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MANAGEMENT OF AGRICULTURAL WASTES AS AN ALTERNATIVE ENERGY SOURCE

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Abstract

Animal manure represents one of the most under utilized resource in the United States. In 2000, air-dry manure pack that has accumulated in beef and dairy cattle confined feeding operations exceeded 131 million tons. This quantity manure is not efficiently utilized and often considered a source of pollution. The major outlet for animal manure is application to cropland. 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. Manure application to cropland will also reduce soil erosion, restore eroded cropland, improve solar heat absorption, increase water infiltration rates, reduce nutrient leaching, and increase crop yield. Manure added at rates sufficient to supply all or substantial parts of the nitrogen needs of crops will also supply quantities of phosphorus, potassium, and secondary and minor elements at levels more than adequate for most soil-crop-climate conditions.

Manure is a bulky and low-grade fertilizer. 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 mineralization rate of organic matter in the manure, which is influenced by the manure properties, soil properties, soil temperature and moisture.

The objective of this study is to evaluate the simultaneous effect of these variables on the optimal quantity of manure that satisfies the nutrient requirements for crops in different rotation systems at least cost and to estimate the maximum distance manure can be transferred from its source to the receiving field to equate it hauling and application cost to the cost of using synthetic fertilizers.

MANAGEMENT OF AGRICULTURAL WASTES AS AN ALTERNATIVE ENERGY SOURCE

Introduction

Animal manure represents one of the most under utilized fertilizer resources in the United States (U.S.). In 1976, over 160 million tons of dry weight animal manure was produced in the U.S. About 40 percent of this total was produced in confined areas (Van Dyne and Gilbertson, 1978). Using the method developed by Araji and Sell (1981), it is estimated that in 1998, air-dry manure pack that has accumulated in beef and dairy cattle confined feeding operations in the U.S., exceeded 131 million tons. This portion is not efficiently utilized and often considered a source of pollution.

The major outlet for animal manure is application to cropland. 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 (McCalla, 1942; Beaumont, 1974; Dubetz et al., 1975; Haynes, 1984; Sommerfeldt & Chang, 1985; Sommerfeldt and Chang, 1987; and Sommerfeldt et al., 1988; Chang et al., 1990; and Cassman et al., 1995). Manure application will also reduce soil erosion, restore eroded cropland, improve solar heat absorption, increase water infiltration rates, reduce nutrient leaching, and increase crop yields (Cumming et al., 1975; Lund et al., 1975; Pratt & Page, 1977; Frye et al., 1985; Wen & Easter, 1987; Dormaar et al., 1988; Evans et al., 1990; and Freeze et al., 1993). In addition, animal manure provides more trace elements than commercial fertilizer (Haynes, 1984). Pratt (1982) showed that manure added at rates sufficient to supply all or substantial parts of the nitrogen needs of crops will also supply quantities of phosphorus, potassium, and secondary and minor elements at levels more than adequate for most soil-crop-climate conditions. In general, all studies since the 1940's indicate that manure is a valuable bio-resource that should be utilized.

Economically, animal manure, as a source of fertilizer in crop production, is a valuable resource to be utilized (Roka and Haag, 1996). The problem with the use of animal manures as an alternative to commercial fertilizer; however, is the direct effect of its nature and composition on hauling and application cost. Manure is bulky and low-grade fertilizer. On air-dry weight basis, its total plant nutrient contents are only 10 to 20 percent of those of most commercial fertilizers (CAST, 1975). The rate of manure application to satisfy the nutrient requirements of plants is a function of the composition of the manure, and the nitrogen mineralization rates (Powers et al., 1975). Gilbertson et al., (1979) showed that the annual mineralization rate of organic nitrogen in animal manure is positively correlated with the waste's nitrogen content. Willrich et al. (1974) estimated four series of decay constants for manure with different nitrogen contents. Pratt (1982), based on data from a 4-year field trial, estimated five series of decay constants for manure with different nitrogen contents. These studies, however, did not consider the effect of manure properties, soil properties, soil temperature and moisture on the mineralization rates of organic nitrogen.

Chae and Tabatabai (1986) measured the effect of soil properties, manure properties, soil temperature, and soil moisture on the mineralization of organic nitrogen under 30°C. Proven (1991) measured the mineralization rates of organic nitrogen at 20°C and 30°C and showed that soil temperature has a significant effect on the mineralization rate of organic nitrogen, and that mineralization ceased when soil temperature drops below 5ºC.

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 mineralization rate of organic matter in the manure, which is influenced by the manure properties, soil properties, soil temperature and moisture. The objective of this study is to evaluate the simultaneous effect of these variables on the optimal quantity of manure that satisfies the nutrient requirements for crops in different rotation systems at least cost.

Materials and Methods

Data Collection

Data developed by Chae and Tabatabai (1986) on the mineralization rate of organic nitrogen (N) for three types of manure applied to five different soils is used in this study to determine the optimal amount of manure needed to satisfy the nutrient requirement of crops in a given rotation system (Table 1). This is the only recent data available on the mineralization of organic nitrogen under different manure and soil conditions. Chae and Tabatabai (1986) measured the amount of N mineralized in mg Kg^{-1} soil for 13 two-week periods under soil temperature of 30°C. To facilitate modeling, the data is converted to lb. N/lb. manure and adjusted for soil temperature as shown in the method section. The properties of the manures are shown in Table 2 and the properties of the soils are shown in Table 3.

Daily soil temperature in several locations in Idaho is collected each year and compiled for several years by the Idaho Climate Lab. Data on manure hauling and spreading cost was obtained from Custom Hauling and Spreading Services in the Twin Falls area of Idaho in 1998-1999. Data on the quantity and cost of recommended commercial fertilizer presently applied to crops in the rotation systems considered in this study were obtained from the Crop and Livestock Costs and Returns Estimates, published annually by the Department of Agricultural Economics at the University of Idaho.

