients in runoff represented combined runoff and leaching losses. Nutrients, C, and mass loss during composting was determined by the difference between the amounts at the beginning and at the end of the composting. Nitrogen loss during composting ranged from 19 to 42% and was related to the initial manure N content. Ammonia volatilization (calculated by difference) accounted for >92% of the N loss whereas combined runoff nitrate and ammonium loss was <0.5%. Mass loss was relatively low (15-20%) while C loss ranged from 46 to 62% and was basically all through bio-oxidation. Phosphorus runoff loss, the main mechanism for P loss, was low (<2%). Manure N/P ratio decreased during composting, indicating a greater soil P buildup potential with compost application. Potassium and Na losses in runoff were high (>6.5% each) in 1992 and 1993; they were low (<2% each) in 1994 due to fewer rainfall. Calcium and Mg losses were <6% each year. Nutrient and salt loss during composting resulted in reduced electrical conductivity of the composted manure. Ammonium and P concentrations in runoff would create surface water pollution if runoff was not diluted with fresh water.

About 11 million head of cattle and calves are on feed at any time in the USA (USDA, 1993). About two-thirds of the beef cattle feeding in the USA occurs in Nebraska, Texas, Kansas, Iowa, and Colorado. More than 80% of the fed cattle are produced in feedlots of more than 1000 head capacity (Eghball and Power, 1994). Feeder cattle weighing 230 to 320 kg are normally purchased by or consigned to the feedlot operator, placed on high energy feed for 100 to 180 d, and slaughtered at 450 to 550 kg. Manure is normally cleaned from beef feedlots when animals are marketed or once each year. Manure collected from feedlot is somewhat stable since it has been on the feedlot surface for a long period of time. Typically, in the central and southern Great Plains, manure scraped from beef feedlots becomes mixed with as much as 50% soil and has lost about 50% of its original N content (Eghball and Power, 1994). About 26.4 million Mg of manure is collected annually from all feedlots in the USA. Nitrogen, P, and K in the feedlot manure, if all collected and utilized, would have a value of $461 million (Eghball and Power, 1994).

Composting manure is a useful method of producing a stabilized product that can be stored or spread with little odor, pathogens, weed seeds, or fly breeding potential (Sweeten, 1988). Composted manure can be applied to soil as an odorless and relatively dry source of nutrients compared with noncomposted manure. Another advantage of composting is improved handling characteristics of manure by reducing volume and weight (Willson and Hummel, 1975). Decomposition of manure occurs through biological action and spontaneous chemical reactions. The initial chemical and biological composition of manure is a function of ration fed, animal age, type of feedlot, and other factors that can influence manure production and decomposition.

In composting, N loss through volatilization can be a major problem. The main factors influencing gaseous N loss are total N content of material, temperature, high pH (>8), and turning (Martins and Dewes, 1992). In a constant temperature/humidity chamber, ammonia volatilization during composting of cattle manure resulted in a 35% decrease in ammonium-N content but total N content was not significantly changed (Stone et al., 1975). Hansen et al. (1993) reported ammonia loss during composting of poultry manure in reactor vessels to be three times greater with a C/N ratio of 15 compared with 20. In composting mixtures of straw and various kinds of liquid manure (swine, poultry, and cattle) in containers, between 46.8 and 77.4% of the initial N was lost, primarily as ammonia with a small amount (<5%) as NO_x (Martins and Dewes, 1992). Nitrogen loss during composting of a sewage sludge–straw mixture resulted primarily from ammonia volatilization (Witter and Lopez-Real, 1988). In the initial stages of composting, the N loss amounted to 16 to 29% of the initial N content, whereas it was >60% when composting a lime-conditioned sludge with higher initial N content. Compared to fresh manure, 3-mo stabilized farmyard manure had significantly greater concentrations of total N, water-soluble substances, and lignin, and less organic C, lipid, and hemicellulose, as well as a lower C/N ratio (Levi-Minzi et al., 1986).

Nitrogen can also be lost from manure in runoff and by nitrate leaching during composting. Relative quantities of N lost by these processes are controlled mainly by site-specific conditions. Ott et al. (1983) found high K loss (28%) during composting of farmyard manure through leaching, while nitrate concentration in the leachate was low enough (8 mg NO_3–N kg^{-1}) not to create an environmental problem. Since N losses are less than the reduction in volatile solids due to bio-oxidation, total N concentration during composting usually increases.

