BUL 829

Optimal Utilization of Animal Manure on Cropland

University of Idaho
College of Agricultural and Life Sciences

Authors:

A. A. Araji, professor, and Z. O. Abdo, former research assistant, Department of Agricultural Economics and Rural Sociology, University of Idaho.

Introduction

Animal manure contains all the essential micro and macro elements required for plant growth. Land application of animal manure increases soil organic matter and improves a number of soil properties including soil tilth, water-holding capacity, oxygen content, and soil fertility. It also reduces soil erosion, restores eroded croplands, improves solar heat absorption, increases water infiltration rates, reduces nutrient leaching, and increases crop yields. In general, results of research indicate that manure is a valuable bio-resource that should be utilized (McCalla, 1942; Beaumont, 1974; Pratt, 1982; Araji and Stodick, 1990; and Cassman et al., 1995).

Idaho produces over 600,000 head of fed beef cattle annually and has an estimated 325,000 head of dairy cattle in confined feeding operations. Air-dry (45% to 50% moisture) annual manure pack accumulation in beef feedlots ranges from 4.1 tons to 4.9 tons per animal, depending on its beginning weight and feeding period (Araji and Sell, 1981). Dairy cattle with an average weight of 1000 lb produce an estimated 5 tons of air dry manure annually (USDA, 1992). Altogether, confined beef and dairy feeding operations in Idaho produce over 2.5 million tons of air-dry manure pack annually. This quantity is expected to increase in the future, thus increasing costs associated with alternative disposal methods and the potential for environmental problems.

Increasing energy costs for production of synthetic fertilizer may provide livestock producers with an economic outlet for their manure as an alternative to commercial fertilizer. The major outlet for animal manure is application to cropland. However, three physical and biological factors may restrict the use of animal manure on cropland. These include pathogen transmission, impact on crop yields, and composition of the manure. Pathogens do not present restrictions on the amounts of manure used when manure is incorporated into the soil. However, they can limit the amount of manure used on pastures when it is applied to the surface of the soil. Incorporation of manure into the soil represents little threat to the health of humans or animals (Burge, 1974).

Application of large quantities of manure may cause high salt levels that can reduce yields. The application of up to 60 tons of dry weight manure increased yields in corn, which is a crop with low tolerance to salinity. However, corn yields decreased with the application of greater than 60 tons per acre (USDA, 1979).

The greatest barriers in the use of manure as an alternative to commercial fertilizer are direct effects of its nature and composition. Manure is a bulky, low-grade fertilizer. On an air-dry weight basis (45% to 50% moisture), its total plant nutrient contents are only 10 to 20 percent of commercial fertilizer (CAST, 1975). For example, 8 tons of chicken manure are needed to meet the nutrient requirements for a wheat crop that would use 100 lb of commercial nitrogen and 40 lb of commercial phosphorus. The cost to haul and spread manure may limit the total amount of manure that can be added to land to satisfy crop nutrient requirements.

Objective

Effective utilization of animal manure on cropland is a function of the cost associated with hauling and spreading the bulky waste materials. This cost is directly related to the quantity of manure needed to satisfy the nutrient requirements of crops in a given rotation system. The quantity of manure needed is a function of the nutrient

Table 1: Chemical and physical properties of various soils in Iowa

Soil		pH	Carbon as		Sulfur		Nitrogen as			C/N RATIO	Physical Properties		
Type	Family		Organic	Inorganic	Total	Organic	Total	NH	NO		Clay	Sand	Moisture
			--- $g\ kg^{-1}$ ---		--- $g\ kg^{-1}$ ---		$g\ kg^{-1}$	---$mg\ kg^{-1}$---			-------------- $g\ kg^{-1}$ --------------		
1	Fine-silty, mixed, mesic Mollic Hapludalfs	5.1	18.6	0	0.262	0.249	1.82	6	6	10.28	190	30	230
2	Fine-loamy, mixed, mesic Typic Haplaquolls	6.5	30.8	0	0.333	0.322	2.51	3	6	12.32	250	380	210
3	Fine-loamy, mesic Typic Calciaquolls	7.6	35.9	29.6	0.470	0.466	2.76	5	7	13.06	290	330	280
4	Fine-loamy, mixed, mesic Mollic Hapludalfs	6.4	12.6	0	0.175	0.168	1.15	2	5	11.02	170	190	140
5	Fine, montmorillonitic, mesic Cumulic Hapaquolls	7.0	57.6	5.7	0.580	0.570	4.59	6	10	12.60	400	130	360

Source: Chai and Tabatabai

content of the manure and the mineralization rate of organic matter in the manure. The mineralization rate is influenced by the properties of the manure, the properties of the soil, soil temperature, and moisture. We will examine the impact of these factors on the optimal quantity of manure needed to satisfy the nutrient requirements for crops in rotation systems in Idaho at least cost.

