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A Four-Year Field Trial With Animal Manures

I. Nitrogen Balances and Yields

II. Mineralization of Nitrogen

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ABSTRACT

Data are presented for a 4-year field experiment with various rates of both dry and liquid manures, and two levels of irrigation. Yields of sudangrass and barley forages were increased at moderate rates of manures, but higher rates decreased yields. Effects of the rate of irrigation water on yields were not significant. Leaching of NO_3^- was correlated with rates of manures applied. Increased drainage volumes decreased NO_3^- concentrations of leachate only at the high rates of manures, but increased mass emissions of NO_3^- for all manure treatments. A N balance in which the sum of accumulation in the organic matter, in crop removal, and in leaching losses was subtracted from the total N input in manures and irrigation water to obtain unmeasured losses, indicated that volatilization losses were small unless large excesses of manure were applied.

The measured mineralization of the N added in dry dairy manure and in liquid feedlot manure agreed well with mineralization calculated from decay series. The relationships between forage yields and amounts of N leached as NO_3^- , and between yields and calculated rates of N mineralization, were studied. The N in the dry dairy manure, which averaged 1.6% N on a dry weight basis, was about 45% available the first year after application, whereas the N in the liquid feedlot manure, which averaged 4.5% N on a dry weight basis, was about 75% available. The problems of conducting experiments with animal manures as N sources, and the implications of calculated mineralization rates, are discussed.

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II. Mineralization of Nitrogen

INTRODUCTION

DURING THE PAST FEW YEARS, many reports and reviews have dealt with animal manures. A recent report of the Council for Agricultural Science and Technology (CAST, 1975) emphasized comparisons of manures with inorganic fertilizers. Manures are low-grade fertilizers of variable composition. The total plant nutrient content is usually only 10% of that of most inorganic fertilizers. Concentrations of nutrients and soluble salts, and water content vary, and are seldom determined. Thus, optimum rates of application are difficult to predict. Other disadvantages result from the physical properties of manures. Application techniques for precision placement have not been developed. Whereas fertilizer needs are seasonal, manures are produced continuously. These circumstances create difficult manure storage problems.

Azevedo and Stout (1974) summarized the problems and potentials for use of animal manures in agriculture, especially in California. Meek *et al.* (1975) discussed the composition of manures that are produced in Western U.S.A., and formulated guidelines for their use. Powers *et al.* (1975), after reviewing data on the composition of manures from all parts of the U.S.A., found no regional or climatic differences that were useful in formulating guidelines for their use on croplands. They recommended that rates of application be based on composition, and predicted N mineralization rates.

Pratt *et al.* (1973) developed a decay series approach to predicting rates of application of various types of animal manures. The decay series was used as a method of stating yearly rates of min-

eralization of organic N. Powers *et al.* (1974) developed guidelines, for use of beef feedlot manure, based on decay series and on the amount of salt in the manure; and Powers *et al.* (1975) recommended guidelines based on decay series, salt content of the manures, salt content of the irrigation water (if the land is irrigated), and mean annual rainfall (if the land is not irrigated).

The use of decay series for making recommendations presupposes that decay series have been determined for various types of manures. Very few experiments have been conducted in the manner in which the decay series could be determined. Thus, there is need for research that will develop this type of information. Although the research reported herein was not designed specifically for determining decay series, the data collected were used to verify the utility of the decay series concept, and to compare directly determined mineralization with calculated mineralization for a 4-year period. The objectives of the experiment from which the data reported were taken, were to measure the effects of liquid and dry manures on a Hanford sandy loam, and the effects of dry manure on three soils of different profile and textural characteristics. Data for yields and NO_3^- accumulation in barley and sudangrass forages grown on the Hanford soil have been reported by Pratt *et al.* (1976). The present paper supplies data on the variability in mineral element contents of manures, compares calculated amounts of organic N accumulated in soils with values determined by soil analysis, and discusses the utility of the decay series.

