ESTIMATES OF NITROGEN AVAILABILITY OF POULTRY MANURE AND SEWAGE SLUDGE AMENDMENTS IN MINED PRIME FARMLANDS[1]

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Abstract: The application of poultry manure and sewage sludge may speed up the return of productivity of prime farmland following surface mining, as well as for utilizing nutrients in these wastes. However, excessive application may result in nitrate contamination of ground water. This research was carried out under laboratory and field conditions to test this concern. The objective was to examine nitrogen mineralization indices used to evaluate nitrogen availability to wheat (Triticum astivum). Two field experiments were established in fall 1992 in western Kentucky. Sewage sludge was applied to both topsoil and subsoil at one site, and poultry manure was applied to only the topsoil at the second site. Three rates of organic amendments were used in these experiments. Soil available nitrogen was evaluated by both biological mineralization and chemical extraction methods. A 7-day anaerobic incubation method was well correlated with grain yield and was superior to other chemical methods in predicting nitrogen availability. Both sewage sludge and poultry manure application to the topsoil provided a high available nitrogen source for wheat growth, which resulted in a higher yield than that for the unamended control.

Additional Key Words: organic wastes, nitrogen availability indices, mineralizable nitrogen.

Introduction

Availability of nitrogen may limit revegetation of prime farmlands disturbed during surface mining. An effective reclamation method to provide nitrogen and improve soil productivity is to add organic wastes to mined soils (Barnhisel and Zhai 1992). A portion of nitrogen in organic wastes may be mineralized during the cropping season by microbial processes. This mineralization provides a certain amount of nitrogen as NH_4^+ and NO_3^-, which are easily accessible to plants. Organic waste application rates are generally based on the crop yield goals and the nitrogen availability provided by these wastes. It would be useful to evaluate nitrogen mineralization indices to guide waste loading rates because excess application would cause adverse environmental pollution through excessive nitrogen loss to water systems.

Numerous nitrogen mineralization indices, which include both chemical and biological methods for assessing nitrogen availability, have been evaluated. Examples of such indices include HCl-extractable nitrogen, acid $KMnO_4$-oxidizable nitrogen, boiling water-extractable nitrogen, and soil Kjeldahl nitrogen. These indices are derived through relatively inexpensive and rapid procedures. However, they do not simulate real nitrogen mineralization processes mediated by microorganisms. If these indices are used to predict crop production, they must be calibrated under field conditions. Biological incubation indices that simulate natural microbial processes are generally considered to be the most reliable laboratory methods for assessing plant-available nitrogen (Stanford 1982). A 7- to 14-day anaerobic incubation index is considered to be the most accurate method currently available for assessing biological nitrogen availability. It is a simple, rapid method and well-correlated with other long-term aerobic incubations (Keeney 1982).

Little is known of the reliability of these indices under field conditions, particularly for organic wastes applied to surface-mined soils. The objective here is to determine if these biological and chemical nitrogen

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mineralization indices can be used to predict nitrogen availability of poultry manure and sewage sludge in surface-mined prime farmland planted to wheat.

Materials and Methods

Field Experiments

The poultry manure and sewage sludge sites are located at two western Kentucky sites in Henderson and Muhlenberg counties, respectively. Two prime farmland soils were reconstructed in summer 1992. Sewage sludge was applied at the rate of 22.4 Mg/ha and was incorporated in the upper 20 cm of subsoil prior to the replacement of the topsoil. The topsoil received an additional application of sewage sludge at 0, 11.2, and 22.4 Mg/ha, which was also incorporated. Poultry manure was incorporated only in topsoil at the rates of 0, 33.6, 67.2 Mg/ha. Following organic waste incorporation, soil samples were collected and soft red winter wheat was planted at both sites. Above-ground plant tissue was sampled during anthesis period, and grain samples were also collected at harvest. Grain yield was measured with a MF8 plot combine. All plant samples were dried at 65°C and ground to pass a 0.425-mm screen, using a stainless steel Wiley Mill, and total nitrogen was determined by a standard micro-Kjeldahl procedure. Soil samples were air dried and ground to pass a 2-mm sieve. The pH, total nitrogen, NH_4-N, NO_3-N, and organic matter were determined by standard laboratory methods (Page 1982). The soil microbial mass was determined by the chloroform fumigation method (Parkinson and Paul 1982).

Biological Nitrogen Mineralization Method

Anaerobically mineralized NH_4-N was determined by a slight modification of the procedure described by Keeney (1982). Ten grams of fresh soil was incubated with 25 mL of distilled water for 7 days in a stoppered 50-mL flask at 40°C. After incubation, 13 mL of 1M KCl was added, and the flask was mechanically agitated for 10 s and allowed to stand for 30 min. The flask was reagitated for 10 s, and the mixture was vacuum filtered through Whatman #42 paper. The incubation flask was rinsed with 13 mL of distilled water, and the rinse was filtered. The filtrate was measured for NH_4^+-N by a standard micro-Kjeldahl procedure. Net nitrogen mineralized was the difference of this measurement and inorganic nitrogen in the sample.

