# PRINCIPLES OF FEEDYARD MANURE QUALITY

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## INTRODUCTION

In the "no-discharge" regulatory framework mandated by the federal Clean Water Act, land application of manure is a standard management practice for confined animal feeding operations (CAFOs). Although the agronomic value of manure has been recognized for centuries, traditional attitudes have cast land application as a means of disposal rather than beneficial use. Similar to waste commodities of other types, manure is considered to have little intrinsic value except as compared to the costs of (a) substituting other suitable sources of nutrients or moisture and (b) regulatory controls over long-term storage.

The actual value of manure as a source of essential plant nutrients is closely linked to the cost of standard inorganic equivalents for the region in which the manure is to be applied. Furthermore, the traditional approach to calculating the agronomic value of manure – computing the sum of the inorganic equivalencies of all plant nutrients contained in it – ignores the principle of the "limiting nutrient" and therefore overstates its economic value. Introducing manure into the marketplace as a source of nutrients and organic matter requires more accurate, credible data regarding its short-term value.

Managing manure to match the nutrient-cycling capabilities of the crops to which they are applied optimizes the value of the materials and reduces the environmental stress associated with excess application of limiting nutrients. In many cases of practical interest, use of manure to satisfy the nitrogen requirements of a crop results in excessive application of phosphorus, potassium or micronutrients. Such a practice reduces the average economic value ($/T) of the manure. Consequently, managing manure to reduce nitrogen losses associated with storage, transport or application is often the most effective way of maximizing the material's economic value. Other considerations in determining manure value are ash and water content, weed seeds, pathogens and manure texture.

## INDICATORS OF MANURE QUALITY

Manure is a complex and highly variable mixture of organic matter, water, nutrients and inert materials. Manure's extreme variability makes its intrinsic quality difficult to assess, but its relative quality (i. e., a comparison of two different manure types with respect to an expected use) can be evaluated on reasonable economic grounds. Table 1 is a list of parameters that affect the quality of manure. The top four (water content, ash content, nutrient content and nutrient ratio) are the easiest to translate into economic terms because they can be linked directly to the costs of purchasing and transporting inorganic fertilizers.

Water Content. Water is the most abundant constituent of fresh (i. e., as excreted) manure, accounting for up to 85-90% by weight of the manure bulk. When deposited on the feedyard surface, however, it dries rapidly in response to solar radiation, wind and hoof action. The moisture content of manure as it is scraped from the feedyard surface, therefore, depends greatly on climate, stocking density (animals per unit area) and the timing, frequency and method of pen scraping. Although water is beneficial to crops, it is a liability in land-applied manure because of its major contribution to hauling costs.

Ash Content. Ash may be viewed generically as the inert fraction of the solids in the manure bulk, although a small portion of the total ash content consists of plant-essential nutrients. Ash is determined by subjecting manure to elevated temperatures that cause the organic matter to oxidize to carbon dioxide and trace gases, then measuring the residue. Because ash is plentiful but largely inert within manure, it also makes a major contribution to hauling costs and is therefore a liability with regard to manure quality.

Nutrient Content. Nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), iron (Fe), calcium (Ca), zinc (Zn) and others are present in manure at significant concentrations and represent the principal source of quality and value in manure. All other things being equal, higher nutrient content suggests higher manure quality.

Nutrient Ratios. Although nutrients are present in manure at significant concentrations, they are usually out of balance with respect to the requirements of the crop to which the manure is to be applied. The primary example of this relates to N and P, which are the two macronutrients most commonly limiting in crop systems. If the N:P ratio of the manure and the N:P ratio required by the plant are significantly different, deficiencies or