Analysis of Variables

Analysis of covariance (ANCOVA) was used to evaluate the effect of manure and soil properties on the mineralization of organic nitrogen. A full model containing dummy variables to separate the effect of each soil-manure combination on the mineralization process over time is shown in Equation 1.

$$Y = b_0 + b_1 \cdot T + \sum_{i=2}^{15} b_{1i} \cdot S_i \cdot T \qquad (1)$$

Where:

- Y = the cumulative mineralized nitrogen, lb. N/lb. of manure
- b_0 = intercept
- b_1 = slope; reflecting the behavior of the mineralization process of the first soil-manure combination over time
- i = is from 2 to 15 (fifteen different soil-manure combinations)
- T = time, two-week period
- b_{1i} = slope; reflecting the behavior of the mineralization process due to the i^{th} soil-manure combination
- S_i = a dummy variable used to separate the effect of different soil-manure combination

The reduced model generated from Equation 1 is shown in Equation 2.

$$Y = b_0 + b_1 \cdot T \qquad (2)$$

The sum of squared error (SSE), for the full and the reduced models were estimated and used to determine the Cow-F statistic as shown in Equation 3.

$$\text{Chow-F} = \frac{\{(SSE_R - SSE_F)/k\}}{\{SSE_F/(n-p)\}} \qquad (3)$$

Where:

SSE_R = sum of the squared error for the reduced model

SSE_F = sum of the squared error for the full model

N = number of available observations (195)

P = number of parameters to be estimated by the full model (16)

K = number of parameters omitted from the full model to produce the reduced model

The Chow-F statistic of 42.76 (p-value 0.0001) is significant at the 0.05 level, indicating that the fifteen manure-soil combinations differ significantly from each other in the mineralization process of organic nitrogen over time (Table 4).

Mineralization Rates

The mineralization rate of organic nitrogen in each manure-soil combination is essential to determine the quantity of manure required to satisfy the nutrient requirements for crops in a given rotation system. Several models were developed and tested for their accuracy in predicting the mineralization rates of organic nitrogen over time. All models were compared using mean squared errors (MSE's) and coefficients of multiple determinations (R^2). The best-fit models were further tested using residual plots, autocorrelation plots, partial autocorrelation plots, inverse autocorrelation plots, and white noise tested plots generated by SAS.

The four linear models tested had high MSE and low R^2 compared to the other models. The linear model with logarithmic transformation of time is used to improve the fitness; however, the results show the manure to immobilize in some cases, and in other cases, the mineralization continues linearly. The residual plots for all fifteen manure-soil combinations also indicate the existence of mis-specification in the linear models. All plots suggested the existence of a cyclical pattern with large variation in the first period that dies out by the last period. These results are not consistent with the mineralization of organic nitrogen in manure treated soils, as shown by the data set.

Multinomial transformations are used to correct the cyclical trend and the heterogeneity of the variance, and thus, improve the fitness of the models. Although such transformations do improve the error behavior, they reduce the models' prediction capacity. Models resulting from such transformations tend to predict nitrogen accumulation (immobilization) instead of a continuous mineralization, which is not consistent with the trend in the data set. The Q-Q graphs for the linear models also indicate a light tailed distribution of the residuals. Due to the above statistical results, the linear models were considered poor predictors of the mineralization of organic nitrogen over time.

Four different non-linear functional forms were developed and tested to explain the mineralization process of organic nitrogen, they are: (1) two parameter exponential function, (2) three parameter exponential function, (3) three parameter Weibull function, and (4) four parameter Weibull function (Bain and Englelhardt, 1994). The best-fit nonlinear models are the four-parameter Weibull and the three- parameter exponential. The first assumes time dependent mineralization rates, and the second assumes a fixed mineralization rate. Both models have higher R^2 and lower MSE than the linear models. These models, however, predict that the accumulated mineralized nitrogen reaches an asymptote very fast, which sets a limit on the mineralization of organic nitrogen over time. Consequently, the non-linear models tend to underestimate the actual amount of nitrogen that will mineralize from organic nitrogen in the manure.

The non-linear models have a serious model mis-specification as detected from the residual plots. The Q-Q graphs show the existence of a non-linear trend that cannot be explained by the models. The trend is cyclical in some cases, and most cases is quadratic indicating a lack of fit. Thus, the non-linear models are considered poor predictors of the mineralization of organic nitrogen over time.

Exponential smoothing method is found to be most effective when the parameters describing the time series are changing slowly over time. This method uses last period error to add to or subtract from this period value to predict next period value. Three different exponential smoothing models were compared and tested, they are: (1) Double Brown, (2) Linear Holt, and (3) Holt-Winter two-parameter (Bowerman, 1993; Makridakis et al., 1983).

Compared to the others, the Holt-Winter two-parameter model had the lowest MSE and the highest R^2 coefficients for all fifteen manure-soil combinations. It is the best model to explain the mineralization of organic nitrogen for the fifteen manure-soil combinations. This is due to the dampening component in the data set (Table 5). The Holt-Winter's two-parameter double smoothing with a damped trend is composed of three different equations: one for the level or movement around the mean (Equation 4), one for the trend or linear relation (Equation5), and one for the prediction or the damped part (Equation 6), as shown below.

$$a_0(T) = \alpha \cdot Y_T + (1-\alpha) \cdot \{a_0(T-1) + \phi \cdot b_1(T-1)\} \tag{4}$$

$$b_1(T) = \beta \cdot \{a_0(T) - a_0(T-1)\} + \{(1-\beta) \cdot \phi \cdot b_1(T-1)\} \tag{5}$$

$$\hat{Y}_{T+\tau} = \begin{Bmatrix} a_0(T) + \phi \cdot b_1(T) & 1 \le T \le 13 \;\&\; \tau = 1 \\ a_0(T) + \sum_{i=1}^{\tau} \phi^i \cdot b_1(T) & T \ge 13 \end{Bmatrix} \tag{6}$$

Where:

α	= level smoothing constant between 0 and 1
ϕ	= damping factor between 0 and 1
β	= trend smoothing constant between 0 and 1
$a_0(T)$	= the level component of the cumulative mineralized nitrogen, i.e. the fixed amount or the constant in the predication equation for period T
$b_1(T)$	= the trend component or the component of the cumulative mineralized nitrogen that changes with time at that period (T); simply it is the slope component
$Y_{T+\tau}$	= the T + τ period estimate of the cumulative mineralized nitrogen
T	= time period in the actual data set with a maximum of 13 two-week periods for each soil
τ	= time beyond period 13