Mineralization of Organic Nutrients in Soils Amended with Manure

Nitrogen, phosphorus, and potassium are the elements most frequently needed by major crops in Idaho in relatively large quantities. Sulfur is also used, but in lower quantities than the other elements. Potatoes are the only major crop in Idaho that require sulfur; they use from 30 to 80 lb per acre, depending on the location (Smathers). Previous studies show that both phosphorous and potassium in manure are equally available to plants regardless of whether they are from organic or inorganic sources.

Using manure as a source of nitrogen fertilizer requires an understanding of the underlying chemical processes. Organic nitrogen and organic sulfur in the manure must mineralize before they are available to plants. Of all the plant nutrients, crop requirements for nitrogen are the highest. Thus, the main concern with the use of manure as fertilizer is nitrogen content. Manure added at rates sufficient to supply all or substantial parts of the nitrogen needs of crops will also supply quantities of phosphorus, potassium, sulfur, and secondary and minor elements at levels more than adequate for most soil/crop/climate conditions (Pratt, 1982).

The only available study that precisely measured the mineralization of organic nitrogen in soils amended with manure is the one sponsored by the Environmental Protection Agency (EPA) and conducted by Chase and Tabatabai (1986). This study measured the mineralization rates of organic nitrogen in three types of animal manure applied to five different Iowa soils. The mineralization of organic sulfur was similarly measured by Tabatabai and Chase (1991). Soil properties for the five Iowa soils used in this study are shown in Table 1. The properties of the animal manures used in their study are shown in Table 2.

Mineralization Rates

The mineralization of organic nitrogen in the three types of manure differs significantly for the five different soils in the Chase and Tabatai study. Using Idaho temperature data, the amount of organic nitrogen remaining unmineralized after a 26-week incubation period ranged from a high of 81 to 86 percent to a low of 31 to 54 percent for the five soil types (see Figures 1 through 5, pp. 9-11). The Iowa soil type most similar to those found in southern Idaho is soil type 3 (see Table 1). For this soil type, between 45 to 63 percent of the organic nitrogen remained unmineralized during the 26-week incubation period (see Figure 3). These results clearly show that soil properties and manure properties significantly affect the mineralization of organic nitrogen in soil amended with manure.

The mineralization rate of organic nitrogen in soil type 3 amended with chicken, hog, and cow manure is used to determine the optimal quantity of manure needed to satisfy the nutrient requirements of the crops in the two rotation systems under southcentral Idaho soil and climate conditions. According to Paul McDaniel, University of Idaho soil scientist, soil type 3 is similar to many southern Idaho soils in terms of its pH level (alkaline), lime (CaC03) content, and soil texture (percentage of sand, clay). The main difference is that the organic carbon level in soil type 3 is greater than would be found in a typical southern Idaho soil. He felt that application of manure over several years would bring the organic carbon content in southern Idaho soils up to the level found in Iowa soil type 3.

Manure Application Rates

Based on the quantity of synthetic nitrogen presently used by Idaho farmers, manure application rates were determined to meet the nutrient requirements of crops in two common rotation systems in southcentral Idaho, potato-wheat-wheat (P-W-W) and sugarbeets-wheat-wheat (S-W-W). The mineralization rate of organic nitrogen is the key variable to determine the quantity of manure needed to satisfy the nutrient requirements of crops in the two rotation systems. The mineralization data for organic nitrogen provided by Chase and Tabatabai (1986) were used in an exponential smoothing statistical model (see p. 5) to determine the mineralization rate over time under southcentral Idaho soil and climate conditions. Data on the quantity of commercial fertilizers presently applied to crops in the two rotations in southcentral Idaho were obtained from the Crop and Livestock Cost and Return Estimates, published annually by the Department of Agricultural Economics and Rural Sociology at the University of Idaho (Smathers). Five years of average daily soil temperature data for the Twin Falls area were obtained from the climatology lab at the University of Idaho.

Table 2: Nutrient content of animal waste

Animal waste	pH	Organic C	Sulfur		Nitrogen as			C/N Ratio
			Total	Organic	Total	NH	NO	
		— g kg –1 —	— g kg –1 —		— g kg –1 —	— mg kg –1 —		
Chicken	7.7	380	1.60	0.733	22.0	785	1450	19.22
Hog	6.2	434	2.04	0.592	21.2	1160	194	21.86
Cow	5.9	473	1.99	0.659	22.4	204	153	21.45

Source: Chai and Tabat

The flowing equation simultaneously incorporates this information to determine the optimal quantity of manure that satisfies the nutrient requirements of crops in the two rotation systems.

