Estimating Animal Waste Applications to Supply Crop Nitrogen Requirements[1]

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ABSTRACT

An equation was developed which estimates the amount of animal waste required to supply the desired amount of N for crops. This equation was based on annual mineralization rates which varied with time after application and with N content of the waste. When we calculated waste requirements to supply N needs using the equation, values were satisfactory for wastes containing 4% or less N. Residual N in soil fertilized with animal waste was closely correlated ($r = 0.92$) with values predicted by the equation.

Additional Index Words: **manure, corn, grain sorghum, manure N content, soil total N.**

Mathers, A. C., and D. W. Goss. 1979. Estimating animal waste applications to supply crop nitrogen requirements. Soil Sci. Soc. Am. J. 43:364–366.

ORGANIC WASTES have been used as sources of plant nutrients for many centuries. Much research on use of barnyard manure to maintain soil productivity was conducted before World War II. After World War II, when N fertilizers became abundant and inexpensive, research on organic wastes decreased. In recent years, large amounts of manure have been produced by concentrated animal feeding and large poultry operations. Interest in disposing of this manure coupled with increased N costs have renewed interest in using organic wastes as fertilizers.

Realizing the need to match crop N-requirements with manure application, Pratt et al. (7) and Willrich et al. (8) published decay constants or availability constants, indicating the rate at which N could be expected to become available to crops from manure incorporated in soil. Powers et al. (6) and Willrich et al. (8) developed equations, based on these decay constants, to predict the amount of manure needed to supply plant-N requirements. However, data to evaluate these equations were limited and they were somewhat cumbersome to use.

Additional data were collected and another equation was developed to predict manure required to supply plant-N needs. This equation which requires only the percent N in the waste is easy to use and correlates well with data of Herron and Erhart (2) and Mathers and Stewart (3) and additional data collected where manure was applied to produce grain sorghum [*Sorghum bicolor* (L.) Moench].

PROCEDURE

Decay constants from Pratt et al. (7) and Willrich et al. (8) for manure with different N percentages are shown in Table 1. These decay constants indicate the fraction of the applied manure decomposed the first year after application and the fraction of the residual manure that decomposes each succeeding year. After 3 or 4 years, the residual manure is relatively stable so the decay constant does not change. The percentage total N and the decay constants in Table 1 were used to calculate the amount of total N in manure required to supply 100 kg of available N to plants each year for 20 years. Table 2 shows these values for years 1, 2, 5, 10, and 20. After we made several regression analyses, we found that regression of the natural logarithm (ln) of the amount of manure N (R) required to supply 100 kg of available N/year on the ln of time (t) in years fitted the data generated by decay constants very closely. This regression equation can be written as follows:

$$\ln R = B \ln t + \ln A$$

where A and B are regression constants. Taking the antilogarithm of each side of the equation, we can write it

$$R = At^B. \qquad [1]$$

We determined regression equations for nine manure sources with different N percentages. Percent N and the regression constants A and B for the different manures are shown in Table 3. The regression constants A and B seemed to be functions of the percent N in the manure, regardless of source. Source of waste and ration determine the percent N and decomposition rate of manure. However, the percent N seems to be the main factor controlling the decay rate of manure. Therefore, we determined regression analyses of A on ln (percent N) and of B on ln (percent N).The following equations and correlation coefficients show the results of these analyses:

$$A = 445.2 - 234.7 \ln (\%\ N) \quad r = 0.89 \qquad [2]$$

$$B = -0.5057 + 0.3254 \ln (\%\ N) \quad r = 0.88 \qquad [3]$$

Substituting Eq. [2] and [3] in Eq. [1] gives

Table 1—Decay constants and average N values for animal wastes.

Source	N	Decay constants†
	%	
Poultry (hens)‡	4.5	0.9, 0.1, 0.05
Poultry (broilers)§	3.8	0.75, 0.05, 0.05
Dairy, fresh§	3.5	0.50, 0.15, 0.05
Dairy, anaerobic§	2.0	0.30, 0.08, 0.07, 0.05
Swine	2.8	0.90, 0.04, 0.02
Bovine, fresh‡	3.5	0.75, 0.15, 0.10, 0.05
Dry corral‡	2.5	0.40, 0.25, 0.06, 0.03
Dry corral‡	1.5	0.35, 0.15, 0.10, 0.05
Dry corral‡	1.0	0.20, 0.10, 0.05

† Fractions of residual manure decaying each successive year. Last value in the series is the decay constant for each year thereafter.
‡ Pratt et al. (7).
§ Willrich et al. (8).