Manure Application Rate

The accumulated mineralized nitrogen from organic nitrogen in the manure, estimated by the Holt-Winter model for each of the fifteen manure-soil combinations, was used in Equation 7 to estimate manure application rates for crops in a given rotation system.

$$R = \left(P - \sum_{k=0}^{z} \mathrm{Re}\, m_{m+(k\cdot 19)} \right) \Big/ Y_m^a \qquad (7)$$

Where:

R	= manure application rate (ton/acre)
P	= amount of nitrogen required to provide for the plant uptake (lb./acre)
Z	= number of periods elapsed after the first year up to, but not including, the current year
$\mathrm{Rem}_{m+(m.19)}$	= the cumulative mineralized nitrogen released from the remaining organic nitrogen, applied in year k, and available at the last period
Y_m^a	= cumulative mineralization rate (lb N/lb manure) adjusted for soil temperature

m = the last two-week period at which the plant uptakes all of its needs of nitrogen in a year; this period varies depending on the crop

In the Twin Falls area of Idaho, 19 is the maximum number of two-week periods in a year in which soil temperature is over 5ºC and mineralization occurs. Both $Rem_{m+(k.19)}$ and Y_m^a are estimated from the best-fit model resulting from the previous step. Y_m^a is expressed as:

$$Y_m^a = \sum_{j=1}^{m} \left(\hat{Y}_j - \hat{Y}_{j-1}\right) \cdot Q_{10\,j} \cdot \frac{1}{2.24 \cdot 10^4} \qquad (8)$$

Where:

j = T+τ

T and τ = as defined in Equation 6

$\hat{Y}_j = \hat{Y}_{T+\tau}$ = defined in Equation 6

$2.24 \cdot 10^4$ = a constant computed based on Chae and Tabatabai (1986)data; this constant is equal to $\frac{0.448(kgManure)}{20(kgSoil)} \cdot 1000000$, and is used to transform the units of the cumulative mineralization rate from (mg N/kg Soil) to (lb N/lb manure)

Q_{10} = temperature effect for any time period j, which depends on the temperature at that period of time

A typical chemical or enzymatic reaction has an approximate Q_{10} of 2.0. A nonlinear extrapolation method is used to determine the mineralization rate estimated by the best-fit model at different soil temperatures. The extrapolation relation was shown by Provin (1991) to be 2^H if soil temperature (H) is greater than 30°C, $\left(\frac{1}{2}\right)^H$ if less than 30°C, and zero if soil temperature is less than 5°C.

Application Cost

The hauling and spreading cost to apply manure to crops is a function of the distance traveled, transportation cost per ton/mile after the first mile round trip, and the cost per ton for loading and hauling one mile round trip. The hauling and spreading cost is defined in Equation 9.

$$C = \sum_{i=1}^{N} \left(C_L + C_t \cdot (D_i - 1) \right) \tag{9}$$

Where:

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

Custom services in Idaho generally use trucks with 10-ton capacity equipped with an 8-foot spreader. These services charge $19 per truck for loading and hauling one mile round trip, and $1.50 per mile per truck load for each additional mile after the first mile round trip. For the purpose of this study, custom service charge is used to account for the fixed and variable costs associated with loading, hauling and spreading manure.

The distance traveled to haul and spread the manure (D_i) is the most important variable affecting the cost of utilizing animal manure on cropland. In this study, two field shapes were considered to estimate the distance traveled; they are: (1) rectangular field and (2) circular field.

Rectangular Field

The distance traveled to haul and spread manure on a rectangular field is estimated by Equation 10.

$$D_i = \left\{2L + \frac{W \cdot 8.25}{R \cdot M} + \left([K_{i-1}] + [K_i] - 2\right) \cdot \frac{M}{5280} + d_{i-1} + d_i\right\} \quad (10)$$

Where:

D_i = the distance traveled in miles to haul and spread the ith load of manure

i = 1 to N

N = number of truck loads needed to haul and spread the manure required for a field of size A and is equal to $\frac{\mathrm{R} \cdot \mathrm{A}}{\mathrm{W}}$

R = manure application rate (ton/acre)

A = area of the field (80 acres), and A is equal to $width \cdot l$

l = length of the field (0.25 mile)

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 ith load, and $[K_i]\left(\frac{\mathrm{M}}{5280}\right)$ 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

di = 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 ft)

Circular field

The distance traveled to haul and spread manure on a circular field is estimated in Equation 11.

$$D_i = \left\{ 2L + \frac{W \cdot 8.25}{R \cdot M} + K_{i-1} + K_i + d_{i-1} + d_i \right\} \tag{11}$$

Where:

Di, L, W, R, and M as defined in Equation 10.

i = 1 to Q

$K_i = \frac{i \cdot W \cdot 8.25}{R \cdot M} - \sum_{j=i}^{O_1} \pi \cdot (r - j \cdot M)$, if O_i is even

$K_i = \{\pi \cdot (r - j \cdot M)\} - \left(\frac{i \cdot W \cdot 8.25}{R \cdot M} - \sum_{j=i}^{O_1} \pi \cdot (r - j \cdot M) \right)$, if O_i is odd

$d_i = \left((O_1 - 1) \cdot \frac{M}{5280} \right)$

O_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

In the case of the circular field the cost function is shown in Equation 12.

$$C = 2 \cdot \sum_{i=1}^{Q} C_L + C \cdot (D_i - 1) \tag{12}$$

Where:

$Q = \frac{N}{2}$, and Q is calculated using File Maker Pro software.