Soil temperatures significantly affect the mineralization of organic nitrogen. Mineralization rates of organic nitrogen in soils amended with manure will decrease by almost 50 percent as soil temperatures drop from 30°C to 20°C (Provin). Previous studies have shown that the mineralization of organic nitrogen and organic sulfur in the manure ceases when soil temperature drops below 5°C. Daily soil temperature in the Twin Falls area is above 5°C for an average of 38 weeks during the year.

Model for Determining Manure Application Rate

$$R = \left(P - \sum_{k=0}^{z} \mathrm{Re}\, m_{m+(k \cdot 19)} \right) / Y_m^a$$

Where:

R = manure application rate per acre

P = amount of nitrogen presently used for crops in each rotation system

Z = number of periods when soil temperatures in southcentral Idaho are above 5° C (19 two-week periods)

$\mathrm{Re}m_{m+(k \cdot 19)}$ = the cumulative mineralized nitrogen produced from the organic nitrogen in the manure applied in previous year, K

Y_m^a = cumulative mineralization rate (lbN/lb manure) adjusted for soil temperature (All mineralization stops when soil temperature is below 5°.)

m = the last period at which the plant uptakes all of its needs of nitrogen in a year

Optimal quantities of manure (air dry basis, 45%-50% moisture) that satisfy the nutrient requirements of crops for the two rotations in this study under southcentral Idaho soil and climate conditions are shown in Table 3. For both rotations, the optimal quantities are highest in the first three years of the rotation. Application levels decline, then stabilize in the fourth year and thereafter.

Table 3: Optimum quantities of manure (tons per acre) needed to satisfy the nutrient requirements of crops in two rotations under southcentral Idaho's soil and climate conditions

Rotation	Manure Type	Year in Crop Rotation								
		1	2	3	4	5	6	7	8	9
		P	W	W	P	W	W	P	W	W
P-W-W	Chicken	30	10	10	29	10	9	29	10	9
	Hog	34	9	11	30	9	10	31	9	10
	Cow	39	7	12	35	7	11	35	7	11
		S	W	W	S	W	W	S	W	W
S-W-W	Chicken	16	11	10	14	10	9	14	10	9
	Hog	17	12	10	14	11	9	15	11	9
	Cow	20	11	11	16	11	11	17	11	11

LEGEND: P = potatoes
W = wheat
S = sugarbeets

For the potato-wheat-wheat (P-W-W) rotation, the optimum quantities of manure stabilize at 29, 10, and 9 tons per acre per year for the three crops using chicken manure; 31, 9, and 10 tons per acre per year for the three crops using hog manure; and 35, 7, and 11 tons per acre per year for the three crops using cow manure. For the sugarbeets-wheat-wheat (S-W-W) rotation, the optimum quantities of manure stabilize at 14, 10, and 9 tons per acre per year using chicken manure; 15, 11, and 9 tons per acre per year using hog manure; and 17, 11, and 11 tons per acre per year using cow manure.

Nearly all of the estimated 2.5 million tons of animal manure produced annually in Idaho is from beef and dairy cattle in confined feeding operations. The optimal quantity of cow manure as estimated in this study can provide the crops in these rotations with the quantity of nitrogen, phosphorus, potassium, and sulfur as well as micro and macro elements equal to what is presently applied by farmers in southcentral Idaho to these crops using chemical fertilizers.

The EPA has expressed concern that dumping large quantities of manure (over 40 tons per acre per year) may increase the phosphorus content in surface water and thus potentially stimulate the growth of algae. Phosphorus is not toxic to human and animal health and it does not leach to groundwater except in very sandy soils. The average yearly air dry weight manure application rates estimated in this study are 17.6 tons per acre of cow manure for the P-W-W rotation and 13 tons per acre for the S-W-W rotation. Phosphorus in cow manure is 0.5 percent of the dry matter content. The optimal quantity of cow manure estimated for the rotations in this study will provide 175 lb of phosphorus per acre for potatoes, 45 lb for wheat, and 80 lb for sugarbeets. These quantities are very close to what is presently used by farmers in southcentral Idaho and will cause no harm to surface water.

Potatoes are the only crop in these two rotations that requires sulfur. Sulfur use for potato production in southcentral Idaho is 80 lb per acre. Organic sulfur in cow manure is 0.2 percent of the dry matter content. About 70 percent mineralizes during the first 26-week period (Chase and Tabatabai, 1991). The optimal stabilized quantity of cow manure for the P-W-W rotation will provide over 70 lb of mineralized sulfur per acre for the potatoes.

