The Economic Merit of Animal Manures as a Source of Plant Nutrients or Energy Generation

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PREFACE

Whether as plant nutrient, physical amendment to improve soil water retention, or for electricity generation, manure is a resource. How manure is managed and utilized can have either negative or positive environmental and economic implications. In 1994, when the UC Agricultural Issues Center and the UC Davis Animal Agricultural Research Center presented findings from their joint study entitled *Animal Agriculture Impacts on Water Quality in California*, appropriate management and uses were discussed in general terms.

In the past, a great emphasis was placed on land application of manure nutrients at agronomic rates. Inherent in this concept is an understanding of the interactions between nutrient concentrations in the materials being applied, soil nutrients, availability and losses, and water management. This project was initiated to identify the origin and applicability of "accepted" values for manure nutrients excreted, lost, and available for crop production systems. Much of the literature addressing manure nutrient availability results from research that identified the beneficial effects of inorganic fertilizer compared to the control (manure). Also, some of the institutionalized values were the best guessed estimates at the time presented, and have been little improved since. Many of the projects were undertaken in states with fewer growing days than in California. An understanding of the climate from which the data originated is important to determine if results are directly applicable to California, or if they require further interpretation.

Now, in this report can be found a more detailed discussion of the various factors to consider to ensure that manure production results in enhanced operational efficiency and profitability. Related publications in this series from the UC Agricultural Issues Center and UC Davis Animal Agriculture Research Center include the conference summary, *Animal Agriculture Impacts on Water Quality*, and three reports, *Technologies and Management Practices for More Efficient Manure Handling; Livestock Management in Grazed Watersheds: A Review of Practices that Protect Water Quality; and Pathogens Excreted by Livestock and Transmitted to Humans through Water*.

UC Agricultural Issues Center
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The Economic Merit of Animal Manures as a Source of Plant Nutrients or Energy Generation

Introduction

Animal numbers have increased over the years. Current statistics estimate California animal populations: poultry (broilers and layers) 55,210,000; beef cattle, 840,000; dairy cattle, 1,260,000; sheep, 1,000,000; swine, 240,000 (USDA, 1997). Since the conversion of animal feed to animal product is not 100% efficient, manure is produced.

Greater concern about water and air quality, as well as other natural resources, has refocused attention to manure management. Manure should be viewed as a renewable resource that may be used to increase farm efficiency and profitability. Manures must be managed in the short term, collected and stored, and in the long term, utilized at agronomic rates.

This report focuses on the economic value of manure uses. An abbreviated background of physical and chemical forms of manure, and nutrient conservation and losses associated with storage, handling and utilization are provided to foster an understanding of their impacts on the manure's value. Key manure management topics covered include: estimating nutrient concentration in manure, the affect of collection and storage on manure nutrient availability, the utilization of manure nutrients in a cropping system, and non-cropping methods of manure utilization.
I. Manure Physical Forms and Units of Measure

Manure consists of both feces and urine. To more easily compare between animal species, manure production is expressed per 1,000 pounds of live animal weight, or per animal unit (AU). Manure volume is reported as cubic feet per AU per day (ft³/AU/d). Daily total solids production and particular amounts of nitrogen (N), phosphorus (P), and potassium (K) are often reported in terms of percentages or parts per million (ppm). Reference table values or mass balance techniques are used to estimate the amount of manure excreted daily (Appendix 1). Additionally, estimates of other contributors to the waste steam (wasted feed or spoiled wash water, bedding, etc.) must be made. This information can serve to judge the amount of land necessary for manure nutrient utilization and is needed to adequately design storage and handling facilities.

Once excreted, manure is collected, stored, treated, and utilized. Facility design and manure handling practices alter the moisture and nutrient content of manure. Liquid manure contains more than 95% moisture; slurry or semi-solid manure is between 75% and 95% moisture; and solid manure is defined as less than 75% moisture. The physical form of the manure at the time of utilization will limit its utilization potential due to transportation costs.

The nutrient content of manure can be estimated by one of two methods. The first method is to use values found in standard tables (Appendix 1). The actual amount of nutrients excreted can vary from the standard values by as much as 50% based on diet, stage of production, and age (ASAE, 1977). A second and more precise method to estimate nutrient excretion considers nutrient intake and animal productivity. However, the mass balance technique requires knowledge of the amount of nutrients consumed and the quantity of nutrients deposited in the product (milk, meat, and fiber). Excreted nutrients account for the difference.
II. Manure as a Fertilizer

All nutrients excreted are not conserved during the collection, storage, handling, and utilization processes. Losses of nutrients, particularly N, and decomposition of organic material will result in a different chemical composition of material utilized than that of the manure excreted.