**TABLE 1. COMPARISON OF THE CHARACTERISTICS OF MANURE AND COMPOST WHICH ARE OF GREATEST IMPORTANCE TO THE FARMER AS AN END-USER.**

| Manure Characteristic | Desirable State | Fresh or Stockpiled Manure | Composted Manure | Comments |
|---|---|---|---|---|
| **Water content** | low | 25-85% | 15-25% | Heat generated in composting accelerates evaporation, reducing hauling costs per unit nutrient content |
| **Ash content** | low | variable | depends | Ash content in compost directly related to ash content of manure feedstock |
| **Nutrient content** | high | moderate when fresh | lower than fresh manure | Highly variable, but averages 1-2% N (dry-weight basis) and 1-1.6% $P_2O_5$ in fresh manure; composting drives off N |
| **N:$P_2O_5$ ratio** | matched to crop needs | about 1.25 | typically 1.0 or less | Ratio needed by grain crops can be 3.0 or higher. Composting drives off gaseous N but retains most of the $P_2O_5$ |
| **Weed seeds** | low | variable | may be reduced | Extended thermophilic composting reduces viability of weed seeds deposited by wind on feedyard surface or manure stockpiles; thicker-skinned seeds may be resistant |
| **Odor** | Low intensity and inoffensive tone | sharp and ammonia-like | musty | Odors generally associated with compounds produced in the absence of oxygen. Composting, an aerobic process, produces less offensive odors |
| **Pathogens** | low | variable | may be reduced | Extended thermophilic composting can cause protein breakdown and subsequent microbe death; some microbes resistant to thermal destruction |
| **Texture** | friable | chunky | friable | Compost is much more easily and evenly spread than stockpiled manure |

## LAND AREA REQUIREMENTS

The total area of cropland required to balance manure-borne nutrients with those removed in harvested biomass depends on the application method, cropping system, yield goals, grazing pressure and soil type. It also depends on which nutrient is being considered. Land-area requirements may vary by a factor of two to nine or more as a result of imbalances in manure nutrient content with respect to crop requirements. Producers can compute rough estimates of the land-area requirements from liveweight-based standards for manure production published by the American

Society of Agricultural Engineers (ASAE), Midwest Plan Service (MWPS) or Natural Resources Conservation Service (NRCS). For the cattle feeder, average manure composition can be (a) determined by laboratory analysis or (b) estimated from the Total Quality Manure Management Manual (see Table 4 therein) published by the Texas Cattle Feeders Association (TCFA, 1995). Because of the extreme variability of manure and the change in cattle rations over the past twenty years, laboratory analysis is by far the preferred method.

To demonstrate how to compute land area requirements (LAR), consider a feedyard that has generated a manure stockpile containing 1,000 tons of manure containing 25% moisture by weight (wet basis), 1.25% elemental nitrogen (N; dry basis) and 0.5% elemental phosphorus (P; dry basis). The manure is to be applied to irrigated corn with a yield goal of 200 bushels per acre (bu/ac). Pre-plant soil tests show some residual N and P such that achieving the 200 bu/ac yield goal will require 220 lb/ac of available N and 65 lb/ac of available $P_2O_5$. Assuming that 45% of the N and 75% of the P (NRCS, 1992) in the manure will be available to the crop in the first year, how many acres of cropland would be required to eliminate the stockpile in one growing season? The answers differ depending on whether we use N or P as the basis for our calculations.

1. Compute the total nutrient content (expressed in lb/T) contained in the stockpiled manure. First, we must convert the nutrient contents to their equivalents in lb/ton and adjust for moisture content (MC; %wb). (To convert from elemental P to $P_2O_5$, multiply by 2.29.)

   *Total nutrient content (lb/T, wb) = Nutrient content (%db) x (1-MC/100) x 20*

   Total N = 1.25 x 0.75 x 20 = 18.8 lb/T (wb)

   Total $P_2O_5$ = 0.5 x 0.75 x 20 x 2.29 = 17.2 lb/T (wb)

2. Next, we compute the amount of available nutrients (lb) contained in the entire stockpile.

   *Available nutrient content (lb) = Total nutrient content (lb/T) x availability x stockpile wt (T)*

   Available N = 18.8 lb/T x 0.45 x 1000 T = 8,460 lb available N

   Available $P_2O_5$ = 17.2 lb/T x 0.75 x 1000 T = 12,900 lb available $P_2O_5$

3. We can now compute the land area requirements on a N ($LAR_N$) and P ($LAR_P$) basis.

   *LAR (ac) = Available nutrients (lb) ÷ soil-test nutrient requirement (lb/ac)*

   $LAR_N$ = 8,640 lb available N ÷ 220 lb/ac N = 39.3 ac

   $LAR_P$ = 12,900 lb available $P_2O_5$ ÷ 65 lb/ac $P_2O_5$ = 198.5 ac

From this illustration, using numbers that are well within published norms, it is clear that the stockpiled manure is out of balance with respect to the N and P requirements of irrigated corn. Applying the manure to meet the N requirement (e. g., at a rate of 25.4 T/ac) would result in a 405% overapplication of P.