Application Cost

The hauling and spreading cost of applying manure to cropland is a function of the optimal quantity of required manure, distance traveled, and the cost per ton for loading, hauling, and spreading. Custom manure-hauling services in the Twin Falls area generally use trucks with a 10-ton capacity equipped with an eight-foot spreader. They charge $19 per truck for loading and hauling a one-mile round-trip. They also charge $1.50 per mile per truckload for each additional mile after the first round-trip mile. This custom service charge is used to account for the fixed and variable costs associated with loading, hauling, and spreading manure. The hauling, loading, and spreading cost for each rotation is estimated below:

Estimating Manure Hauling, Loading, and Spreading Cost

$$C = \sum_{i=1}^{N} \left(C_L + C_t \cdot \left(D_i - 1 \right) \right)$$

Where:

- C = hauling and spreading cost for each crop in the rotation ($ per acre)
- C_L = round-trip cost of loading and hauling a truckload of 10 tons of manure for the first mile
- C_t = round-trip transportation cost for spreading a truck load of 10 tons of manure after the first mile
- D_i = distance traveled to spread the i^{th} truckload of manure
- N = number of truckloads needed per acre to satisfy the nutrient requirements of the crops in a given rotation system

The most important variable affecting the cost of utilizing animal manure on croplands is the distance traveled to haul and spread the manure (D_i). It is a function of the optimum quantity of manure, the area of the field, the length of the field, the distance of the manure pile from the field, the capacity of the truck, and the width of the spreader. A set of simple equations has been developed to estimate the distance traveled to haul and spread manure on a rectangular field and on a circular field (see page 8).

The costs of applying the optimal quantity of manure to satisfy the nutrient requirements of the crops in the two rotations in this study are estimated and compared to the cost of applying commercial fertilizer (Table 4). The results show that the costs differ with types of manure and the distance between the source of the manure and the receiving field. Under southcentral Idaho soil and climate conditions, the cost of applying cow manure to the P-W-W rotation ranges from 31 percent of the cost of applying commercial fertilizer for a 1/2-mile distance between the source of the manure and the receiving field to 82 percent of the cost of commercial fertilizer for a 12-mile distance between the source of the manure and the receiving field. For the S-W-W rotation, the cost ranges from 49 percent of the cost of commercial fertilizer for a 1/2-mile distance between the source of the manure and the receiving field to 86 percent of the cost of commercial fertilizer for a 6-mile distance between the source of the manure and the receiving field.

Maximum Distance

The maximum distance traveled between the source of the manure and the field to equate the cost of applying the required quantity of manure to the cost of applying commercial fertilizer is estimated on p. 7.

The maximum distance to transfer manure from its source to the receiving field is summarized in Table 5. For the P-W-W rotation under southcentral Idaho soil and climate conditions, the results show that cow manure can be transferred a maximum distance of 16 miles from its source to the receiving field to equate its application cost to the cost of commercial fertilizer for a circular field. For the S-W-W rotation, cow manure can be transferred a maximum distance of 8.3 miles from its source to the receiving field to equate its application cost to the cost of commercial fertilizer for a circular field.

Table 4: Manure application cost per acre for two rotations by shape of the field and distance from the receiving field[ab]

Manure Type	Distance from the field (miles)	Rotation P-W-W (potatoes - wheat - wheat)				Rotation S-W-W (sugarbeets - wheat - wheat)			
		Rectangular Field		Circular Field		Rectangular Field		Circular Field	
		Cost ($/ac)	% of commercial fertilizer cost	Cost ($/ac)	% of commercial fertilizer cost	Cost ($/ac)	% of commercial fertilizer cost	Cost ($/ac)	% of commercial fertilizer cost
Chicken	0.5	87	28	80	26	72	42	65	38
	3.0	117	38	111	36	96	56	89	52
	6.0	155	50	148	48	132	77	120	70
	9.0	192	62	185	60	155	90	150	87
	12.0	241	78	232	75	196	114	191	111
Hog	0.5	93	30	83	27	76	44	69	40
	3.0	124	40	114	37	101	59	96	56
	6.0	161	52	155	50	132	77	127	74
	9.0	201	65	195	63	165	96	158	92
	12.0	241	78	232	85	196	114	191	111
Cow	0.5	96	31	98	28	82	49	77	45
	3.0	130	42	124	40	119	65	107	62
	6.0	170	55	164	53	148	86	141	82
	9.0	213	69	204	66	182	106	188	103
	12.0	253	82	247	80	220	128	212	123

[a]Commercial fertilizer cost per acre, including application, is $219 for potatoes and $45 for wheat (two years) for a total of $309 for the three-year rotation.