Manure is commonly added to soil as an organic amendment and nutrient source. The primary manure nutrients utilized are N, P, and K. The ultimate fertilizer value of manure is dependent on the quantity and form of manure nutrients applied to the land. Excreted manure and applied manure contain N, P, and K in different chemical forms. The chemical form of manure nutrients determines their availability to the crop. A glossary of chemical properties and processes relating to manure is in the Glossary section (page 27).

A. Manure Nutrients of Fertilizer Value

Manure nitrogen (N) found in the environment is in one of three forms: organic nitrogen (organic—N), ammonium (NH$_4^+$—N), and nitrate (NO$_3^-$—N). The fate of manure N is determined by its chemical form. A brief discussion of the N cycle is useful to better understand the potential fertilizer value of manure N (Figure 1).

Soil properties such as water-holding capacity, texture, and cation exchange capacity determine the amount of manure that can be effectively applied (Follett and Croissantl, 1990) in order to optimize N utilization. Organic—N is unavailable to plants. However, soil microbes mineralize organic—N to ammoniacal—N (NH$_4^+$—N). The rate of mineralization depends on manure type, soil type, soil moisture and temperature, and manure incorporation method. Nitrogen availability estimates range from 30% to 80% in the first cropping season. A common estimate for N availability used in determining an application rate is 60% of the organic—N and 80% of the NH$_4^+$—N in the first cropping season (Pratt et al., 1976).
Ammoniacal—N is directly available to the plant or can be converted by bacterial nitrification into NO$_3^-$ form. Although NH$_4^+$ can bind to soil particles in clay soils, it is mobile in poorer quality soils. Also, NH$_4^+$ can be converted to NH$_3$ that can be volatilized to the atmosphere. The volatilization of NH$_3$ is influenced by soil pH, temperature, air contact, and moisture. The greater the duration of time between manure spreading and incorporation, the greater the amount of N volatilization.

The plant absorbs large amounts of N in the NO$_3^-$ form. Nitrate is both mobile and volatile. Excess application of water (rainfall or irrigation) can leach NO$_3^-$ beneath the crop root zone making it unavailable for plant use.

Also, nitrate can be denitrified by soil microbes. Complete denitrification of NO$_3^-$ to N$_2$ can occur when soils become saturated with water and anaerobic conditions are formed. Nitrogen gas (N$_2$) is released to the atmosphere.

Phosphorus is another nutrient found in manure. About one-third of manure P is bound to organic matter. This must be mineralized by soil microbes to be plant-available. Approximately two-thirds of manure P is in the inorganic form. This P must be solublized to be plant-available. Solublization depends on soil pH and the concentrations of soluble aluminum, iron, and calcium in the soil (Magette et al.,
Phosphorus is more easily available in neutral soils. In acidic soils (pH 4 or less) P may form insoluble iron and aluminum phosphate. In extremely alkaline soils (pH 8.5 or more) insoluble calcium phosphates form. All result in decreased plant availability of P (Janick et al., 1974).

Phosphorus is lost from the soil system through particle erosion and subsequent runoff (Magee et al., 1985). Although soluble P does not move in non-phosphorus-saturated soils, solubilized P can leach in saturated soils. Once the soil P saturation point has been reached, P moves freely with water, and can migrate into irrigation or rainfall runoff waters (Voss, 1973). Soil can become saturated with P as has been reported from areas where large applications of animal manures have persisted in the Midwest and Northeast (Cast 1992; Westphal et al., 1989).

Manure contains solable K, which is immediately available to the plant. Potassium is soluble and may be lost to runoff or volatilized, in part, to the atmosphere (Ewanek, 1996). There are animal health ramifications of elevated applications of K to forage crops (Horner, 1995). The K concentration in forages harvested from fields with elevated K soil concentrations are greater than the concentrations of forages from fields with lower K concentrations. Adverse health problems have been reported from the feeding of the high K forages to ruminants (Horner, 1995; Sanchez et al., 1994).