Maximum distance

The maximum distance traveled to equate the cost of hauling and spreading the required quantity of manure to the cost of commercial fertilizer for a given rotation system is estimated by Equations 13 and 14.

$$L_{mas} = \frac{(C_S - C)}{2N \cdot C_t} \cdot A \text{, for a rectangular field} \tag{13}$$

$$L_{max} = \frac{(C_S - C)}{4Q \cdot C_t} \cdot A \text{, for a circular field} \tag{14}$$

Where:

L_{max} = the maximum distance traveled

C_s = the cost of commercial fertilizer, and C,N,A,Q and C_t as defined in Equations 10 and 11

Results and Discussion

Manure application rate, cost and distance estimated in this study, using the models outlined in the materials and method section, were converted from short tons per acre to metric tons per hectare, cost was converted from $ per acre to $ per hectare, and distance was converted from miles to kilometers using the standard conversion ratios. Manure application rates per hectare were determined for the following three-year rotation systems: (1) Potato-Wheat-Wheat (PWW) and (2) Sugar beets-Wheat-Wheat (SWW). For both rotations, the quantities of manure that satisfy the nutrient requirements of the crops decline in the first and second three-year rotations, and stabilize in the third three-year rotation, and thereafter. Soil type 1 requires the highest quantity of manure to satisfy the nutrient requirements of crops in both rotations followed by soil type 2. Soil types 3, 4, and 5 require about the same quantity of manure, which is significantly less than soil types 1 and 2.

For rotation system 1, the stabilized optimum quantity of manure, ranges from a high of 220-66-72 metric tons per hectare for cow manure applied to soil type 1, to a low of 58-16-18 metric tons per hectare for chicken manure applied to soil type 4 (Table 6). For rotation system 2, the optimum stabilized quantity of manure ranges from a high of 108-75-71 metric tons per hectare for cow manure applied to soil type 1, to a low 28-20-18 metric tons per hectare for chicken manure applied to soil type 4 (Table 7). In general, both rotations require less chicken manure to satisfy the nutrient requirements of the crops compared to hog or cow manure. The reason may be due to chemical properties of chicken manure. Compared to cow and hog manure, chicken manure has higher pH, lower organic carbon, higher inorganic nitrogen content, and a lower C/N ratio (Table 2).

Application Cost

For both rotation systems, the cost of applying manure to a rectangular field is slightly higher than for a circular field. For rotation system 1 and a rectangular field the cost of applying all three types of manure is the highest for soil type 1 followed by soil type 2. The cost of applying manure to soil types 3, 4, and 5 is about the same, and significantly less than the cost for soil types 1 and 2. The cost of applying manure to soil type 1 ranges from a high of 91 percent of the cost of commercial fertilizer for cow manure, to a low of 70 percent of the cost of commercial fertilizer for chicken manure. The cost of applying manure to soil type 2 ranges from a high of 55 percent of the cost of commercial for hog manure, to a low of 44 percent for chicken manure. The cost of applying manure to soil type 3 ranges from a high of 31 percent of the cost of commercial fertilizer for cow manure, to a low of 28 percent for chicken manure. The cost of applying manure to soil type 4 ranges from a high of 30 percent of the cost of commercial fertilizer for cow manure, to a low of 25 percent for chicken manure. For soil type 5, this cost ranges from a high of 32 percent of the cost of commercial fertilizer, to a low of 27 percent for chicken and hog manure (Table 8).

For rotation system 2, and a rectangular field, it is not economical to apply manure to soil type 1. The cost ranges from a high of 136 percent of the cost of commercial fertilizer for cow manure, to a low of 103 percent for chicken manure. For soil type 2, the cost ranges from a high of 81 percent of the cost of commercial fertilizer for hog manure, to a low of 66 percent for chicken manure. For soil type 3, the cost ranges from a high 49 percent of the cost of commercial fertilizer for cow manure, to a low of 42 percent or chicken manure. For soil type 4, the cost ranges from a high of 44 percent of the cost of commercial fertilizer for cow manure, to a low of 37 percent for chicken manure. For soil type 5, the cost ranges from a high of 50 percent of the cost of commercial fertilizer for cow manure, to a low of 41 percent for chicken manure (Table 9).

The economics of utilizing manure on cropland as an alternative to commercial fertilizer is influenced by the cost of hauling and spreading the manure and the cost of commercial fertilizer. In the long run, both costs fluctuate with fluctuation in the price of oil. Custom service cost for hauling and spreading manure has been the same for 1997, 1998 and 1999. Commercial fertilizer cost is based on the actual input rates and prices of the various fertilizer used for crops in 1998.

The input rates for potatoes per hectare are: 325 kg of nitrogen, 262 kg of phosphorus, 112 kg of potassium, 22 kg liquid phosphate, 90 kg of sulfur, and $74 for micronutrients. Commercial fertilizer cost for potatoes also includes $26 for custom fertilizer application and $39 for consultant fee. Input rates for wheat per hectare are: 112 kg of nitrogen, 45 kg of phosphorus, and $13 for custom fertilizer applications. For sugar beets, input rates are: 168 kg of nitrogen, 112 kg of phosphorus, $13 for custom fertilizer applications, and $39 for consultant fee. Commercial fertilizer prices per kg reported by the budget generator for 1998 and 1999, and used in this study are: $0.77 for nitrogen, $0.24 for phosphorus, $0.15 for potassium, $0.37 for liquid phosphate, and $0.18 for sulfur.

Discussion of Results

The utilization of animal manure as an economic alternative to commercial fertilizer has not been adequately analyzed by previous studies. The method developed in this study is a significant addition to previous methods used in evaluating the economic utilization of manure on cropland. It simultaneously estimates the mineralization rate of organic nitrogen and determines optimal application rate and least cost utilization of manures with different properties applied to soils with different properties and temperature. Compared to previous studies, the method developed in this study more accurately determines the breakeven hauling distance to transfer manure from its source to the receiving fields for different manure-soil combinations.

Freeze and Sommerfeldt (1985), using a budgeting method, estimated breakeven hauling distance for feedlot manure to range from 15 to 33 km. It was determined for two assumed manure application rates (34 tones/ha. and 67 tones/ha.) for irrigated wheat with first and second year sugar beets and sweet corn in rotation. Their results showed that the breakeven hauling distance was little affected by the two application rates considered, and that the associated breakeven hauling distance for sugar beets was 10-15 times higher than for wheat. The authors did not adjust for the mineralization rate and the year-to-year residual effects of organic nitrogen in the manure. They recommended long term research to consider a wide range of application rates.

