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Mineralization of manure nutrients

B. Eghball, B.J. Wienhold, J.E. Gilley, and R.A. Eigenberg

ABSTRACT: In order to apply manure or compost to fulfill the nutrient requirements of a crop, knowledge of the amount of nutrients mineralized following application is needed. Nutrient mineralization from applied manure depends on temperature, soil moisture, soil properties, manure characteristics, and microbial activity. Since these factors cannot be accurately predicted, nutrient mineralization from applied manure can only be approximated. Nitrogen (N) availability from applied manure includes the inorganic N ($\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$) in manure plus the amount of organic N mineralized following application. Nitrogen mineralization differs for different manure types since the inorganic/organic fraction and quality of organic N varies among manure types. Mineralization of organic N is expected to be low for composted manure (~ 18%) and high for swine or poultry (hens) manure (~ 55%). Phosphorus (P) availability from all animal production sources of manure is high (> 70%), as most of the manure P is inorganic and becomes plant-available after application. Potassium (K) availability from manure is nearly 100%; therefore, manure can be used similar to K fertilizer. When manure was analyzed for plant-available nutrients, greater than 55% of calcium (Ca) and magnesium (Mg) and less than 40% of zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), sulfur (S), and boron (B) were plant-available. To effectively utilize the nutrients in manure, their mineralization potential should be considered when determining application rates.

Keywords: Animal waste, compost, micronutrients, nutrient availability

The optimal amount of manure to be applied to a field depends on its composition, the soil nutrient availability, the crop grown, and the environmental conditions.

When manure is used as a source of a particular nutrient, knowledge of the mineralization rate under field conditions is needed. Since mineralization is microbially driven, it is influenced by several factors, including temperature, soil moisture, soil properties, and manure characteristics. Nitrogen (N) mineralization increases with increasing temperature under conditions found in agricultural soils (Cassman and Munns 1980; Eghball 2000). Growing degree day, which is a function of temperature, has been used to predict N availability from applied manure (Griffin and Honeycutt 2000). Mineralization is greatest when soil moisture is near field capacity and declines with soil drying (Cassman and Munns 1980).

Manure characteristics can significantly influence nutrient mineralization. Mineral composition of animal manure varies with animal size and species, housing and rearing

management, feed ration, manure storage, and climate. For example, N contents of beef cattle manure were 31, 42, 27, and 19 g kg^{-1} (3.1, 4.2, 2.7 and 1.9%, respectively) of total solids when collected from scraping under slotted floors, in pits or tanks, in bedded units, and in earthen feedlots, respectively (Overcash et al. 1983). Fresh and scraped beef manure had phosphorus (P) contents of 11 and 7 g kg^{-1} (1.1 and 0.7%) of dry weight, and potassium (K) contents of 25 and 20 g kg^{-1} (2.5 and 2.0%), respectively (Westerman et al. 1985). About 58% of N is in the urine, mostly as urea (Overcash et al. 1983). About 96% of P is contained in feces, while 73% of K is excreted in urine (Safley et al. 1985).

Composting offers benefits but the process can alter manure characteristics and thereby influence nutrient mineralization. Composting manure is a useful method of producing a stabilized product that can be stored or spread with little odor or fly breeding potential (Sweeten 1988). Other advantages of composting include killing pathogens and weed seeds and improving the handling character-

istics of manure by reducing its volume and weight (Rynk et al. 1992). Composting also has some disadvantages: nutrients and carbon (C) can be lost during the process; it requires land, equipment, and labor; and the process can produce unpleasant odors. Eghball et al. (1997) found a 20 - 40% loss of total N and 46 - 62% loss of total C during composting of beef cattle feedlot manure, as well as significant losses of K and sodium (Na) (> 6.5% of total K and Na) in runoff from composting windrows during rainfall. The N and C pools of composted manure differ from noncomposted manure in that most of the easily mineralizable N has already been converted to inorganic forms and the remaining N is in more stable pools and less subject to mineralization and most C has been lost as CO_2 .