METHODS AND MATERIALS

The soils on which the experiment was located were a Hanford sandy loam, Ramona sandy loam, and a Domino clay loam. The experimental sites were on the University of California Moreno farm located a few miles south of Riverside, and all were within an area having a radius of one-half mile.

The experiment on the Hanford soil consisted of a check, three rates of dry dairy manure (average 69% dry matter) collected from dairy corrals, and two rates of liquid manure from a feedlot in which the urine plus feces is collected daily and hauled to croplands. The dry manure came from one dairy farm, except the material for the last application, which came from a different dairy. All liquid manure came from a feedlot where young steers were fed a highly concentrated ration. On the Ramona and Domino soils, only the middle rate of dry manure (average of 79 metric tons per ha/yr) was used. In all treatments there were two irrigation levels and three replications on each soil. Barley (*Hordeum vulgare* 'Numar') planted in the fall and sudangrass (*Sorghum sudanese* 'Trundan V.') planted in the late spring were harvested for forage. Irrigation water was applied by sprinkler systems. Plot size was 15 × 15 m, with guard areas of equal size. The experiment started with

barley in the fall of 1970 and terminated with the harvest of sudangrass in the summer of 1974. Manure was added before planting each crop, so that the annual rate was split into two applications.

Soil samples to a depth of 25 cm were taken in the fall of 1974 from treated and check plots. This sampling depth represented the depth of incorporation of manure by disc plowing. In the case of the Ramona and Domino soils, the check plots were in the guard areas, which had received no manure, but which had been fertilized with inorganic nitrogen sources. Samples were composites of 40 subsamples which had been shown by exploratory sampling to give true means within 5% of the measured means, within a confidence level of 95%. Accumulated organic N was calculated as the amount of organic nitrogen in the treated plots minus that in the check plots. Bulk densities were measured so that quantities of organic N could be calculated accurately and specifically for the three soils. The total N added in manures, minus the accumulated organic N, provided an estimate of the sum of the quantities of N that were removed in harvested crops, leached in the form of NO_3^- and volatilized as NH_3 or as N_2O and N_2 gases.

RESULTS

The average dry matter contents of the dry and liquid manures were 69 and 11%, respectively, and the average N contents were 1.63 and 4.52% of the dry weight, respectively. However, there was considerable variability in dry matter and N contents as well as in other constituents. Data on the composition of the manures applied at various dates during the experiment are presented in Table 1.

Dry matter contents ranged from 49 to 80% for the dry dairy manure, and from 9 to 16% for the liquid feedlot manure. Nitrogen content varied from 0.75 to 2.2% for the dairy manure, and from 2.4 to 5.6% for the liquid material. However, by excluding the last application, the variations were considerably less.

Total N mineralized from manures during the 4-year period was estimated

TABLE 1
COMPOSITION OF DRY DAIRY MANURES AND LIQUID FEEDLOT MANURES
ADDED ON VARIOUS DATES DURING 4 YEARS OF A FIELD TRIAL

Application date	Dry matter*	N	P	K	Na	Cl	Ca
%							
Dry manure							
October 70	80	2.2	0.55	2.6	1.0	1.3	2.9
May 71	61	1.3	0.38	2.7	1.0	1.3	2.6
October 71	49	2.2	1.25	4.8	1.1	2.0	5.4
May 72	62	1.4	0.81	3.5	0.76	1.2	4.2
October 72	75	2.1	0.48	3.1	0.75	1.4	2.2
May 73	68	1.5	0.54	3.4	0.82	1.4	2.2
October 73	80	1.5	0.37	2.4	0.40	1.7	1.6
May 74	78	0.75	0.34	2.6	0.47	2.2	1.8
Liquid manure							
October 70	9.7	5.6	0.93	3.9	2.7	3.7	1.9
May 71	12.2	4.4	0.78	2.3	2.1	3.1	2.3
October 71	10.0	5.0	1.89	3.4	1.6	2.4	4.7
May 72	10.9	4.3	1.70	3.4	1.6	2.2	4.1
October 72	10.2	5.2	1.03	4.1	1.8	3.2	2.0
May 73	10.7	4.1	0.81	2.9	1.4	2.6	1.0
October 73	9.0	5.2	0.95	3.6	1.2	2.6	1.8
May 74	15.8	2.4	0.51	2.5	0.54	0.92	1.9