Assuming now that the inorganic fertilizers typically used in the area are anhydrous ammonia (82-0-0) at $185 per ton and dry superphosphate (11-52-0) at $250 per ton, we can estimate the gross potential fertilizer value of the manure. The traditional method of doing that is to convert the individual nutrient contents to their equivalents in commercial fertilizer and add up the resulting nutrient values. In our example, we are neglecting other nutrients like potassium, sulfur and iron, but accounting for their contributions to the overall value is straightforward.

1. Compute the replacement cost per unit of active inorganic ingredient.

   *Replacement cost ($/lb) = Fertilizer cost ($/T) x (100 / % active ingredient) ÷ 2000*

   N replacement cost = $185/T x (100/82) ÷ 2000 = $0.113/lb N

   $P_2O_5$ replacement cost = $250/T x (100/52) ÷ 2000 = $0.240/lb $P_2O_5$

2. Compute the individual replacement value of the nutrients in the manure by multiplying the nutrient replacement cost by the available nutrient content of the manure and adding together the contributions of each nutrient.

   *Replacement value of manure ($/T) = Replacement cost ($/lb) x available nutrients (lb/T)*

   N replacement value in manure = $0.113/lb x 8.5 lb/T = $0.96/T

   $P_2O_5$ replacement value in manure = $0.240/lb x 12.9 lb/T = $3.10/T

   Total replacement value of plant-essential nutrients in the manure (N and $P_2O_5$) = $4.06/T

In reality, the "total replacement value" of $4.06/T represents the theoretical maximum potential value of the manure if the individual nutrients could be extracted and isolated as individual fertilizers. Because that is an impractical option and we must therefore use the manure in its natural, mixed state, we can only take credit for the full $4.06/T for application rates up to the rate at which the first *limiting nutrient* requirement is satisfied by manure application. We expand on the *limiting nutrient* concept in the next section.

This entire development of manure-quality principles assumes a consistent program of soil and manure testing. Such a program is essential for accurate nutrient management planning, manure marketing and regulatory compliance. Your state Cooperative Extension Soil Testing Laboratory or commercial laboratory can supply you with detailed soil- and manure-sampling guidelines appropriate to your location, soils and CAFO regulations. For details concerning sampling methods, frequency and interpretation of results, consult McFarland et al. (1997).

## LIMITING NUTRIENTS

As we have seen, land application rates of manure depend on the nutrient being considered. Commer-cial inorganic fertilizers, which consist of just one or two major nutrients, can be mixed to meet all of the nutrient requirements of the crop with great precision, no matter what crop is being grown. Manure, on the other hand, is a complex mixture of many nutrients that are normally present in different rations than those required by the crop. Consequently, applying manure at a rate that satisfies one nutrient requirement will result in either an excess or a deficiency of another.

If the application rate of manure to meet the crop requirement for one nutrient results in a deficiency in another, a supplemental application of inorganic fertilizer can make up the deficiency. If the manure application results in an excess of another nutrient, however, a net accumulation of that nutrient will occur and may result in non-point source (NPS) pollution, either by surface runoff or deep soil percolation. Furthermore, applying manure at a rate exceeding the soil-test requirements for an essential nutrient represents a waste of money and nutrients. We introduce, therefore, the concept of the limiting nutrient, which is defined as follows:

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| A limiting nutrient for land application of manure is that economically-essential nutrient which, when all agronomic requirements, availability fractions and regulatory restrictions have been considered, results in the lowest recommended application rate for a particular year. |

In our previous example, we showed that the maximum application rate of an average stockpiled feedyard manure to meet the N and P requirements of an irrigated corn crop were 25.4 T/ac and 5.0 T/ac, respectively. If manure is applied to meet the N requirements, an excess of P will result. In this case, therefore, P is the limiting nutrient. Beyond the rate of 5.0 T/ac, we can no longer justify taking economic credit for P in the manure because commercial P fertilizer would not have been applied at rates exceeding the 65 lb/ac $P_2O_5$ indicated by the soil test. Therefore, the first 5.0 T/ac could be credited at $4.06/T, but each additional ton per acre (up to 25.4 T/ac maximum) would be worth only $0.96/T, which represents the N contribution only. Above 25.4 T/ac, there is no clear justification for assigning any fertilizer value to the manure at all, because both the N and P requirements have been met. This concept is shown graphically in Fig. 1.