Manure provides nutrients to crops for several years. Pratt et al. (1973) developed a decay series (based on best judgments and some laboratory data) to estimate N availability in the first, second, third, and fourth year after manure application. The decay series was different for each manure type. For example, the decay series for beef cattle manure (15 g kg^{-1} N) (1.5% N) was 0.35, 0.10, 0.05, and 0.02, indicating that 35% of total manure N was available in the first year and 10, 5, and 2% of the original N was available in the second, third, and fourth year after application, respectively. The decay series for poultry manure was 0.90 and 0.01, while for swine manure it was 0.75, 0.04, and 0.01. Klausner et al. (1994) developed an N decay series of 0.21, 0.09, 0.03, and 0.03 for dairy manure based on corn (*Zea mays* L.) uptake. In addition to N, residual amounts of other nutrients can remain in the soil for several years.

The availability of P, K, and other nutrients from manure and compost needs to be determined so that these organic resources can be effectively utilized. The objective of this paper is to present information regarding mineralization and the availability of nutrients in manure.

Nutrient Mineralization and Availability

Nitrogen. Estimation of the amount of organic N mineralized following application

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of manure or composted manure is critical for effective use of these resources. Specifically, information regarding the availability of manure N to a crop following application is essential for determining N-based application. Even though both nitrate ($\text{NO}_3\text{-N}$) and ammonium ($\text{NH}_4\text{-N}$) in manure are immediately available to plants, ammonium can convert to ammonia and be lost to the atmosphere following manure application. Manure should be managed to minimize ammonia loss following application. Nitrogen mineralization can be determined in a number of ways. Most studies determining N mineralization from applied manure have been conducted in the laboratory using incubation (Castellanos and Pratt 1981; Chae and Tabatabai 1986; Bonde and Lindberg 1988; Cabrera et al. 1993). Laboratory incubation studies can be important for evaluating N mineralization mechanisms but relating incubation results to mineralization under actual field conditions can be difficult. Other studies have determined N availability in dairy manure (Motavalli et al. 1989) and beef cattle feedlot manure or composted manure (Eghball and Power 1999a; Eghball and Power 1999b) by plant nutrient uptake differences between fertilized and manured plots. Bitzer and Sims (1988) determined N availability in poultry manure by grain yield differences. The estimated amounts of organic N mineralized in the first year after application of various manure types are given in Table 1.

Generation of *in situ* mineralization data can be time consuming and costly, but is valuable for developing a practical mineralization index for waste products under field conditions. The *in situ* resin core method has been used to measure N mineralization and nitrification in forest ecosystems (DiStefano and Gholz 1986; Binkley et al. 1992). The method was also used in a dryland agroecosystem to determine soil N mineralization (Kolberg et al. 1997). Eghball (2000) measured N mineralization from applied manure and composted manure during the growing season using the *in situ* resin method. Organic N mineralization from composted manure was about half (11%) of that for noncomposted manure (21%) during the corn growing season (June to October) in eastern Nebraska. Lower N mineralization from compost was because most of the easily convertible C and N compounds were lost during the composting process and the remaining C and N were in more stable forms (Eghball et al. 1997).

Table 1. Estimated mineralization of manure organic N and availability of total N in the first and second year after application.

Manure	Organic N	Total N available	Total N available
	mineralized 1st yr	1st yr	2nd yr
		%	
Cattle feedlot [†]	30	40	15
Composted manure [†]	18	20	8
Poultry (hens) [†]	55	90	2
Poultry (broiler, turkeys) [†]	55	75	5
Swine [#]	40	90	2
Dairy [*]	21	32	14

[†]Eghball and Power (1999b) and Eghball (2000)

^{*}Moore et al. (1998)

[#]Hatfield et al. (1998)

^{*}Motavalli et al. (1989) and Klausner et al. (1994)