Chemical Nitrogen Extraction Methods

1. 6M HCl Method. Release of nitrogen in HCl was determined by heating a mixture of 5 g of soil and 15 mL of 6M HCl (1:3) in sealed glass test tubes for 12 h at 100°C (Bremner 1949). The extract was analyzed for total nitrogen by the same Kjeldahl procedure.

2. $KMnO_4$ Method. The acid $KMnO_4$ oxidation method was essentially that of Stanford and Smith (1972). Two hundred milliliters of 0.5M H_2SO_4 was added to plastic tubes containing 8-g samples of air-dried soils. The tubes were sealed and shaken for 1 h and centrifuged at 3800 xg for 10 min, and the acid extracts were decanted and discarded. The residue was then resuspended with 200 mL of 0.1M $KMnO_4$ in 0.5M H_2SO_4, shaken again, centrifuged, and the supernatant solutions were decanted and analyzed for NH_4-N by the Kjeldahl procedure.

3. Boiling Soil Method. Nitrogen is extracted in boiling water was used according to Keeney (1982). Duplicate 10-g air-dried soil samples placed in glass tubes were washed twice with 25-mL increments of 0.01M $CaCl_2$ to remove mineral nitrogen initially present. The soil residues were then boiled for 16 h in 25 mL of 0.01M $CaCl_2$. The extracts were recovered by centrifuging, and then the soil was washed twice with 25-mL increments of 0.01M $CaCl_2$. An aliquot of the combined extract and washing was analyzed for NH_4-N by the same Kjeldahl procedure.

Statistical Analyses

Standard analyses of variance and of simple and multiple correlation coefficients were calculated to indicate the relationships among wheat grain yield, above-ground tissue nitrogen concentration, mineralizable nitrogen, and chemically extractable nitrogen by the Statistical Analysis System (SAS).

Results and Discussion

Soil Properties

Selected soil properties after poultry manure and sewage sludge application are shown in table 1. Soil pH and microbial biomass were not largely altered, but total nitrogen, organic matter, and inorganic nitrogen increased as the loading rates increased.

Table 1. Effect of poultry manure and sewage sludge amendments on selected soil properties.

Rate, Mg/ha	pH	TN[1], g/kg	OM, g/kg	IN, mg/kg	MB, mg/kg
Poultry manure:					
0	5.8	0.22	4.6	15	91
33.6	6.1	0.55	9.6	66	110
67.2	6.3	0.98	16.7	72	115
Sewage Sludge:					
0	5.8	0.24	4.5	18	87
11.2	6.0	0.30	6.1	31	104
22.4	6.2	0.66	7.4	53	108

[1]TN, total nitrogen; OM, soil organic matter; IN, inorganic nitrogen; MB, microbial biomass (C).

Crop Response

Poultry manure and sewage sludge application significantly increased wheat tissue nitrogen concentration, grain yield, grain nitrogen concentration, and above-ground tissue dry matter compared with the control (table 2), but there was no significant difference between the two high loading rates. Higher yields from soils amended with poultry manure were closely related to more available nitrogen by mineralization from the poultry manure than from the sewage sludge treatments.

Biological Nitrogen Mineralization Index

Biological mineralized nitrogen is given in table 3. Poultry manure treatments released more inorganic nitrogen than did sewage sludge. High mineralization rates of poultry manure may be related to higher loading rates. However, the research indicated that the high mineralization rates resulted mostly from the more easily mineralized portion in poultry manure (Zhai and Barnhisel 1993). The amount of nitrogen mineralized increased as loading rates increased for both poultry manure and sewage sludge. Evaluation of biological mineralization and chemical extraction indices is based on the relative degree of correlation with wheat grain yield. Nitrogen biologically mineralized was well correlated with grain yield ($r=0.91^*$ for poultry manure; $r=0.92^*$ for sewage sludge).

Table 2. Effect of soil amended with poultry manure and sewage sludge on wheat response.

Rate, Mg/ha	Yield, Mg/kg	Tissue N, g/kg	Grain N, g/kg	Dry matter, g/kg
Poultry manure:				
0	2.75 a[1]	0.86 a	1.82 a	1.55 a
33.6	4.88 b	1.14 b	2.03 b	2.03 b
67.2	5.07 b	1.20 b	2.06 b	2.18 b
Sewage Sludge:				
0	3.31 a	0.86 a	1.51 a	1.19 a
11.2	4.24 b	1.04 b	1.74 b	1.42 b
22.4	4.65 b	1.10 b	1.96 b	1.69 b

[1]Comparison within column for same treatment only ($p<0.05$).