[b]Commercial fertilizer cost per acre, including application, is $82 for sugarbeets and $45 for wheat (two years) for a total of $172 for the three-year rotation.

NOTE: These costs are based on the following price assumptions: N is $0.31/lb, P is $0.21/lb, K is $0.13/lb, S is $0.16/lb, liquid phosphate is $0.33/lb, and post-planting N is $0.35/lb. The input rates for potatoes are 210 lb N preplant, 180 lb P, 100 lb K, 80 lb S, 20 lb liquid phosphate, and 80 lb of N post-planting. Input rates for wheat are 100 lb of N and 40 lb of P. For sugarbeets, input rates are 75 lb N preplant, and 75 lb N post-planting.

Estimating Maximum Distance For Transporting Manure

$$L_{max} = \frac{(C_s - C)}{4Q \bullet C_t} \bullet A, \text{ for a circular field}$$

$$L_{max} = \frac{(C_s - C)}{2N \bullet C_t} \bullet A, \text{ for a rectangular field}$$

Where:

L_{max} = the maximum distance traveled

C_s = the cost of commercial fertilizer

C = loading and hauling cost of a truckload of 10 tons of manure for the first round-trip mile

C_t = transportation cost for spreading a truckload of 10 tons of manure after the first round-trip mile

N = number of truckloads needed to haul and spread the optimal required quantity of manure on a rectangular field

Q = number of truckloads needed to haul and spread the optimal required quantity of manure on a circular field

A = area of the field

Summary

Confined beef and dairy cattle feeding operations in Idaho produce over 2.5 million tons of animal manure annually. Animal manure is a viable bio-resource that should be economically utilized. It contains all the essential elements for plant growth. The major outlet for animal manure is application to cropland. Effective utilization of animal waste on cropland is a function of the cost associated with hauling and spreading the wastes. This cost varies with the quantity of manure needed to satisfy the nutrient requirements of crops in any rotation system. The quantity of manure needed is a function of the nutrient content of the manure and the mineralization rate of organically combined molecules.

Nitrogen, phosphorus, and potassium are the elements that are most frequently needed in relatively large quantities. For some crops in certain locations, sulfur is also required. Phosphorus and potassium are equally available to plants from organic sources as from inorganic sources. Nitrogen and sulfur in manure must be mineralized before they are available to plants. The mineralization of organic nitrogen and sulfur is a function of the properties of the manure, the properties of the soil that receives the manure, and soil temperature.

Manure application rates per acre were determined for the following three-year rotation systems: potatoes-wheat-wheat (P-W-W) and sugarbeet-wheat-wheat (S-W-W). The optimum quantity of manure required for both rotations decreases during the first three years of the rotation, as organic nitrogen from previous years' manure applications becomes available through mineralization. Optimum quantities stabilize in the fourth year of the rotation and thereafter.

Practically all of the manure produced in Idaho is cow manure from confined beef and dairy cattle feeding operations. Optimum quantities of cow manure needed to satisfy the nutrient requirements in a three-year crop rotation of potatoes-wheat-wheat stabilize at 35, 7, and 11 tons per acre, for a yearly average of 17.6 tons per acre. For the sugarbeets-wheat-wheat rotation, optimum quantities stabilize at 17, 11, and 11 tons per acre for these three crops, for a yearly average of 13 tons.

Based on the assumptions of this study, we have determined the maximum distance to transfer manure from its source to the receiving field to equate its application cost to the cost of commercial fertilizer. For cow manure applied to rotation P-W-W under southcentral Idaho soil and climate conditions, this distance is estimated at 16 miles, assuming a circular field. For rotation S-W-W, this distance is estimated at 8.3 miles. The practical implications of these results are that cow manure could reasonably satisfy the nutrient needs for typical crop rotations on a number of farms in the Twin Falls area, reducing environmental costs associated with waste disposal and reducing fertilizer costs for farmers within close proximity to confined feeding operations in this area. As costs of using fossil fuels inevitably rise, it will become economical for farmers at greater distances from confinement operations to consider the substitution of animal waste for commercial fertilizer.