The amount of N available from manure applied to a growing crop includes the inorganic content of manure ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) plus the amount of organic N mineralized following application. Manure N mineralization depends on the N constituents in manure. About 92% of urea in manure was mineralized during aerobic incubation (Van Kessel et al. 2000). The fraction of organic N mineralized in the first year after application for different manure types are given in Table 1. The estimated fraction of organic N mineralized in the field in the year of application ranged from 18% for composted manure to 55% for poultry (hens) and swine manure (Table 1), indicating different N components in each manure type. The average C:N ratios for manure from broiler litter, laying hens, beef cattle, dairy, and swine are 14, 6, 19, 16, and 14, respectively (Rynk et al. 1992). No significant correlation was observed between the fraction of organic N mineralized and the C:N ratio of manure. This indicates that the composition of C and N in manure is much more important than the general C:N ratio. Availability of total N ranged from 20% for composted manure to 90% for swine and poultry manure (hens). Greater N availability from swine and poultry manure is due to the high ammonium-N concentrations in these manure types. The estimated availability of total N in the first and second year after application is also given in Table 1.

Manure can be applied to provide N requirements of a crop based on the N availability assumption in the first year after application. For example, if beef cattle feedlot manure is applied to provide 150 kg N ha⁻¹ (134 lb ac⁻¹) to a corn crop, then the total amount of N applied would be 375 kg N ha⁻¹ (335 lb N ac⁻¹), since only 40% of the N is available in the year of application. Some of

the residual N (15%) becomes plant-available in the second year. Because a small amount of N becomes plant-available in the second, third, and fourth years after application (Table 1), soil testing for nitrogen may provide a better indication of manure N availability than the uncertain estimated values for N availability.

Phosphorus. Phosphorus-based manure application is becoming more common in areas with high risk of P loss in runoff. Pote et al. (1996) found increased P loss in runoff as the soil P test increased. Eghball and Power (1999b) found that P-based manure or compost application resulted in soil test P levels similar to the original soil P level after four years of application but N-based application resulted in significant P build-up in the soil. In order to apply manure to replace P removal by a crop, the amount of organic P mineralized following application needs to be determined. But most of the P in manure is inorganic (> 75%) (Table 2), indicating that P availability following application should be very high. Based on the soil test P changes and plant P uptake one year after application (Eghball and Power 1999b), P availability in the first year after application was 85% for beef cattle feedlot manure and 73% for composted feedlot manure (Table 3). Slightly lower P availability from composted manure indicates a chemical reaction of P during composting, which caused P to become less plant-available. There was substantial variability in the estimates of P availability from manure and composted manure (Table 3). Motavalli et al. (1989) found that P availability from injected dairy manure ranged from 12 to 89% based on corn P uptake. The low P availability in this study was due to a small P response from applied manure P. In a field study, Wen et al. (1997b) found that 69% of

Table 2. The fraction of total P (TP) as organic P (OP) or inorganic P (IP) in different manure types.

	OP/TP	IP/TP
	%	
Feedlot manure [†]	25	75
Composted manure [†]	16	84
Dairy [†]	25	75
Poultry litter [†]	10	90
Swine [†]	9	91

[†]Eghball (2002)[†]Sharpley and Moyer (2000)**Table 3. First year P availability from composted and noncomposted beef cattle feedlot manure application in a N- and P-based manure and compost applications study in Nebraska[†].**

Treatment	Phosphorus availability	Average
	%	
Annual N-based manure	113	Manure = 85 ± 13 [†]
Annual P-based manure	57	
Biennial N-based manure	71	Compost = 73 ± 14 [†]
Biennial P-based manure	98	
Annual N-based compost	57	Compost = 73 ± 14 [†]
Annual P-based compost	71	
Biennial N-based compost	113	
Biennial P-based compost	52	

[†]Eghball and Power (1999b)[†]Mean ± standard error

composted manure P was plant-available.