* Percent of total weight. All other data are percent of dry matter.

by determining the increase in total N in the soil. The amounts of N added, minus that determined to have accumulated in the soil, were then compared with amounts of organic N not mineralized, as calculated from decay series.

The decay series used were 0.75, 0.15, 0.10, 0.05 for the liquid manure, and 0.45, 0.10, 0.05, 0.05 for the dry manure. The series for liquid manure was taken directly from Pratt *et al.* (1973), and the series for dry manure was a modification of a series used by Pratt *et al.* (1973). The first number gives the fraction of the total N that is in a mineral form at the time of application, plus the N that will mineralize the first year. The second number is the fraction of the residual organic N that will mineralize the second year. The third and fourth numbers, respectively, represent the fractions of the residual organic N that will mineralize the third and fourth years, and each year thereafter. The available N during any one year is

taken as the sum of the available N from the application for the year being considered, plus that mineralized from residual organic N from all previous applications.

Statistical analysis of data for total N in soils revealed that irrigation levels had no effect, but that treatments and soils had highly significant effects on total N in the plow layer. However, when the increases in organic N were calculated by subtracting the organic N in the check plots from that in the treated plots, the variations among soils with the same treatment were relatively small and nonsignificant. The data subjected to statistical analysis were the differences in mg N/kg of soil converted to a kg/ha basis using the measured bulk density of the soil of the plow depth (0–25 cm).

Data for calculated amounts of N mineralized are presented in Table 2. The dry manure was added as it came from the dairy, assuming an average of

TABLE 2
DATA FOR TOTAL N ADDED AND CALCULATED AMOUNTS OF MINERALIZED N

Treatment Manure	Average rate metric ton/ha per yr	Year	Total N added	Calculated N mineralized				Sum of application
				1970-71	1971-72	1972-73	1973-74	
Dry	40	1970-71	556	250	31	14	13	308
		1971-72	682		307	38	17	362
		1972-73	800			360	44	404
		1973-74	494				222	222
		Sum for 4 years	2,532					1296
Dry	79	1970-71	1,112	500	61	28	26	615
		1971-72	1,364		614	75	34	723
		1972-73	1,600			720	88	808
		1973-74	988				445	445
		Sum for 4 years	5,064					2591
Dry	158	1970-71	2,224	1001	122	55	52	1230
		1971-72	2,728		1228	150	68	1446
		1972-73	3,200			1440	176	1616
		1973-74	1,976				889	889
		Sum for 4 years	10,128					5181
Liquid	41	1970-71	1,012	759	38	21	10	828
		1971-72	1,000		750	38	21	809
		1972-73	1,032			774	39	813
		1973-74	652				489	489
		Sum for 4 years	3,696					2989
Liquid	42	1970-71	2,024	1518	76	43	19	1656
		1971-72	2,000		1500	76	42	1618
		1972-73	2,064			1548	77	1625
		1973-74	1,304				978	978
		Sum for 4 years	7,392					5877

Fig. 1. Relationship between increase in total soil nitrogen in the plow layer, (0 to 25 cm depth of the Hanford soil), as calculated from decay series, and increase determined by soil analysis. Decay series were 0.45, 0.10, 0.05, 0.05—for solid manure and 0.75, 0.15, 0.10, 0.05—for liquid manure. Data are for a 4-year period.

30% water content. However, at the time the manure was added, samples were taken for water and N analyses so that the dry weight and N added could be calculated. Because the dry weight and N contents varied among application dates, their values added varied considerably from year to year.