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Nutrient loss, specifically N, P, and K losses, reduces potential of compost as a plant nutrient source. Quantification of amount of nutrient and mass loss during composting in field conditions is important to understanding the composting process and implementing methods for conservation of nutrients to reduce potential adverse environmental impacts. Total and runoff loss of nutrient, carbon, and mass during composting of beef cattle feedlot manure has not been quantified. The objective of this study was to determine the amount of nutrient, carbon, and mass loss during composting of beef feedlot manure under field conditions.

MATERIALS AND METHODS

Beef cattle feedlot manure was composted in a windrow on a concrete area at the University of Nebraska Agricultural Research and Development Center near Mead in the summers of 1992, 1993, and 1994. Manure was collected from an unpaved feedlot with a concrete apron behind the feed bunks. Manure was composted in a windrow 3 m wide, 10 m long, and 1 m high each year. The compost area was enclosed on all sides with a 0.2-m high metal sheet to drain the runoff and leachate to a fiberglass tank (4000-L capacity) through drainage pipes. The amount of runoff and leachate were measured volumetrically and a representative sample was taken for chemical analysis within 24 h of each rainfall. Samples were analyzed for electrical conductivity, pH, dry matter, nitrate, ammonium, total Kjeldhal N, soluble P, and total P, K, Na, Mg, and Ca. A rain gauge was placed near the compost site to determine the amount of rainfall for each event and a sample of rain water was collected for the above chemical properties in 1992. Because nutrient concentration of rain water was not significant, we did not collect rain samples in 1993 and 1994. Dry weight of the material being composted was determined at the beginning and at the end of the process. The manure was analyzed both before and after composting for total N, C, P, K, Na, Ca, Mg, and NO_3-N, NH_4-N, pH, EC, available P (Bray and Kurtz no. 1), and ash content. Total amounts of mass and nutrient lost during composting were determined by the difference between the amounts at the beginning and at the end of the composting period. The amount of manure and nutrient loss by runoff was determined by measuring amounts in the water collected. Because leaching was eliminated, mass of materials collected in the tank would represent potential loss by both runoff and leaching.

A model-3 CSIRO data logger with six temperature sensors was used to determine the temperature of the composting manure at depths of 0.25, 0.55, and 0.85 m within the 1-m high composting pile. The material was mixed with a front-end loader every 7 to 10 d or as required, based on temperature status of the composting material. Water was added to the composting windrow when the moisture level fell below 40%.

RESULTS AND DISCUSSION

Nutrient contents of beef cattle feedlot manure before and after composting in 1992, 1993, and 1994 are given in Table 1. Available P was about 22% of total P for both composted and noncomposted manure, while combined nitrate and ammonium as a proportion of total N was 2.2% for noncomposted and 3.1% for composted manure.

In 1992, the manure mass loss during 110 d of composting was 20% of initial mass (Table 2). The mass loss was lower than the normal range of 35 to 50%, because the feedlot manure contained a relatively large amount of soil (59% ash) and a relatively smaller amount of carbon. A carbon source was not added to the manure, because this is not the common practice for composting beef feedlot manure as it is removed from the feedlot. Nitrogen loss during composting in 1992 was 42.5% of the initial manure N, while C loss was 62% (Table 2). Of the total amount of N lost, 3.2% was removed by runoff and 96.8% was apparently volatilized. Volatilization losses were estimated by the difference between total and runoff N losses. Some loss of N as a result of denitrification during composting may also occur. However, denitrification requires the manure to be saturated, and since we kept the composting manure at 40 to 60% water content throughout the period, denitrification of N was probably minimal.

Phosphorus loss during composting in 1992 was 0.8% of initial manure P, all of which was accounted for in the runoff (Table 2). Unlike N, runoff loss is the main mechanism of P loss during composting. Potassium and Na losses during composting were 15.8 and 15.5% of initial manure K and Na, respectively, while Ca and Mg losses were each <2%.

In 1993, manure mass loss during composting was 14.9% (Table 2). Carbon loss was 45.9% of initial manure C, and N loss was 19.3% of initial N. Phosphorus runoff loss in 1993 was 2.2% of initial manure P (Table 2). Potassium and Na losses during composting were 11.3 and 13.7% of initial manure K and Na, respectively.

Table 1. Concentration of nutrients (on dry wt. basis) and ash, electrical conductivity (EC), and pH in the feedlot manure before and after open composting in open windrows in 3 years.