B. Impacts of Collection, Storage, and Handling on Final Concentration

All excreted nutrients are not available for utilization. Management decisions and climatic conditions during collection and storage will influence the final nutrient concentration of manure. Estimating the amount of nutrients excreted does not adequately define the needed cropping and land practices to use nutrients at agronomic rates. This is because nutrient transformations and losses that occur between excretion and utilization must be considered. To facilitate an understanding of manure management critical points for nutrient conservation, a manure management flow chart is provided (Appendix 2).

Biological decomposition is responsible for nutrient loss during handling and storage. Animal nutrition, animal production stage, housing system, and type and use of bedding affect the concentrations of N, P₂O₅, K₂O, and total solids (TS) in fresh manure. In addition, collection and storage methods, as well as season of collection impact the final nutrient value of manure as applied to the crop (Lindley et al., 1988).

B.1. Manure collection and storage

Animal housing determines much of the manure collection and storage system. The quantity of manure collected is a function of the location of manure deposition and its subsequent collection system. Scrape methods can leave uncollected manure or bedding material behind, while flushing systems add water (thereby requiring greater storage capacity) and dilute nutrient concentrations. Rainfall can
result in two additional sources of influent. The first, is the actual rain deposited in the pond. The second, is facility runoff water collected as a result of rainfall on exposed animal housing areas. Excessive water accumulation in areas of high manure deposition will result in runoff or leaching of valuable nutrients. Therefore, all rainfall that contact manured surfaces must be collected and stored.

The rate of N loss due to volatilization, denitrification, or leaching is variable and will depend on the storage time, storage system, and method of application. Table 1 shows average N loss during storage for several different dairy waste management systems. Table 2 summarizes daily N loss rates for liquid storage of cattle and swine manures available from several studies.

Table 1. Estimated Nutrient Losses During Storage and Handling for Various Dairy Waste-Management Systems

<table>
<thead>
<tr>
<th>System</th>
<th>N* Loss (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep pit storage, liquid spreading</td>
<td>30 to 65</td>
</tr>
<tr>
<td>Anaerobic lagoon, irrigation or liquid spreading</td>
<td>60 to 80</td>
</tr>
<tr>
<td>Oxidation ditch, anaerobic lagoon, irrigation or liquid spreading</td>
<td>70 to 90</td>
</tr>
<tr>
<td>Bedded confinement, solid spreading</td>
<td>30 to 40</td>
</tr>
<tr>
<td>Open lot, solid spreading, runoff collected and irrigated</td>
<td>50 to 60</td>
</tr>
</tbody>
</table>

*Nitrogen loss values assumed that manure was applied to the ground surface and was incorporated within a few hours.

Table 2. Summary of Average Nitrogen Loss of Liquid Manures by Storage Time and Treatment

<table>
<thead>
<tr>
<th>Author</th>
<th>Cattle Manure (percentage total nitrogen loss/days)</th>
<th>Swine Manure</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balsari (1987)</td>
<td>25.2 / 90-120</td>
<td>--</td>
<td>Anaerobic</td>
</tr>
<tr>
<td>Loynachan et al. (1976)</td>
<td>--</td>
<td>16-26 / 83</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Thalmann (1982)</td>
<td>13.7-14 / 20</td>
<td>--</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Wedekind &amp; Kuehn (1971)</td>
<td>8.7-14.8 / 68-168</td>
<td>--</td>
<td>Anaerobic</td>
</tr>
<tr>
<td>Wedekind &amp; Kuehn (1971)</td>
<td>--</td>
<td>13.8 / 125</td>
<td>Anaerobic</td>
</tr>
<tr>
<td>Besson et al. (1982)</td>
<td>3.2 / 48</td>
<td>4.8 / 51</td>
<td>Anaerobic</td>
</tr>
<tr>
<td>Besson et al. (1982)</td>
<td>6.9 / 43</td>
<td>5.3 / 45</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Muck &amp; Steenhuis (1982)</td>
<td>3.0-6.0 / 40</td>
<td>--</td>
<td>Anaerobic</td>
</tr>
</tbody>
</table>

*Source: Dewes et al. 1990, adapted from Table 1.
In addition to storage method and time, environmental conditions can impact N loss. Luebs et al. (1973) and Lorimer et al. (1975) reported that high air temperatures and low relative humidity increased NH$_3$ losses. Muck and Richards (1983) indicated that average daily temperature affected N loss in free-stall dairy barns. They concluded that although little N loss occurred for average daily temperatures below 5°C, 40 to 60% N loss could be expected for temperatures between 5°C and 25°C.