Chemical Extraction Methods

The 6M HCl method extracted the most nitrogen, followed by the 0.1M $KMnO_4$ and boiling soil methods (table 3). The 6M HCl method probably extracts greater amounts of nitrogen than are readily biologically available. The amount of nitrogen released by 6M HCl was not significantly correlated with wheat yield for sewage sludge study ($r=0.65$). Although it was correlated significantly with poultry manure treatment ($r=0.78$*), it did not represent the actual amounts of nitrogen that crop used during growth season. This was also observed in another study by Serna and Pomares (1992). The 0.1M $KMnO_4$ method had intermediate extractibility compared with the 6M HCl and boiling soil methods. The amount of nitrogen extracted by this method was only about one-half that extracted by 6M HCl, but it was about two times higher than that extracted by boiling soil. Significant correlation between grain yield and N extracted by $KMnO_4$ was observed for poultry manure treatment ($r=0.76$*), but not for sewage sludge study ($r=0.51$). Significant correlationships were obtained between boiling extractable nitrogen and grain yield for both poultry manure ($r=0.89$*) and sewage sludge ($r=0.75$*) treatments. Wheat yields from poultry manure treated plots were significantly correlated with total nitrogen, but were not sewage sludge. Therefore, we concluded that extracting methods employed to predict nitrogen availability under field condition are different for organic wastes applied to soil. Some extracting methods are suitable for poultry manure, but not for sewage sludge, although O'Keefe et al. (1986) evaluated nitrogen availability for amended sludge compost and found that chemical methods were well correlated with soil available nitrogen.

Multiple Correlation With Wheat Grain

The multiple regression analysis to select the good prediction of wheat yield is shown in table 4. Coefficients from the linear regression analysis between wheat grain yield (dependent variable) and biological and chemical nitrogen availability indices (independent variables) were improved by multiple regression. Biological mineralizable nitrogen was the major contribution to correlation coefficients both for poultry manure and sewage sludge treatments. When 6M HCl extractable nitrogen was added to the model, correlation coefficients improved markedly only for sewage sludge treatment. When $KMnO_4$ extractable nitrogen was added to the model, The improved relationship only attributed to poultry manure treatment. Correlation coefficients were not improved much when boiling extractable nitrogen combined in, although coefficients were slightly higher than those obtained in previous multiple correlation equations. Addition of soil total nitrogen parameter into the model significantly improved correlation coefficients both for poultry manure and sewage sludge treatments. This could be explained on the bases that the nitrogen in these organic wastes can be released fairly fast compared with soil organic matter and result in meeting the wheat nitrogen requirement for entire growing season through nitrogen mineralization process.

From above evaluation of correlation between wheat yield and nitrogen availability indices, we conclude that nitrogen mineralized by a 7-day anaerobic incubation method is the best single index to predict nitrogen availability. Chemical extraction methods are not all reliable for two different organic waste treatments. They may be selectively used as the reference when biological mineralization method is used. Anaerobic mineralized nitrogen plus total soil nitrogen are well correlated with wheat yield and can be used as important parameters to predict wheat yield for mined soils amended with poultry manure and sewage sludge.

Table 3. Means of nitrogen mineralized or extracted by several nitrogen availability index methods.

Rate, Mg/ha	Biological N, mg/kg	HCl N, mg/kg	$KMnO_4$ N, mg/kg	Boiling N, mg/kg
Poultry manure:				
0	17	150	58	25
33.6	157	445	210	92
67.2	288	755	428	156
Sewage Sludge:				
0	15	129	64	26
11.2	94	244	168	75
22.4	160	442	192	124

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Table 4. Stepwise multiple correlation of wheat grain yield and nitrogen availability indices.

	Equations	R^2
Poultry manure	$Y^1 = 2.89 + 0.009X1$	0.83*
	$Y = 2.95 + 0.01X1 - 0.0005X2$	0.83*
	$Y = 2.79 + 0.01X1 + 0.002X2 - 0.005X3$	0.86*
	$Y = 2.63 + 0.007X1 + 0.002X2 - 0.006X3 + 0.007X4$	0.86*
	$Y = 2.73 + 0.007X1 + 0.005X2 - 0.005X3 + 0.01X4 - 2.64X5$	0.88*
Sewage sludge	$Y = 3.21 + 0.009X1$	0.85*
	$Y = 3.44 + 0.02X1 - 0.0027X2$	0.94*
	$Y = 3.46 + 0.02X1 - 0.002X2 - 0.003X3$	0.94*
	$Y = 3.49 + 0.017X1 - 0.003X2 + 0.0004X3 - 0.004X4$	0.95*
	$Y = 3.54 + 0.016X1 - 0.0001X2 - 0.0002X3 - 0.002X4 - 1.87X5$	0.96*

[1]Y, wheat grain yield; X1, biological mineralized nitrogen; X2, 6M HCl extracted nitrogen; X3, 0.1M $KMnO_4$ extracted nitrogen; X4, boiling water extracted nitrogen; X5, soil total nitrogen.