Table 2—Total N in manure required to supply 100 kg of available N to plants each year for years 1, 2, 5, 10, and 20 calculated using decay constants.

Source	N	Year 1	2	5	10	20
	%	kg				
Poultry (hens)	4.5	111	109	108	106	103
Poultry (broiler)	3.8	133	131	125	117	108
Dairy, fresh	3.5	200	170	154	133	113
Dairy, anaerobic	2.0	333	271	199	145	109
Swine	2.8	111	110	110	109	108
Bovine, fresh	3.5	133	126	120	114	107
Dry corral	2.5	250	156	157	134	113
Dry corral	1.5	285	206	172	140	112
Dry corral	1.0	500	300	217	138	104

[1] Contribution from Federal Research, Science and Education Administration, USDA, in cooperation with the Texas Agric. Exp. Stn., Texas A&M Univ. Received 27 July 1978. Approved 5 Oct. 1978.

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Table 3—Regression constants A and B for manures with different N percentages and decay constants.

Source	N	A	B
	%		
Poultry (hens)	4.5	111.8	−0.0257
Poultry (broiler)	3.8	138.8	−0.0766
Dairy, fresh	3.5	203.9	−0.1903
Dairy, anaerobic	2.0	358.3	−0.3967
Swine	2.8	111.1	−0.0090
Bovine, fresh	3.5	133.6	−0.0709
Dry corral	2.5	221.5	−0.2251
Dry corral	1.5	269.7	−0.2910
Dry corral	1.0	488.8	−0.5354

$$R = [445.2 - 234.7(\ln \% \text{ N})]\ t^{(0.8254(\ln \% \text{ N}) - 0.5057)}$$

To convert to metric tons of manure (M) required to supply 100 kg of N, the rate, R, in kilograms of total N is divided by the decimal equivalent of the percent N in the manure and 1,000 kg/metric ton. These two factors combined equal 10 times the percent N in the manure. This factor can be included in the equation as follows:

$$\frac{M = 445.2 - 234.7(\ln \% \text{ N})}{10(\% \text{ N})}\ t^{(0.8254(\ln \% \text{ N}) - 0.5057)} \qquad [4]$$

Table 4 shows the metric tons of manure required to supply 100 kg of available N calculated by decay constants in Table 1 and by using Eq. [4]. These results were in good agreement, so we proceeded to check the predictions of Eq. [4] against field data where manure had been used.

Table 4—Metric tons of dry waste required to supply 100 kg of N calculated by use of decay constants or equation $R = At^B$.

Time years	Dry corral			Dairy broiler caged fresh litter layers		
	% N					
	1	1.5	2.5	3.5	3.8	4.5
	metric tons					
	From decay constants					
1	50.0	19.0	10.0	5.7	3.5	2.5
2	30.0	13.7	6.2	4.9	3.4	2.4
5	21.7	11.5	6.3	4.4	3.3	2.4
10	13.8	9.3	5.3	3.8	3.1	2.4
20	10.4	7.5	4.5	3.2	2.8	2.3
	From equation					
1	44.5	23.3	9.2	4.3	3.5	2.0
2	31.3	18.0	7.9	4.0	3.3	2.0
5	19.7	12.8	6.6	3.7	3.1	2.0
10	13.9	9.9	5.7	3.4	2.9	2.0
20	9.8	7.6	4.9	3.2	2.8	1.9

EVALUATION

Data reported by Herron and Erhart (2) and data from two experiments conducted at the USDA Southwestern Great Plains Research Center were used to evaluate Eq. [1], [2], and [3], which were the basis for Eq. [4].