The relationship between calculated and measured increases in organic N in the Hanford soil is presented in Fig. 1. The correlation was found to be highly significant. The regression coefficient is nearly 1.0, indicating that, on the average, the decay series used in this soil give nearly one-to-one estimates of mineralized and accumulated organic N. In the Ramona soil, the accumulated N values were 1794 and 2136 kg/ha, re-

spectively, for the low and high irrigation treatments. For the Domino soil, comparable data were 2105 and 2353 kg/ha. These data should be compared with 2473 kg/ha calculated from the decay series. The agreements between calculated and measured values for the Ramona and Domino soils were not as close as that for the Hanford soil; but, except for one value for the Ramona soil, the measured values were all within 15% of the calculated values.

The relationships between calculated N mineralization rates and forage yields of barley and of sudangrass are presented in Figs. 2 and 3. An analysis of variance for sudangrass yields revealed that there were significant differences between the check and the first

Fig. 2. Relationships between average (in metric tons) forage yields of two crops, with two irrigation treatments, and average calculated nitrogen mineralized from application of dry dairy corral manure to a Hanford soil.

two rates of dry manure treatments. However, the difference between the check and the highest rate of dry manure was not significant. With barley yields, the differences between check and treatments were significant except in the case of liquid manure and the lowest irrigation rate. Differences in yields between the dry and liquid manures were small when compared on an equal N availability basis (compare Figs. 2 and 3).

The relationships between nitrate-nitrogen concentration in drainage water and calculated nitrogen mineralized from manures during the 4 years of the field trial are presented in Fig. 4. The linear relationships are obvious, although, because of the few points for each curve, correlation coefficients were not calculated. The effects of irrigation treatments on nitrate concentration are evident at the high levels of mineral nitrogen.

DISCUSSION

The decay series used here for dairy corral manure was nearly the same as the series calculated for feedlot manure

from a 3-year experiment in Imperial Valley, California (Meek *et al.*, 1974). From data for the accumulation of or-

Fig. 3. Relationships between average forage yields of two crops, with two irrigation treatments, and average calculated nitrogen mineralized from liquid manure applications to a Hanford soil.

ganic N in this experiment in the Imperial Valley, Meek³ calculated a decay series of 0.50, 0.10, 0.05 from plots that received manure, containing 2% N, only at the beginning of the 3-year period. Pratt *et al.* (1973) reported a decay series of 0.40, 0.20, 0.06 for a feedlot manure containing 2.2% N that was used on sweet corn in Coachella Valley, California, by Tyler *et al.* (1964). Thus, the N in dairy corral and feedlot manures, containing 1.6 to 2.2% N, appears to mineralize at a rate of about 40 to 50% during the first year after application, 10 to 20% the second year, and 5% the third year, in the irrigated soils of southern California.

These mineralization rates have im-

plications not only in terms of adjusting manure application rates to crop needs, but also for calculating hazards of leaching NO_3^- to ground waters. Actually, the decay series can be used to calculate the effects of various management practices. Figures 5, 6, and 7, which present the results of such calculations, reveal the high rates of mineralization during the first year after large applications, followed by the low rates during years when manures were not applied. This is shown for a sequence in which manure was applied at a rate of 2000 kg N/ha every fourth year, as compared to annual applications of 500 kg N/ha. The potential for leaching of NO_3^- is high during the year

³ Personal communication from B. D. Meek of ARS-USDA, Brawley, California.

Fig. 4. Relationships between nitrate-nitrogen concentration in the drainage water of the 1.5- to 4.5-meter depth beneath plots of Hanford soil treated with manures, and calculated mineralized nitrogen for 4 years.

following large applications, but is largely dependent on the decay series.