Table 5: Distance in miles for transporting manure that equates its application cost to the costs of using commercial fertilizer

Type of Manure	Rotation P-W-W (potatoes - wheat - wheat)		Rotation S-W-W (sugarbeets - wheat - wheat)	
	Rectangular Field (mile)	Circular Field (mile)	Rectangular Field (mile)	Circular Field (mile)
Chicken	17.8	18.4	9.8	10.4
Hog	17.0	17.6	9.1	9.7
Cow	15.4	16.0	7.8	8.3

Equation to Estimate Distance Traveled to Spread Manure on a Rectangular Field

The distance traveled to haul and spread manure on a rectangular field is estimated by the following equation:

$$D_i = \left\{ 2L + \frac{W \cdot 8.25}{R \cdot M} + \left([K_{i-1}] + [K_i] - 2 \right) \cdot \frac{M}{5280} + d_{i-1} + d_i \right\}$$

Where:

- D_i = the distance traveled in miles to haul and spread the i[th] load of manure
- i = 1 to N
- N = number of truckloads needed to haul and spread the manure required for a field of size A this is equal to $(R \cdot A)/W$
- R = manure application rate (ton/acre)
- A = area of the field (80 acres), and A is equal to the spreader width l
- l = length of the field (0.25 miles)
- L = distance of manure pile from the field in miles (0.5 miles)
- K_i = $\frac{i \cdot W \cdot 8.25}{R \cdot M \cdot l}$ = the number of times the truck will go up and down the field to spread the i[th] load, and $[K_i]\left(\frac{M}{5280}\right)$ is the distance from the edge of the field to the new spreading location for the i[th] load
- $[K_i]$ = a step function equal to the least integer greater than or equal to K_i
- d_i = $\{[K_i] - K_i\} \cdot l$, if $[K_i]$ is even
- d_i = $\{[K_i] - K_i + 1\} \cdot l$, if $[K_i]$ is odd
- d_i = distance traveled in miles from the side of the field to the location of spreading the i[th] load
- W = capacity of truck in tons (10 tons)
- M = width of spreader (8 feet)

Equation to Estimate Distance Traveled to Spread Manure on a Circular Field

The distance traveled to haul and spread manure on a circular field is estimated by the following equation:

$$D_i = \left\{ 2L + \frac{W \cdot 8.25}{R \cdot M} + K_{i-l} + K_i + d_{i-1} + d_i \right\}$$

Where:

- D_i = the distance traveled in miles to haul and spread the i[th] load of manure
- i = 1 to Q
- R = manure application rate (ton/acre)
- L = distance of manure pile from the field in miles
- W = capacity of truck in tons (10 tons)
- M = width of spreader (8 feet)
- K_i = $\frac{i \cdot W \cdot 8.25}{R \cdot M} - \sum_{j=i}^{Q_i} \pi \cdot (r - j \cdot M)$, if Qi is even
- K_i = $\{\pi \cdot (r - j \cdot M)\} - \left(\frac{i \cdot W \cdot 8.25}{R \cdot M} - \sum_{j=i}^{Q_i} \pi \cdot (r - j \cdot M) \right)$ if Q_i is odd
- d_i = $\left((Q_1 - 1) \cdot \frac{M}{5280} \right)$
- Q_i = the number of times the truck will go up and down the field when spreading the i[th] load
- r = the radius of the field in miles

Figure 1: Percent of nitrogen remaining in organic form by type of manure
Soil Type 1

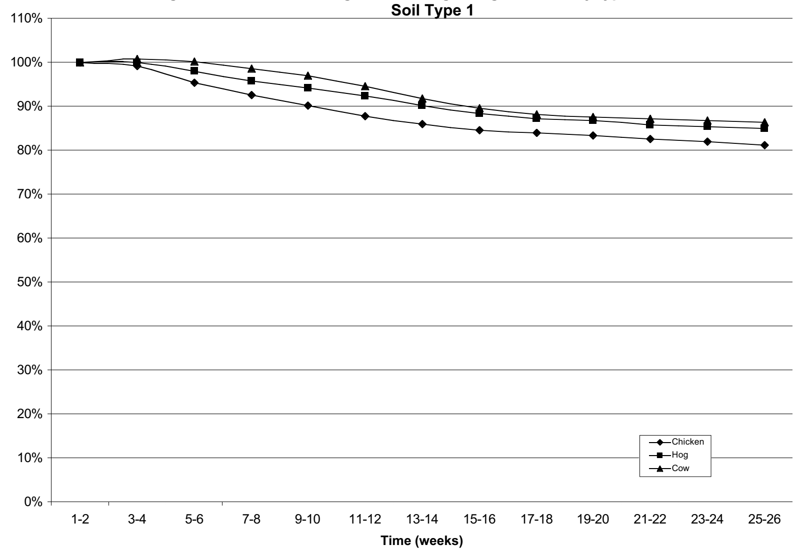
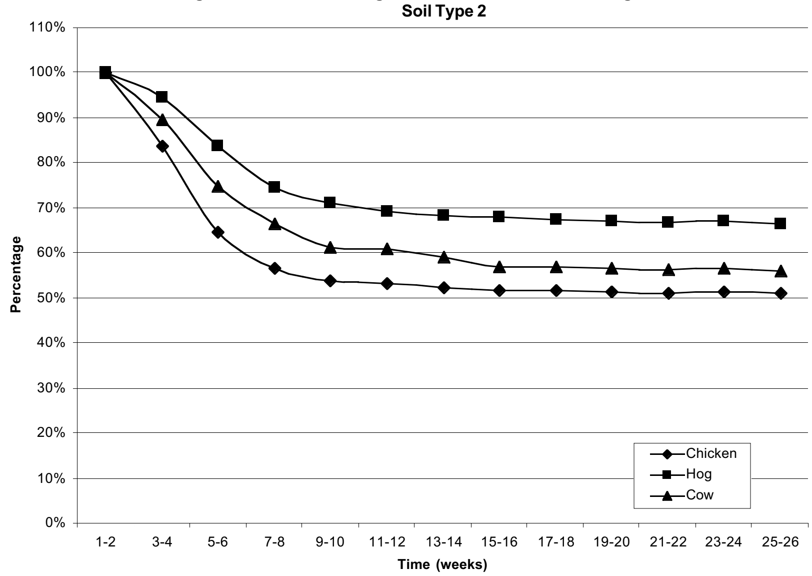