Freeze et al. (1993) used a simulation method to analyze the economics of hauling manure as an amendment for restoring the productivity of artificially eroded wheat cropland. Their results showed that the value of manure as an amendment for restoring the productivity of slightly eroded wheat cropland is sufficient to allow manure to be hauled 3-5 km further than would be the case on non-eroded soils. The breakeven hauling distance can be extended to 20 km further for manure application on highly eroded wheat cropland.

Fleming et al. (1998) defined a general model of manure transportation and calculated net benefit of swine manure for Iowa corn farmers using two storage technologies: (1) anaerobic lagoon and (2) slarry basin. Their results show that the cost of delivering manure nutrients out of lagoon storage is greater than the value of delivered nutrients. When a slarry basin is used as storage, the cost of delivering manure nutrients is less than the value of the nutrients for some herd sizes. However, as herd size increased, marginal delivery cost became greater than the marginal benefit.

The above studies ignored the effect of manure properties, soil properties, soil temperature and moisture on the mineralization rate of organic nitrogen. These studies also ignored the year-to-year residual effects of organic nitrogen in the manure and its accumulative effect on the optimal quantity of manure needed to satisfy the nutrient requirements of crops in a given rotation system. In general, these studies failed to determine the optimal required quantity of manure, its effect on hauling and spreading cost, and the economically maximum distance manure can be hauled from its source to the receiving field.

Araji and Stodick (1990) made the first attempt to determine the optimal quantity of manure needed to satisfy the nutrient requirements of crops in several rotation systems at least cost. They used the Pratt (1982) decay constant for feedlot manure to determine the optimal manure application rate to cropland. Their study determined the maximum distance that equates the cost of hauling manure to the cost of commercial fertilizer. However, the model used was limited to one type of manure applied to one type of soil without adjustment for soil temperature, manure properties, and soil properties in estimating the mineralization rate of organic nitrogen and thus the optimal quantity of manure required. The models developed in this study adjust for all variables and accurately estimate the application of optimal quantity of manure at least cost.

Maximum Distance

The economic potential of utilizing animal manure as an alternative to commercial fertilizer is influenced not only by the distance traveled to spread the manure, but also by the distance between the source of the manure and the receiving field. This distance is lower for rectangular field than for circular field.

The maximum distance to transfer manure to the field, after the first 1.6 km (1 mile) round trip that will equate the cost of using manure to the cost of commercial fertilizer for rotation system 1 is shown in Table 10. The maximum distance for soil types 1 and 2 is significantly less than soil types 3, 4, and 5 for all three types of manure. For rectangular field, the maximum distance for soil type 1 ranges from a high of 4.7 km for chicken manure to a low of 1 km for cow manure. For soil type 2, the maximum distance ranges from a high of 14 km for chicken manure to a low of 9 km for hog manure. The maximum distance for soil types 3, 4, and 5 are about the same and significantly higher than those for soil types 1 and 2. The maximum distance ranges from a high of 35.2 km for chicken manure applied to soil type 4, to a low of 23.6 km for cow manure applied to soil type 5.

For rotation system 2 and a rectangular field, it is not economical to apply manure to soil type 1. For soil type 2, the maximum distance ranges from a high of 5.7 km for chicken manure to a low of 2.5 km for hog manure. The maximum distance for soil types 3, 4, and 5 are about the same and significantly higher than soil type 2. It ranges from a high of 18.4 km for chicken manure applied to soil type 4 to a low of 10 km for cow manure applied to soil type 5.

Summary and Conclusion

Since the early 1940's, research results indicate that animal manure is a viable biological resource with positive environmental and ecological benefits. In 1998, over 131 million tons of animal manure was produced in confined beef and dairy cattle operations in the U.S. This resource is not efficiently utilized and often considered a source of pollution. Land application of manure improves soil properties, increases yield, reduces erosion, and reduces nutrient leaches. The major outlet for animal manure is application to cropland.

Nitrogen, phosphorus, and potassium are the elements that are most frequently needed for crops in relatively large quantities. Phosphorus in manure is equally available to plants as inorganic sources. Potassium is not part of any organic structure. Nitrogen in manure must be mineralized before it is available to plants. Several statistical procedures were developed and tested to estimate the mineralization rate of organic nitrogen over time adjusted for soil temperature. The Holt-Winter two-parameter exponential smoothing is found to be the best method to estimate the mineralization rate of organic nitrogen over time for three types of manure applied to five different soils. The results show that the properties of the manure and the soils significantly affect the mineralization rate of organic nitrogen.

The mineralization rate is the principle factor used to determine the optimal quantity of manure needed to satisfy the nutrient requirement of crops in a given rotation system. Manure application rates were determined for the following three-year rotation systems: (1) potato-wheat-wheat, and (2) sugar beets-wheat-wheat. The quantity of manure required for both rotations decreases over time and stabilizes at the fourth year and thereafter. Manure requirements differed significantly for the 15 different manure-soil combinations analyzed. For rotation 1, the stabilized optimum quantity ranged from a high of 220-66-77 metric tons per hectare for cow manure applied to one type of soil, to a low of 58-16-18 metric tons per hectare for chicken manure applied to another type of soil. For rotation 2, the stabilized optimum quantity ranged from a high of 108-75-71 metric tons per hectare for cow manure applied to one type of soil, to a low 28-20-18 metric tons per hectare for chicken manure applied to another type of soil.

For rotation system 1, manure application costs ranged from a high of 91 percent of the cost of commercial fertilizer for cow manure applied to one type of soil, to 25 percent of the cost of commercial fertilizer for chicken manure applied to another type of soil. For rotation system 2, manure application costs ranged from a high of 136 percent of the cost of commercial fertilizer for cow manure applied to one type of soil, to a low of 37 percent of the cost of commercial fertilizer for chicken manure applied to another type of soil.

The results of the study show that manure can be transferred long distance from its source to the receiving field before its cost equates the cost of commercial fertilizer. For rotation system 1, the maximum distance ranges from a low of 1 km to a high of 35 km, depending on the type of manure and the soil that receives the manure. For rotation system 2, the maximum distance ranges from a low of –3 km to a high of 19 km.