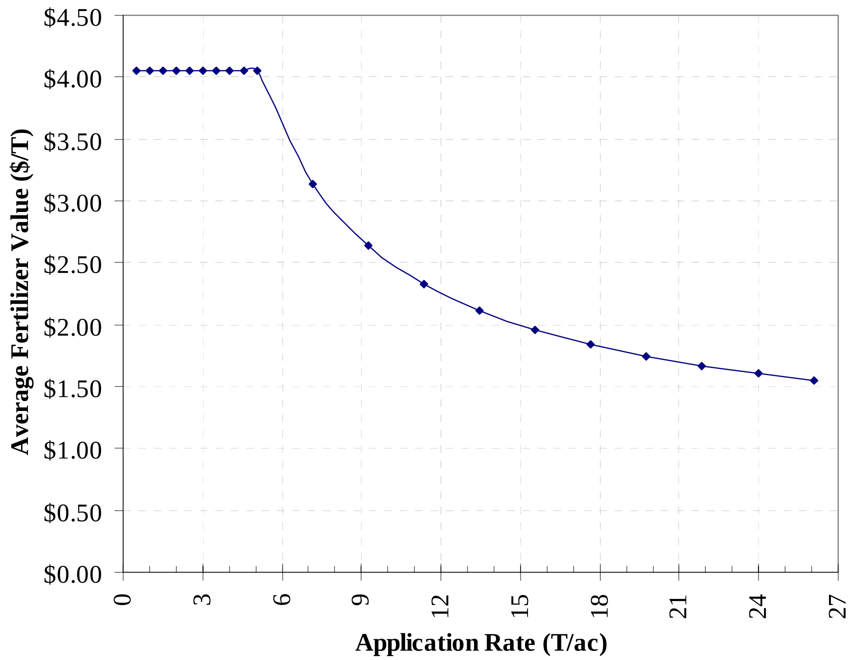


Figure 1. Average fertilizer value of manure based on N and P content.

As can be seen in Fig. 1, the maximum replacement value of the manure remains $4.06/T up to an application rate of 5 T/ac. Above that rate, the average replacement value begins to decline. Not only does P cease to have marginal economic value above that rate, it may also become an environmental liability as it accumulates near the soil surface.

Fig. 2 shows the average value of the same manure, except in this case the soil test indicates a potassium (K) requirement of 130 lb/ac $K_2O$. (To convert from elemental K to $K_2O$, multiply by 1.2.) The graph is based on an elemental K content of 2.5%, 80% first-year availability and an average inorganic (51% $K_2O$) price of $160/T.

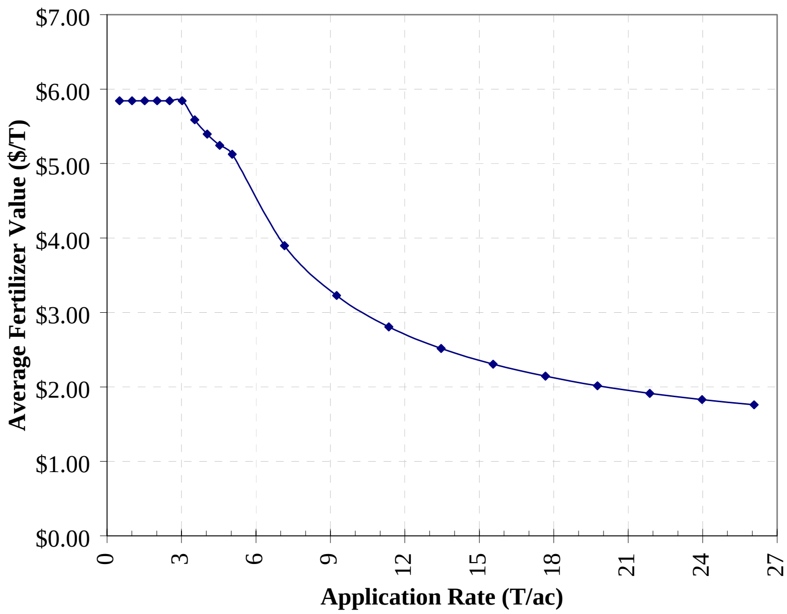


Figure 2. Average fertilizer value of manure based on N, P and K content.