Equation [1] can be transformed to estimate the amount of N remaining as follows: If P is the kilograms of available N needed, then the total amount of N added (R_o) in year (t) to provide that amount of N is

$$R_o = (P/100)At^B$$

which can be rearranged to give the amount of N that becomes available the tth year of R_o applications of manure

$$P = 100\ R_o/At^B. \qquad [5]$$

The amount of N that becomes available in the tth year of equal R_o applications of N in manure is the amount of N mineralized from that year's application plus the amount from 1 year previous, plus the amount from 2 years previous, etc. This equation also gives the sum of all the N mineralized each year from a single application of manure t years ago, containing R_o kg of N. This is true because the total amount mineralized is the sum of the amount mineralized each year. Thus, the amount of unmineralized N remaining (R_r) in the soil t years after an application of R_o kg of N would be

$$R_r = R_o - R_o/At^B. \qquad [6]$$

Herron and Erhart (2) presented the average percent N in the manure (1.55%), the amount of manure applied (11, 22, and 44 metric tons/ha), and the increase in total soil N over the check plots 1 and 3 years after application. Substituting the values of A and B from Eq. [2] and [3] into Eq. [6], we calculated the amount of N remaining in the soil the first and third year after application. The observed and calculated values were compared by linear regression analysis and plotted in Fig. 1.

Seven years of data of grain sorghum grown on Pullman clay loam, a member of the fine, mixed, thermic family of Torrertic Paleustolls, fertilized with 22, 67, and 134 metric tons/ha of beef feedlot manure annually, were available for similar analysis. Soil samples were taken periodically and the total N remaining in the soil was determined. The time period of Eq. [6] was calculated in months since the sampling month varied considerably and there were often two samples taken per year. Equation [6] in the month form is

$$N_R = N_o - N_o/aT^B \qquad [7]$$

when T is in months and $a = A/12$. Substituting Eq. [2] and [3] into Eq. [7], we estimated the total unmineralized N remaining in the soil (over the check) for each sampling period. The manure applied varied from 2.4 to 3.5% N, resulting in the values of A and B varying from year to year. Therefore, the N remain-

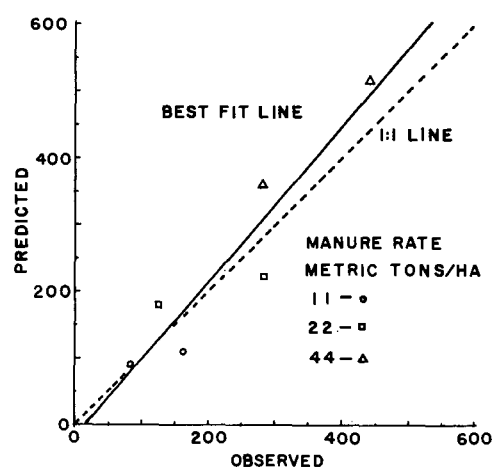

Fig. 1—Regression of predicted on observed total N remaining in soil 1 and 3 years after application of beef feedlot manure. Data from Herron and Erhart (2) $Y = 1.16X - 19.26$. $r = 0.933$.

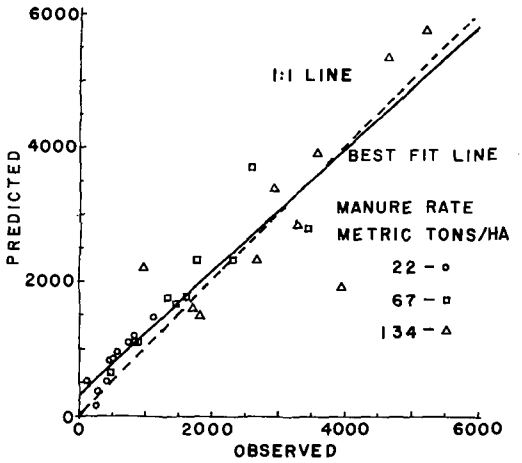

Fig. 2—Regression of predicted on observed total N kg/ha remaining in soil after seven annual applications of beef feedlot manure. $Y = 0.908X + 305.6$ $r = 0.915$.

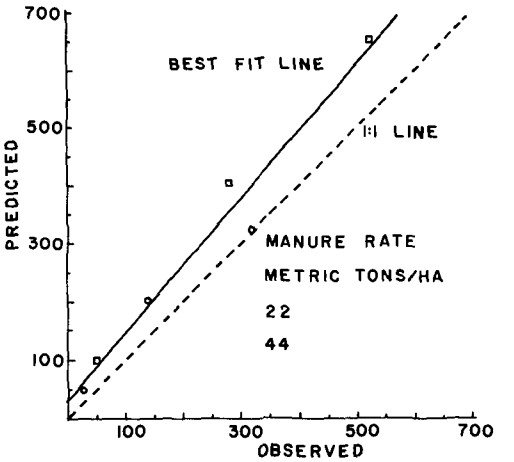

Fig. 3—Regression of predicted on observed total N kg/ha removed by corn plus nitrate-N remaining in the soil after three annual applications of beef feedlot manure. $Y = 1.158X + 30.79$ $r = 0.983$.

ing in the soil from each of the annual applications was calculated for each sampling and these values summed to obtain the total estimated N remaining in the soil. These values were then compared with the observed values using a linear regression analysis (Fig. 2).