Chicken manure is the most economically efficient type of manure. This efficiency is due to its high pH, low organic carbon, high inorganic nitrogen, and low carbon/nitrogen ratio compared to the other types of manure. In addition to its environmental and ecological benefits, the results of this study clearly indicate that animal manure is an excellent economic alternative to commercial fertilizer and a viable biological resource to be utilized on cropland.

The models developed in this study on the mineralization rates of organic nitrogen, manure application rate to satisfy the nutrient requirements of crops in a given rotation system, manure application cost, and the economically maximum distance to transfer manure will provide economists, soil scientists, and environmental scientists with the tools to efficiently utilize animal manure or other biological resources. These models have useful applications in the developed and developing parts of the world on the economic use of a bio-resource that is often considered a waste to be disposed of rather than a resource to be utilized.

Table 1. Amounts of organic nitrogen mineralized within successive 2-week incubation period in animal manure-treated soils.

Soil Type	Animal Manure	Incubation Interval 0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	Total	%
		mg kg^{-1} soil														
1	Chicken	1.7	20.0	33.6	22.8	18.8	18.5	13.9	12.7	11.9	11.3	12.2	11.8	13.2	202	21
	Hog	0.5	17.5	24.4	20.7	13.6	16.4	15.2	15.3	14.6	10.9	12.5	10.5	11.2	183	16
	Cow	0.5	13.6	17.2	17.6	14.7	18.1	19.3	17.2	15.4	11.1	10.4	10.5	10.8	176	13
2	Chicken	7.4	111	117	76.0	51.3	40.4	32.3	28.2	22.9	21.9	22.8	21.1	25.3	578	54
	Hog	2.0	64.3	75.1	81.1	55.0	46.0	32.5	26.8	26.2	21.9	22.8	21.5	25.9	501	37
	Cow	2.6	87.5	94.0	78.8	63.0	38.8	37.0	35.4	23.4	21.4	23.4	21.1	27.1	554	44
3	Chicken	1.7	36.3	94.5	52.9	42.6	29.6	24.8	20.4	18.0	15.1	16.5	13.5	11.8	378	60
	Hog	0	19.2	66.4	46.3	43.0	30.2	23.2	18.3	17.2	15.9	16.0	15.7	14.4	326	42
	Cow	0.1	2.5	39.9	44.0	39.5	31.6	27.4	20.9	21.3	17.8	15.7	13.6	12.5	287	31
4	Chicken	4.2	19.1	66.3	56.3	47.9	35.4	24.0	22.9	49.1	16.7	17.6	14.6	13.4	358	61
	Hog	0.8	0.8	25.5	42.2	40.4	33.9	30.4	24.4	19.9	16.6	16.0	14.9	12.2	278	49
	Cow	0.2	0.6	9.4	27.2	37.1	36.6	30.9	23.8	19.8	16.1	14.8	14.8	11.9	243	36
5	Chicken	12.0	122	112	86.5	60.8	44.1	36.4	31.8	25.9	24.8	20.8	19.7	21.0	617	67
	Hog	2.0	75.7	102	76.0	58.5	46.5	36.3	36.0	29.4	31.7	29.9	25.5	25.3	574	52
	Cow	1.1	76.3	104	88.9	57.2	51.2	36.3	35.3	29.5	25.9	22.6	20.1	22.3	570	51

Source: Chai and Tabatabai, 1986

Table 2: Properties of animal manure studied

Manure	Nitrogen mg/Kg Soil		pH	Organic Carbon g/Kg Soil	C/N Ratio
	Total	**Inorganic**			
Chicken	22,000	2235	7.7	380	19.22
Cow	22,400	357	6.2	473	21.86
Hog	21,200	1354	5.9	434	21.45

Source: Chai and Tabatabai, 1986

Table 3: Chemical and physical properties of soil used

Soil		Nitrogen mg/Kg Soil		pH	Carbon g/Kg Soil		Clay	Sand	Moisture
Type	Family	Total	Inorganic		Organic	Inorganic	g/Kg Soil		
1	Fine-silty, nuxed, mesic Mollic Hapludalf	1.82	12	5.1	18.6	0	190	30	230
2	Fine-loamy, nuxed, mesic Typic Haplaquolls	2.51	9	6.5	30.8	0	250	380	210
3	Fine-Loamy, mesic Typic Calciaquolls	2.76	12	7.6	35.9	29.6	290	330	280
4	Fine-loamy, nuxed, mesic Mollic Hapludalf	1.15	7	6.4	12.6	0	170	190	140
5	Fine montmorlillonitic, mesic Cumulic Haplaquolls	4.59	16	7	57.6	5.7	400	130	360

Source: Chai and Tabatabai, 1986

Table 4: Sum of squared errors, degrees of freedom, coefficient of multiple determination, and Chow-F statistics for full and reduced models.

Statistics	Values
SSE_{Full}	0.89
Df_{Full}	194
SSE_{Red}	208
Df	14
MSE_{Full}	0.0046
Chow-F	42.79
P-value	0.000
$F_{0.05}$	1.743

Table 5: Best-fit exponential smoothing models

Soil	Manure	Best Model	Level Smoothing Weight	Trend Smoothing Weight	Dampening Smoothing Weight	MSE	R^2
1	Chicken	Holt-Winter's	0.999	0.999	0.822	0.0001	0.9760
	Hog	Holt-Winter's	0.999	0.999	0.794	0.0001	0.9740
	Cow	Holt-Winter's	0.916	0.999	0.859	0.0001	0.9790
2	Chicken	Holt-Winter's	0.999	0.999	0.675	0.0028	0.9090
	Hog	Holt-Winter's	0.999	0.999	0.756	0.0009	0.9470
	Cow	Holt-Winter's	0.999	0.999	0.712	0.0016	0.9360
3	Chicken	Holt-Winter's	0.999	0.999	0.761	0.0013	0.9640
	Hog	Holt-Winter's	0.999	0.999	0.827	0.0006	0.9770
	Cow	Holt-Winter's	0.999	0.999	0.898	0.0002	0.9880
4	Chicken	Holt-Winter's	0.999	0.999	0.849	0.0007	0.9800
	Hog	Holt-Winter's	0.999	0.999	0.887	0.0003	0.9860
	Cow	Holt-Winter's	0.999	0.999	0.919	0.0002	0.9890
5	Chicken	Holt-Winter's	0.999	0.333	0.928	0.0025	0.9440
	Hog	Holt-Winter's	0.999	0.999	0.774	0.0012	0.9660
	Cow	Holt-Winter's	0.999	0.999	0.777	0.0012	0.9650

Table 6: Optimum manure application rate, metric tons per hectare, for rotation 1.