Phosphorus availability from all manure types is high and, based on the inorganic P fractions in manure (Table 2), can be assumed to be at least 70%. The P in manure can be used similar to P fertilizer (100% available) in areas with adequate soil P for crop production to avoid soil P accumulation. In P-deficient areas, an estimation of at least 70% availability from manure should be used. The amount of P available in the second, third, and fourth years after application is small and can be determined by testing soil for available P.

Potassium. Potassium in manure and compost is highly plant-available and can be used similar to K fertilizer application. Most of the K (> 70%) is excreted in the urine (Safley et al. 1985), indicating the high solubility of the excreted K. In a field study, Wen et al. (1997a) found K availability of 100% from composted manure. Motavalli et al. (1989) found that K availability from injected dairy manure ranged from 24 to 152% (mean = 73%) of applied K using the fertilizer equivalent approach. Potassium in other manure types is also expected to be about 100% plant-available and therefore, these resources can be

used similar to K fertilizer.

Secondary nutrients and micronutrients.

Plants require macro and micronutrients for normal growth. Secondary nutrients required for plant growth include sulfur (S), calcium (Ca), and magnesium (Mg). Important micronutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Micronutrients are also important for plant growth, as plants require a proper balance of

Summary and Conclusions

Mineralization of nutrients in manure is influenced by temperature, soil moisture, soil properties, manure characteristics, and microbial activity. Since most of these factors cannot be accurately predicted, only an approximation of manure nutrient mineralization following application is possible. Nitrogen mineralization differs for different types of manure and is expected to be the lowest for composted manure. Less N mineralization from compost as compared to noncomposted manure reflects the loss of easily convertible N and C compounds during composting and the presence of stable N compounds. When injected or incorporated immediately after application, swine manure has the highest N availability since a great portion of total N is ammonium (> 70%), which is immediately available to plants. Manures that contain a large portion of organic N (cattle feedlot, dairy) provide less plant-available N since the organic N needs to be mineralized to inorganic N. Phosphorus availability from manure is high (> 70%) since a large portion of the P in manure is inorganic and hence mostly plant-available. Phosphorus in manure can be used as an excellent P source for deficient soils. Potassium availability from manure is almost 100% and should make manure or composted manure a good K source. Information about mineralization or availability of manure secondary and micronutrients is limited. Plant-availability of Ca and Mg in manure was > 55% while plant-availability of Zn, Fe, Mn, Cu, and S in manure was < 40%.

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Nutrient variability in manures: Implications for sampling and regional database creation

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ABSTRACT: The variability of manure nutrient levels within and across farms makes manure sampling and development of reliable tabular values challenging. The chemical characteristics of beef, dairy, horse, sheep, and chicken solid manures in Colorado were evaluated by sampling six to ten different livestock operations for each manure type and comparing the results to values found in the literature. Due to the semi-arid climate of Colorado, manure tends to be drier and have lower ammonium ($\text{NH}_4\text{-N}$) levels and higher phosphate (P_2O_5) and potash (K_2O) levels than those reported in the Midwest. Within-farm variability was assessed by analyzing ten sub-samples from each of nine manure sources. Coefficients of variation were calculated and the sample numbers necessary to achieve 10% probable error were determined. On average, about 25 sub-samples are necessary for nitrogen (N), phosphorus (P), and potassium (K) characterization of solid manures, but determining $\text{NH}_4\text{-N}$ and nitrate ($\text{NO}_3\text{-N}$) concentrations requires over 100 sub-samples to form a representative sample, due to their relatively low concentrations. Data from Colorado, Utah, and New Mexico were combined to form a Mountain West Manure Database. The manure types, with a minimum of 72 farms represented in the database, have narrow confidence intervals. Until we have adequate sample numbers (>72 farms) to establish reliable table values based on local data for all manure types, manure sampling will be recommended.

Keywords: Manure sampling, manure variability, regional manure database

Land-grant universities throughout the United States recommend that farmers sample and analyze animal manure to determine its nutrient content prior to land application. Nutrient management recommendations are dependent on accurate manure nutrient information. Many universities provide table values for use when pro-

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