Figure 2: Percent of nitrogen in the manures remain in organic form
Soil Type 2



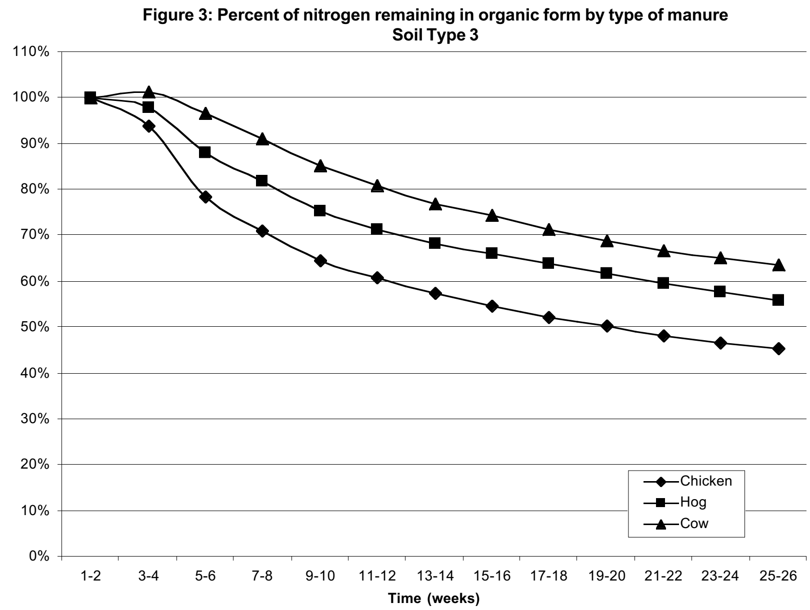


Figure 3: Percent of nitrogen remaining in organic form by type of manure
Soil Type 3
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1-2
3-4
5-6
7-8
9-10
11-12
13-14
15-16
17-18
19-20
21-22
23-24
25-26
Time (weeks)
Chicken
Hog
Cow