Soil Type	Manure Type	Year																	
		P	W	W	P	W	W	P	W	W	P	W	W	P	W	W	P	W	W
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Chicken	186	54	58	168	49	54	170	49	54	170	49	54	170	49	54	170	49	54
	Hog	211	72	67	197	63	61	198	64	61	198	64	61	198	64	61	198	64	61
	Cow	233	69	74	220	66	72	220	66	72	220	6	72	220	6	72	220	6	72
2	Chicken	102	36	36	102	34	35	102	34	35	102	34	35	102	34	35	102	34	35
	Hog	130	43	45	128	42	44	128	42	44	128	42	44	128	42	44	128	42	44
	Cow	108	35	36	106	35	36	106	35	36	106	35	36	106	35	36	106	35	36
3	Chicken	67	22	22	65	22	21	65	22	21	65	22	21	65	22	21	65	22	21
	Hog	76	20	25	67	20	22	69	20	22	9	20	22	9	20	22	9	20	22
	Cow	87	16	27	79	15	25	79	15	25	79	15	25	79	15	25	79	15	25
4	Chicken	65	16	20	58	16	18	58	16	18	58	16	18	58	16	18	58	16	18
	Hog	78	13	25	67	13	22	69	13	22	69	13	22	69	13	22	69	13	22
	Cow	94	4	31	78	14	27	81	4	27	81	4	27	81	4	27	81	4	27
5	Chicken	72	13	20	67	13	20	67	13	20	67	13	20	67	13	20	67	13	20
	Hog	67	22	22	63	20	20	63	20	20	63	20	20	63	20	20	63	20	20
	Cow	76	25	25	74	25	25	74	25	25	74	25	25	74	25	25	74	25	25

Table 7: Optimum manure application rate, metric tons per hectare, for rotation 2.

Soil Type	Manure Type	Year																	
		S	W	W	S	W	W	S	W	W	S	W	W	S	W	W	S	W	W
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Chicken	96	65	56	81	60	51	81	60	51	81	60	51	81	60	51	81	60	51
1	Hog	110	78	67	97	69	60	97	69	60	97	69	60	97	69	60	97	69	60
	Cow	121	78	74	108	75	71	108	75	71	108	75	71	108	75	71	108	75	71
	Chicken	53	36	36	53	35	35	53	35	35	53	35	35	53	35	35	53	35	35
2	Hog	67	45	45	65	44	43	65	44	43	65	44	43	65	44	43	65	44	43
	Cow	56	36	35	54	36	35	54	36	35	54	36	35	54	36	35	54	36	35
	Chicken	63	25	22	32	23	21	32	23	21	32	23	21	32	23	21	32	23	21
3	Hog	38	27	22	31	25	21	31	25	21	31	25	21	31	25	21	31	25	21
	Cow	45	24	24	36	24	24	36	24	24	36	24	24	36	24	24	36	24	24
	Chicken	34	20	18	28	20	18	28	20	18	28	20	18	28	20	18	28	20	18
4	Hog	40	21	22	32	21	20	32	21	20	32	21	20	32	21	20	32	21	20
	Cow	49	22	25	36	22	22	36	22	22	36	22	22	36	22	22	36	22	22
	Chicken	38	20	21	33	19	21	33	19	21	33	19	21	33	19	21	33	19	21
5	Hog	34	25	20	31	23	20	31	23	20	31	23	20	31	23	20	31	23	20
	Cow	40	26	25	37	26	25	37	26	25	37	26	25	37	26	25	37	26	25

Table 8: Manure application cost as a percent of commercial fertilizer cost for rotation 1, rectangular and circular field, 0.805 km (1/2 mile) distance between the source of the manure and the field.

Soil Type	Manure Type	Rectangular Field								Circular Field							
		Application Cost $/Ha[a]				% of Commercial Fertilizer[a]				Application Cost $/Aa[a]				% of Commercial Fertilizer[a]			
		P	**W**	**W**	**Total**	**P**	**W**	**W**	**Total**	**P**	**W**	**W**	**Total**	**P**	**W**	**W**	**Total**
1	Chicken	381	114	124	**618**	57	103	112	**70**	348	104	114	**566**	52	94	103	**64**
	Hog	442	143	138	**724**	66	130	125	**82**	403	131	126	**660**	61	119	115	**74**
	Cow	492	153	163	**808**	74	139	148	**91**	450	141	148	**739**	68	127	136	**83**
2	Chicken	232	79	79	**390**	35	71	71	**44**	213	72	72	**356**	32	65	65	**40**
	Hog	287	99	99	**484**	43	89	89	**55**	262	91	91	**445**	39	82	82	**50**
	Cow	237	84	84	**405**	36	76	76	**46**	217	77	77	**371**	33	69	69	**42**
3	Chicken	148	54	49	**252**	22	49	44	**28**	136	49	44	**230**	20	45	40	**26**
	Hog	158	49	54	**262**	24	44	49	**30**	146	44	49	**240**	22	40	45	**27**
	Cow	178	40	59	**277**	27	35	53	**31**	163	35	54	**252**	25	32	49	**28**
4	Chicken	133	40	44	**217**	20	35	40	**25**	121	35	40	**195**	18	32	36	**22**
	Hog	158	35	57	**250**	24	31	51	**28**	146	32	49	**227**	22	28	45	**26**
	Cow	183	15	64	**262**	28	12	58	**30**	168	12	59	**240**	25	12	53	**27**
5	Chicken	153	35	49	**237**	23	31	44	**27**	141	32	44	**217**	21	28	40	**25**
	Hog	143	49	49	**242**	22	44	44	**27**	131	44	44	**220**	20	40	40	**25**
	Cow	168	59	59	**287**	25	53	53	**32**	153	54	54	**262**	23	49	49	**30**

[a]Commercial fertilizer cost per hectare is $529 for potato and $111 for wheat for a total of $640 for the rotation.