Note in Fig. 2 that the maximum value of the manure is $5.27/T, reflecting the additional value provided by manure K. In addition, K appears to be the first limiting nutrient, its threshold occurring at an application rate of 3 T/ac. As before, an application rate of 5 T/ac satisfies the crop P requirement; this time, however, it results in excess K application. Above 3 T/ac, the fertilizer replacement value no longer includes a contribution from K.

One easy way to assess manure quality is to compare the ratio of available N:$P_2O_5$ in the manure to that of the crop's soil-test requirement. In our example, the two ratios are 1.1 and 3.4, respectively. The closer the two ratios are to one another, the more closely matched the manure is to the crop. In this case, the stockpiled manure is better suited (with regard to nutrient ratios only) for application to cotton, for which the typical N:$P_2O_5$ ratio from the soil test is between 1.0 and 1.3. For soils requiring supplemental K or other elements such as iron (Fe) and zinc (Zn), similar considerations apply.

*Summary.* The classical method of determining the economic value of manure was to add up the values of the commercial equivalents of all of the nutrients contained in manure. Because crop requirements and nutrient concentrations in manure seldom coincide, however, such an approach substantially overstates the value of the manure. From the agronomic and economic perspectives, the concept of a *limiting nutrient* implies a threshold application rate below which manure has its maximum value per ton. Furthermore, and in general, each essential nutrient will have a threshold application rate above which its marginal agronomic value (i. e., the value of the next increment of land-applied manure) is zero.

## MANURE QUALITY DISCOUNTS: ASH AND WATER

## AGRONOMIC VALUE OF MANURE AND EFFLUENT: PUTTING IT ALL TOGETHER

The classical method of determining the economic value of manure was to add up the values of the commercial equivalents of all of the nutrients contained in manure. Because crop requirements and nutrient concentrations in manure seldom coincide, however, such an approach substantially overstates the value of the manure. From the agronomic and economic perspectives, the concept of a *limiting nutrient* implies a threshold application rate below which manure has its maximum value per ton. Furthermore, and in general, each essential nutrient will have a threshold application rate above which its marginal agronomic value (i. e., the value of the next increment of land-applied manure ) is zero.

In the previous example, if we were to apply manure at 3 tons per acre, all of the N, P, K and S contained in the manure would be credited toward the crop requirements for those nutrients. At 6 tons per acre, however, we would have applied twice the phosphorus and 33% more sulfur than we would ordinarily have applied in the form of inorganic fertilizers. Therefore, at 6 tons per acre, we cannot take full economic credit for all of the phosphorus and sulfur contained in the manure. We take full credit for all four nutrients up to 3 tons per acre; we take credit for only the nitrogen, sulfur and potassium for the next 1.5 tons per acre; and we take credit for only the nitrogen and potassium for the next 1.5 tons per acre. *We can only take full credit for those amounts of each nutrient that we would ordinarily have applied in the form of commercial fertilizer. All essential nutrients applied in excess have a marginal value of zero at application rates above their limiting thresholds.*

As a consequence, the average value per ton of manure is constant and is at its maximum at application rates less than or equal to the first threshold rate. Beyond that rate, and beyond all subsequent thresholds for the remaining essential nutrients, the marginal value of manure continues to drop stepwise as thresholds are reached. The net result of that stepwise decline in marginal economic value is a decrease in the average value of each ton of manure. That decrease is shown graphically in Figure 1.

There is a great deal more to the art of assigning economic value to manure than just the value of fertilizer equivalents to its nutrient content. Certainly any method of assigning value must eventually include discounts for water and ash content, which reduce overall manure value in relation to hauling costs. Other characteristics such as texture, weed and pathogen content and odor may also affect the quality of manure for land application.

## REFERENCES