Table 3 presents data for calculated N inputs from organic N sources to meet crop needs, and $\text{NO}_3\text{-N}$ in excess of crop needs, for three decay series for a given cropping sequence that could involve a series of 5 years of row crops followed by 3 years of alfalfa. The sequence is used to show the use of decay series in calculating crop needs, and to illustrate that the amounts of organic material added can be adjusted to meet crop needs for N, depending on the decay series of the organic material and the yearly fluctuations in crop needs.

In a practical sense, the decay series is useless unless one keeps adequate records of manure applications over a period of time. If records are not kept, the only meaningful factor is the avail-

ability of N during the first year or season. In this case, one should develop a method for estimating the residual effects of manures, including effects of all organic N in the soil profile.

The experience in obtaining manures for this field trial illustrates the problem of quality control in these materials. For seven of the eight applications, dry manures were obtained from the same dairyman. During these seven applications, the N content of the manure varied from 1.4 to 2.2% of the dry weight, and the water content of the material delivered to the field varied from 19.8 to 50.3%. When the time arrived for the eighth and last application, the dairyman who had provided the previous supply was unable to furnish the material. Consequently, a new source which had only 0.75% N on a

Fig. 5. Relationships between annual mineralization rates and time, for large applications every fourth year, as compared to annual applications of one-fourth as much N in a manure having a decay series of 0.50, 0.10, 0.05, 0.05—.

dry weight basis was used. The total effect was that the quantities of dry weight and N for each application varied. The difficulty in timing, and also in acquisition of the manures, prohibited analysis of materials before application so that the wet weight could be adjusted to the exact amount of dry weight required. Even with an exact amount of dry weight, the amount of N applied would have varied considerably.

The liquid manure came from the same source for all eight applications. The dry matter content of this material varied from 9.0 to 12.2% except for the last application, when it was 15.8%. Also, the N content varied from 4.1 to 5.6%, except for the last application, when it was 2.42%. The last material delivered could have had much more time in the collection system, so that both water and N were lost.

The problem of finding manures of

Fig. 6. Relationships between annual mineralization rates and time for large applications every fourth year, as compared to annual applications of one-fourth as much N in a manure having a decay series of 0.35, 0.10, 0.05, 0.05—.

high quality and composition is one of the obstacles to the use of manures on croplands. Perhaps the value of manure is so low compared to commercial inorganic fertilizers on a per-ton basis, that marketing a product of consistent quality would not be financially rewarding. However, as economics change, the relative value of manure may make possible the marketing of quality products of consistent composition. If and when this occurs, the task of assigning availability indexes to various products will be greatly simplified.

Considering the variability in the N content of the dry manures added in this field trial, the agreement between

calculated and measured accumulation of organic N in soils was excellent. Perhaps the decay series fit the average, and there were compensating effects of the manures of higher and lower N contents.

The advantages of the liquid manure, with its high N content, are obvious. Maximum yields were obtained with 79 dry tons per ha/yr from the dry manure, whereas 21 tons of dry material from liquid manure gave slightly higher yields. A comparative study of NO_3^- contents of sudangrass forage (Pratt *et al.*, 1975) indicated that 29 dry tons of dry manure were equivalent to 8.6 dry tons from the liquid manure. The

Fig. 7. Relationships between annual mineralization rates and time for large applications every fourth year, as compared to annual applications of one-fourth as much N in a manure having a decay series of 0.15, 0.05, 0.025, 0.025—.

amount of salt added per unit of available N was much smaller with the liquid manure.

Fresh dairy manure is reported to have between 3.5 and 4.0% N, with about half in the form of urea. As the manure is aged in the corral, at least half, and in many instances more than half, of the total N is lost by volatilization of NH_3 . If fresh dairy manure could be incorporated into the soil, or if the volatilization of NH_3 could be prevented during storage of the manure on the corral floor, the amount of dairy manure required to meet the ni-

trogen needs of crops would be reduced by one-half, with a corresponding reduction in soluble salts. At present, we do not have satisfactory methods for preserving the N in manures during storage, but a recognition of N losses can lead to better management of this resource.