Table 9: Manure application cost as a percent of commercial fertilizer cost for rotation 2, rectangular and circular field, 0.805 km (1/2 mile) distance between the source of the manure and the field.

Soil Type	Manure Type	Rectangular Field								Circular Field							
		Application Cost $/Ha[a]				% of Commercial Fertilizer[a]				Application Cost $/Ha[a]				% of Commercial Fertilizer[a]			
		S	**W**	**W**	**Total**	**S**	**W**	**W**	**Total**	**S**	**W**	**W**	**Total**	**S**	**W**	**W**	**Total**
	Chicken	183	138	119	**440**	91	125	107	**103**	168	126	109	**403**	83	115	98	**95**
1	Hog	158	138	217	**514**	108	143	125	**121**	200	146	126	**472**	99	131	115	**111**
	Cow	173	163	242	**578**	120	157	148	**136**	222	158	148	**529**	110	144	136	**124**
	Chicken	124	79	79	**282**	61	71	71	**66**	114	72	72	**257**	56	65	65	**60**
2	Hog	148	99	99	**346**	73	89	89	**81**	136	91	91	**319**	67	82	82	**75**
	Cow	127	84	84	**292**	61	76	76	**69**	114	77	77	**267**	56	69	69	**63**
	Chicken	74	54	49	**178**	36	49	44	**42**	67	49	44	**161**	34	45	40	**38**
3	Hog	79	59	49	**188**	39	53	44	**44**	72	54	44	**170**	36	49	40	**40**
	Cow	89	59	59	**208**	44	53	53	**49**	82	54	54	**190**	40	49	49	**45**
	Chicken	64	49	44	**158**	31	44	40	**37**	59	44	40	**143**	29	40	36	**34**
4	Hog	74	54	49	**178**	36	49	44	**42**	67	49	44	**161**	34	45	40	**38**
	Cow	84	49	54	**188**	41	44	49	**44**	77	44	49	**170**	38	40	45	**40**
	Chicken	79	44	49	**173**	39	40	44	**41**	72	40	44	**156**	36	36	40	**37**
5	Hog	74	54	49	**178**	36	49	44	**42**	67	49	44	**161**	34	45	40	**38**
	Cow	89	64	59	**213**	44	58	53	**50**	82	59	54	**195**	40	53	49	**46**

[a]Commercial fertilizer cost per hectare is $202 for sugar beets and $111 for wheat for a total of $313 for the rotation.

Table 10: Maximum distance to equate the cost of manure application to the cost of commercial fertilizer for rotation 1, rectangular and circular fields.

Soil Type	Manure Type	Rectangular				Circular			
		Kilometers				Kilometers			
		Potato	Wheat	Wheat	Total	Potato	Wheat	Wheat	Total
1	Chicken	8.1	-0.3	-1.2	4.7	9.0	0.6	-0.3	5.7
	Hog	5.5	-2.5	-2.2	2.4	6.4	-1.6	-1.3	3.4
	Cow	3.8	-3.1	-3.5	1.0	4.8	-2.2	-2.6	2.0
2	Chicken	20.5	4.5	4.5	14.0	21.4	5.4	5.4	15.0
	Hog	14.3	1.4	1.3	9.1	15.2	2.3	2.2	10.1
	Cow	19.6	3.7	3.7	13.3	20.5	4.7	4.6	14.2
3	Chicken	38.8	12.5	14.2	28.7	39.8	13.5	15.2	29.6
	Hog	35.9	15.0	12.3	27.3	36.8	15.9	13.3	28.3
	Cow	29.9	23.0	9.9	24.8	30.8	24.0	10.8	25.7
4	Chicken	44.3	22.5	17.3	35.2	45.2	23.4	18.3	36.1
	Hog	35.8	28.7	11.7	29.8	36.8	29.6	13.2	30.8
	Cow	29.2	92.2	8.3	26.9	30.1	93.0	9.1	27.8
5	Chicken	36.6	27.7	14.8	31.0	37.5	28.6	15.7	32.0
	Hog	40.5	14.3	14.7	30.1	41.4	15.2	15.7	31.1
	Cow	32.6	10.2	10.1	23.6	33.5	11.0	10.9	24.4

Table 11: Maximum distance to equate the cost of manure application to the cost of commercial fertilizer for rotation 2, rectangular and circular field.

Soil Type	Manure Type	Rectangular				Circular			
		Kilometers				Kilometers			
		Sugarbeet	Wheat	Wheat	Total	Sugarbeet	Wheat	Wheat	Total
1	Chicken	1.1	-2.2	-0.8	-0.4	2.1	-1.3	0.2	0.5
	Hog	-0.8	-3.4	-2.2	-2.0	0.1	-2.4	-1.3	-1.0
	Cow	-1.8	-4.1	-3.6	-3.0	-0.9	-3.1	-2.7	-2.1
2	Chicken	7.3	4.5	4.5	5.7	8.2	5.3	5.4	6.6
	Hog	4.0	1.3	1.3	2.5	4.9	2.2	2.2	3.4
	Cow	7.1	3.6	3.7	5.1	8.0	4.5	4.6	6.1
3	Chicken	19.6	11.8	14.4	15.8	20.5	12.7	15.3	16.7
	Hog	18.4	10.2	14.2	14.7	19.3	11.1	15.1	15.6
	Cow	14.9	10.5	10.6	12.5	15.9	11.4	11.5	13.4
4	Chicken	24.3	15.2	18.4	19.9	25.1	16.2	19.4	20.9
	Hog	19.6	12.8	15.0	16.4	20.5	13.8	16.0	17.3
	Cow	16.1	14.1	12.4	14.5	17.0	15.0	13.3	15.4
5	Chicken	18.3	17.1	14.4	16.9	19.2	18.0	15.3	17.8
	Hog	20.4	12.1	14.9	16.3	21.3	13.1	15.9	17.3
	Cow	14.9	8.7	10.1	11.7	15.8	9.6	11.0	12.6

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