Variable	Total N	NO_3-N	NH_4-N	Available P†	Total P	Total C	Total K	Total Na	Total Ca	Total Mg	Ash	EC‡	pH‡
	g kg^{-1}											dS m^{-1}	
1992													
Initial manure	15.2	0.03	0.85	1.53	6.84	197.7	11.1	2.0	10.5	4.5	587	12.1	7.4
Composted	11.0	0.12	0.17	1.64	8.74	95.6	11.8	2.2	13.0	5.6	808	7.4	7.7
1993													
Initial manure	8.1	0.00	0.02	0.63	3.06	137.4	11.0	0.7	6.9	3.8	700	3.4	8.9
Composted	7.7	0.04	0.03	0.63	3.15	87.4	11.4	0.8	8.0	4.2	796	2.1	8.3
1994													
Initial manure	9.3	0.03	0.03	0.79	3.15	111.4	8.4	1.1	12.3	4.6	770	1.2	7.6
Composted	7.6	0.38	0.06	1.10	4.07	73.5	9.3	1.1	14.3	5.5	849	1.2	7.4

† Bray and Kurtz number one *P* test.
‡ EC and pH were determined on 2:1 manure or compost to water ratio.

Table 4. Nutrient concentration, solid, pH, and electrical conductivity (EC) of runoff collected from composting beef feedlot manure open windrow in 1993.

Composting days	Rain	Runoff	Solid	pH	EC	Total N	NO_3-N	NH_4-N	Soluble P	Total P	Total K	Total Na	Total Ca	Total Mg
	cm	L	g kg^{-1}		dS m^{-1}	mg kg^{-1}								
6	1.8	250	0.6	7.2	0.5	15	0.1	1.4	8.6	16	115	17	17	6
9	3.0	930	1.3	7.1	0.5	17	0.2	25.7	7.8	17	116	15	17	5
14	2.9	950	1.0	7.1	0.4	17	0.2	3.3	6.4	13	90	10	16	3
18	1.1	110	1.0	7.3	0.6	19	0.0	5.2	11.7	23	134	17	23	5
22	8.8	4160	3.4	7.6	1.8	77	0.4	14.7	9.5	32	427	58	38	17
23	3.5	1870	2.5	7.6	1.8	67	0.3	11.0	11.5	35	447	56	39	19
25	1.4	440	1.5	7.6	1.2	48	0.2	7.1	8.6	30	301	40	28	13
43	1.1	340	4.8	7.3	0.7	76	0.1	7.7	9.6	27	174	19	23	8
51	6.4	2370	1.6	7.6	0.9	46	0.2	14.1	24.0	42	182	26	38	13
60	0.6	150	1.4	7.3	1.0	30	3.0	1.0	8.6	27	231	32	21	9
64	3.7	1550	1.5	6.9	1.1	41	0.7	3.5	10.2	32	271	38	28	14
82	3.7	1020	1.5	7.5	1.2	34	1.8	2.6	10.5	19	270	37	28	11
85	1.5	380	1.0	7.4	0.6	22	1.3	1.3	6.5	15	123	18	13	4
90	1.9	380	0.9	7.4	0.7	18	1.6	0.9	7.2	18	170	24	14	5
107	1.7	250	0.6	7.5	0.3	9	0.9	0.9	4.4	9	55	11	14	3

total P in runoff was 23.7 mg kg^{-1} in 1993 and 17.0 in 1994 (average of all samplings). Total P concentration in 1992 was even higher than in 1993 and 1994. Except for two samplings in 1992 and 1994, nitrate concentration of runoff from the compost pile was <10 mg kg^{-1} (Tables 3, 4, and 5). In a field situation, some of this nitrate would have leached into the soil. Nienaber and Ferguson (1994) found nitrate-N content of 2500 kg ha^{-1} per 7.6-m depth under a site used for composting for 9 yr. They also observed nitrate movement to a depth of 2 m beneath a composting site after only 2 yr of composting activity. Nitrate has a potential of reaching the groundwater if not utilized by growing plants. Ammonium concentrations of leachate were higher than 2.5 mg kg^{-1} level at all sampling times in 1992 and 1994 and in most sampling times in 1993 (Tables 3, 4, and 5). Ammonium-N concentrations >2.5 mg kg^{-1} may be harmful to fish (USEPA, 1973). Potassium and Na concentrations in runoff were also high and may have adverse effects on soil structure.