Data from (3) an experiment with corn (*Zea mays* L.) grown on Pullman clay loam fertilized with three annual applications of 22 and 44 metric tons/ha of beef feedlot manure were used to calculate a regression of predicted on observed N removal. In this study, the manure varied from 1.6 to 3.6% N. Since Eq. [5] predicts available N, the NO_3-N taken up by the plants, and the NO_3-N remaining in the soil were summed. Equation [5] was used to calculate the NO_3-N mineralized for each annual application. The regression and a 1:1 line (Fig. 3) shows the predicted removal was higher than that observed. However, the correlation coefficient ($r = 0.983$) showed that there was a good fit of the predicted and observed N removed.

In all three sets of test data, agreement was good between the predicted and the observed values used. The correlation coefficients of 0.933, 0.915, and 0.983 for Fig. 1, 2, and 3, respectively, and slopes near one and intercepts near zero for each figure indicated that the predicted values were close to the observed. Apparently, the equation accurately estimates mineralization of N from manure incorporated into soil. Therefore, the equation must also accurately estimate the amount of manure required to provide a desired level of N during a crop year when applied at agronomic levels.

When excessive amounts of manure were applied, layers of manure were left at the plow depth, resulting in anaerobic spots where denitrification could take place, and otherwise altered the decomposition rate so the amount of N available could not be predicted. Also, the conditions for plant growth were poor because of excessive ammonia production or high salt levels in the root zone.

Nitrogen is lost when manure is spread, when conditions are anaerobic, and when there is leaching while nitrates are present in the soil. The estimated manure application rate can be adjusted for the spreading and denitrification losses, if these are known. Some values for the amount of N lost from manure during application to land were published by Midwest Plan Service (5). Meek et al. (4) and Adriano et al. (1) discussed denitrification losses from land. Nitrogen loss by denitrification depends on soil texture, soil water, temperature, and a source of energy. It may be as high as 75% on clay soils with high moisture levels. Nitrate leaching may be limited by fertilizing with the correct amount of manure to supply crop-N needs. Nitrogen is released continuously during the growing season so plants use it before it leaches. When the weather is cold, nitrification is very slow.

CONCLUSIONS

The equation, $R = At^B$, provides a method of calculating the amount of manure needed to supply the N required for a crop. By applying an adequate but not excessive amount of N, as estimated by the equation, we can obtain good crop production without waste.

LITERATURE CITED

1. Adriano, D. C., A. C. Chang, and R. Sharpless. 1974. Nitrogen loss from manure as influenced by moisture and temperature. J. Environ. Qual. 3:258–261.
2. Herron, G. M., and A. B. Erhart. 1965. Value of manure on an irrigated calcareous soil. Soil Sci. Soc. Am. Proc. 29:278–281.
3. Mathers, A. C., and B. A. Stewart. 1974. Corn silage yield and soil chemical properties as affected by cattle feedlot manure. J. Environ. Qual. 3:143–147.
4. Meek, B. D., A. J. MacKenzie, T. J. Donovan, and W. F. Spencer. 1974. The effect of large applications of manure on movement of nitrate and carbon in an irrigated desert soil. J. Environ. Qual. 3:253–258.
5. Midwest Plan Service. 1975. Livestock waste facilities handbook. Iowa State Univ., Ames, Iowa. MWPS-18, 89 p.
6. Powers, W. L., G. W. Wallingford, and L. S. Murphy. 1975. Formulas for applying organic wastes to land. J. Soil Water Conserv. 30:286–289.
7. Pratt, P. F., F. E. Broadbent, and J. P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agric. 27(6):10–13.
8. Willrich, T. L., D. O. Turner, and V. V. Volk. 1974. Manure application guidelines for the Pacific Northwest. ASAE Paper No. 74-4601.