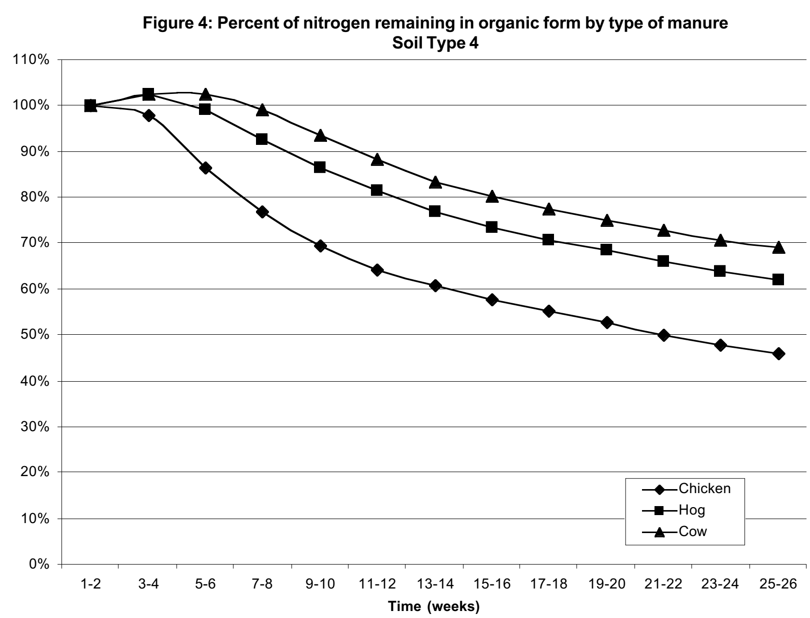
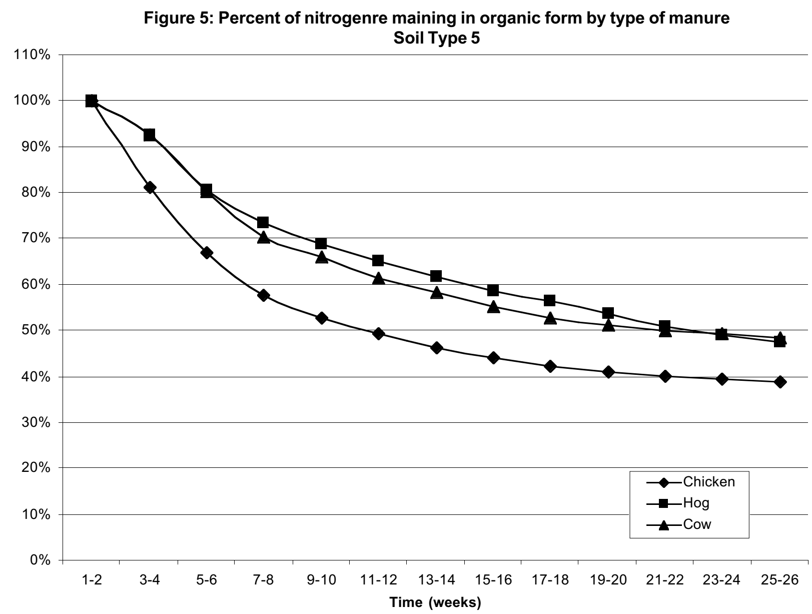


Figure 4: Percent of nitrogen remaining in organic form by type of manure
Soil Type 4
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1-2
3-4
5-6
7-8
9-10
11-12
13-14
15-16
17-18
19-20
21-22
23-24
25-26
Time (weeks)
Chicken
Hog
Cow



References

Araji, A.A. and Sell, D.E. 1981. "Least Cost Use of Animal Manure in Agricultural Production: Effect Of Feedlot Size, Hauling Distance, and Application Rate." Research Bulletin, No. 118. Idaho Agricultural Experiment Station.

Araji, A.A. and L.D. Stodick. 1990. "The Economic Potential of Feedlot Manure Utilization in Agricultural Production." Biological Manure, 32:111-124.

Beaumont, A.B. 1974. Artificial Manures or the Conservation and Use of Organic Matter for Soil Improvement. Orange Judd Publishing Company, Ltd, New York.

Burge, W.D. 1974. "Pathogen Considerations." Chapter in Factors Involved in Land Application of Agricultural and Municipal Manure. ARS-USDA, Beltsville, MD.

Cassman, K.G., Steiner, R., and Johnson, A.E. 1995. "Long Term Experiments and Productivity Indexes to Evaluate the Sustainability of Cropping Systems." Chap. II in Agricultural Sustainability: Economic, Environmental and Statistical Considerations. Edited by Barnett, V.R. Payne, and R. Steiner. UK: John Wiley & Son.

Council for Agricultural Science and Technology (CAST). 1975. Utilization of Animal Manures on Food And Fiber Production. Rep. No. 41.

Chase, Y.M. and M.A. Tabatabai. 1986. "Mineralization of Nitrogen in Soils Amended with Organic Manure." Journal of Environmental Quality, 15:193-198.

McCalla, T.M. 1942. "Influence of Biological Products on Soil Structure and Infiltration." Soil Sci. Soc. Amer. Proc. 7: 209-214.

Pratt, P.F. 1982. "Fertilizer Value of Manure." Paper presented at the Agricultural Waste Conference. March 1982, Mexico City, Mexico.

Smathers, R. L. (various)Crop and Livestock Costs and Return Estimates. University of Idaho Cooperative Extension Publications.

Tabatabai, M.A. and Y. M Chase. 1991. "Mineralization of Sulfur in Soils Amended with Organic Wastes." Journal of Environmental Quality, 20:684-690.

United States Department of Agriculture. 1979. Animal Waste Utilization on Cropland and Pastureland. USDA Utilization Report No. 6 and EPA-600/2-79-059.

United States Department of Agriculture. 1992. Agricultural Waste Management Field Manual. Soil Conservation Service.