If the urea or $\text{NH}_4^+\text{-N}$ or both, could be preserved in dairy and beef feedlot manure, the decay series would probably be about the same as for the liquid feedlot manure used in the study reported here.

TABLE 3

CALCULATED ORGANIC N INPUTS TO MEET CROP NEEDS AND NO₃-N IN
EXCESS OF CROP NEEDS, FOR A GIVEN CROPPING SEQUENCE

Time	Available nitrogen needed for crops	Decay series					
		0.50,0.10,0.05—		0.35,0.10,0.05—		0.15,0.05,0.025—	
		Input	Excess	Input	Excess	Input	Excess
Year		Nitrogen, kg/ha per yr					
1	180	360	0	514	0	1200	0
2	180	324	0	419	0	860	0
3	120	191	0	222	0	395	0
4	360	671	0	912	0	2015	0
5	120	135	0	83	0	0	14
6	0	0	40	0	62	0	87
7	0	0	34	0	56	0	85
8	0	0	32	0	54	0	83
9	180	298	0	369	0	660	0
10	180	272	0	308	0	486	0
11	120	144	0	124	0	60	0
12	360	628	0	826	0	1730	0
13	120	97	0	8	0	0	50
14	0	0	57	0	85	0	129
15	0	0	52	0	80	0	126
16	0	0	49	0	76	0	123
17	180	266	0	307	0	401	0
18	180	244	0	260	0	308	0
19	120	119	0	81	0	0	15
20	360	605	0	790	0	1566	0

LITERATURE CITED

AZEVEDO, J. and P. R. STOUT

1974. Farm manures: An overview of their role in the agricultural environment. Univ. of Calif. Division of Agri. Sci. Manual No. 44, Agricultural Publication, Univ. of Calif., Berkeley, CA 94720.

CAST REPORT

1975. Utilization of animal manures and sewage sludges in food and fiber production. Report No. 41 of the Council for Agricultural Science and Technology (P. F. Pratt, Task Force Chairman). Headquarters Office: Department of Agronomy, Iowa State University, Ames, Iowa 50010.

MEEK, B. D., A. J. MCKENZIE, T. J. DONOVAN and W. F. SPENCER

1974. The effect of large application of manure on movement of nitrate and carbon in an irrigated soil. *J. Environ. Quality* 3:253-258.

MEEK, B., L. CHESNIN, W. FULLER, R. MILLER and D. TURNER

1975. Guidelines for manure use and disposal in the Western Region, USA. Washington State University Agricultural Research Center, Bull 814.

POWERS, W. L., G. W. WALLINGFORD, L. S. MURPHY, D. A. WHITNEY, H. L. MANGES and H. E. JONES

1974. Guidelines for applying beef feedlot manure to fields. Cooperative Extension Service, Kansas State Univ., Manhattan, Kansas. 11 pp.

POWERS, W. L., G. W. WALLINGFORD and L. S. MURPHY

1975. Research status on effects of land application of animal wastes. Environ. Protection Technology Series. EPA-660/2-75-010 June 1975. U. S. Government Printing Office, Washington, D.C. 20403. Stock No. 055-001-01026.

PRATT, P. F., F. E. BROADBENT and J. P. MARTIN

1973. Using organic wastes as nitrogen fertilizers. *Calif. Agri.* 27:10-13.

PRATT, P. F., S. DAVIS, R. G. SHARPLESS, W. J. PUGH and S. E. BISHOP

1976. Nitrate contents of sudangrass and barley forages grown on plots treated with animal manures. *Agron. J.* 68:311-314.

TYLER, K. B., A. F. VAN MAREN, O. A. LORENZ and F. H. TAKATORI

1964. Sweet corn experiments in the Coachella Valley. Univ. of Calif. Agr. Expt. Sta. Bull. 808. 16 pp.

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