Temperature reached 65°C (149°F) within 24 h of starting the composting process at all depths within the compost pile in 1992 (Fig. 1). A temperature of 55°C for 3 d is necessary to destroy the pathogens in the compost while critical temperature for killing most weed seeds is 63°C (Rynk et al., 1992). Temperature was consistently lower at all compost depths in 1993 than in 1992 and reached 55°C only for a short period at the 55-cm depth within the compost. The difference is probably due to lower manure C and N concentrations in 1993 than in 1992 (Table 1). Significant drops in temperature indicate the times when the windrow was turned. Around Day 65, the temperature decreased to 40°C (104°F), indicating the end of the thermophilic process in both years. After this, the windrow was no longer turned, and the material was allowed to cure for an additional 45 d. After this period, the temperature of the composted material was near ambient. In 1994, because of technical difficulties, we were unable to determine temperature for the entire composting period. However, manure temperature reached 65°C after 2.5 d of composting at the 85- and 25-cm depths within the composting pile (data not shown). About 110 d was necessary for completion of the composting process each year.

CONCLUSIONS

Nutrient loss, specifically N, can be a major problem in composting of feedlot manure. As much as 40% of total manure N can be lost during composting. Nitrogen loss during composting was related to total N content of manure. The C/N ratio of manure had a smaller effect on N loss. Losses of K and Na in runoff and leachate from the composting manure can also be substantial in years with large numbers of rainfall events. Phosphorus loss during composting was small and resulted mainly through runoff. Reduced electrical conductivity after composting in 1992 and 1993 indicated that loss of nutrients reduced salt content of the manure. Temperature necessary to destroy pathogens and weed seeds were generated within the compost in 1992 and 1994. These temperatures were not routinely obtained in 1993 because of the low C and N content of manure being composted. Runoff and leaching from composting sites may be a significant contributor of N, P, K, and Na to surface and ground waters. Because of N, K, Na, and C loss

Table 5. Nutrient concentration, solid, pH, and electrical conductivity (EC) of runoff collected from composting beef feedlot manure open windrow in 1994.

Composting days	Rain	Runoff	Solid	pH	EC	Total N	NO_3-N	NH_4-N	Soluble P	Total P	Total K	Total Na	Total Ca	Total Mg
	cm	L	g kg^{-1}		dS m^{-1}	mg kg^{-1}								
5	2.1	265	2.4	6.8	0.9	25	0.3	7.0	10.8	15	151	52	42	14
29	1.3	265	7.0	7.3	1.5	114	0.3	19.6	10.9	22	268	81	47	20
44	2.5	475	1.6	6.9	1.1	35	8.7	11.0	8.9	11	219	56	23	12
55	3.8	1230	3.7	7.1	0.9	72	8.6	19.2	12.6	23	253	65	23	16
72	5.8	1225	1.6	7.0	0.7	30	25.1	5.0	12.1	14	212	58	27	16

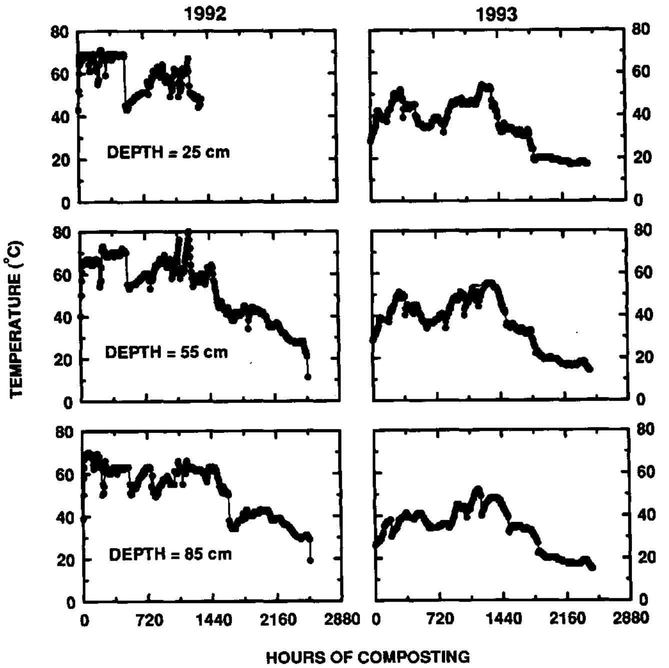

Fig. 1. Temperature of the feedlot manure composting windrows at three depths in 2 yr at Mead, NE.

during composting, beef feedlot manure should be applied to the land without composting unless weed seeds, better handling of manure, odor, or others are of concern.

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