Evaluations of the effects of storage system showed differences in nutrient concentration due to collection method. Collins et al. (1994) examined four different manure collection systems for dairy manure: liquid storage (concrete or steel underground tanks; earthen storage basin) and semi-solid storage (stacked manure; fresh scraped). The liquid manure tank tested at 272.7 ppm, while the earthen manure basin tested at 241.3 ppm. However, comparison of the two liquid storage systems showed that underground tanks had higher total Kjeldahl nitrogen (TKN) levels than did earthen storage basins. This difference was attributed to the increased N volatilization and dilution by rain water in the earthen storage basins. No significant differences in TKN were found between the two semi-solid storage systems.

Collins et al. (1994) found significant changes in P concentration in manure due to storage method and season of collection. Liquid storage methods averaged 1,330 ppm of P, while solid storage methods averaged 16,220 ppm. These differences in P concentration were probably due to dilution effects in the liquid storage systems. However, further comparisons between two liquid storage systems, manure tanks vs. earthen manure basins (ponds), showed that liquid from manure tanks had higher concentrations of P$_2$O$_5$ than did ponds.

The quantity and composition of nutrients volatilized will vary depending on the storage system. (Tables 1 and 2). Anaerobic ponds are designed to store large quantities of materials in the absence of oxygen. These ponds are often between five and forty feet deep. Aerobic ponds are shallow (three to five feet deep), facilitating oxygen penetration into the water. The extent of nutrient volatility depends on temperature, pH, salt concentration and pond type (aerobic or anaerobic).

Nutrient value of manure water can vary greatly both between ponds of similar type and within an individual pond over time. Morse et al. (1996) found that anaerobic ponds used on two different dairy facilities ranged in N concentration from 81 to 351 ppm for TKN and from 60 to 213 ppm for NH$_4^+$. Within a single pond, manure water differed by as much as 118 ppm for TKN and 114 ppm for NH$_4^+$. Dairy one (TKN = 351 ppm) housed its cows in dry lots, collected manure in feed alley lanes, and used pond water for irrigation without recycling. Dairy two (TKN = 81 ppm) housed cows in free stalls, used a solid separator, and recycled water prior to irrigation. In addition, ponds ranged from 19 to 78 ppm for P and 72 to 451 ppm for K. These P and K value ranges were similar to those reported by Falk and Ohlensehle (ADSA, 1994). The large range in nutrient concentrations reflects different manure management systems and different annual weather conditions.
Due to the large variation in nutrient concentration from farm to farm, application rates should be based on site-specific data and not textbook values. It should be noted that sludges accumulate large concentrations of organic N. Pond water and bottom sludge should be sampled and tested for nutrient content to more closely estimate nutrient application rates.

B.2. Manure application

Application rates should be calculated to supply crop nutrient requirements (N, P, and K) without excessive nutrient or salt accumulation. Recent soil and manure tests or reliable estimates for N, P, and K should be used in determining application rates. Typically, N is the most limiting nutrient to plant growth and the largest threat to groundwater contamination (Wallingford et al., 1975). Therefore, N is used to determine application rates. Often this results in over-application of P, K, and salts. Application rates should be determined to prevent detrimental build-up of nutrients.

Application rates should be based on:
- texture and fertility of soil;
- nutrient requirements of the crop;
- nutrient content of manure being applied;
- local climatic factors which may affect availability of major nutrients via mineralization, leaching and denitrification;
- safe, pollution-free recycling of manure nutrients (Alberta Environment Agriculture 1982); and
- previous rate of fertilizer application.

A number of different methods and tools exist for determining manure application rates. For further discussion of considerations and methodologies of manure application refer to Appendix 3.

C. Determination of Value of Manure Nutrients as Fertilizer

The economic value of manure nutrients is a function of crop needs and not the mere presence of nutrients in the manure. The fertilizer value of N, P, and K in manure is based on the quantity of nutrients and their value to crop productivity.

C.1. Determination of the economic value of N, P, and K

The quantity of N, P, and K in manure has specific value as fertilizer nutrients if they are lacking in the soil. The two most common means of quantifying the economic value of manure are replacement cost of synthetic fertilizers and increase in crop yield due to manure fertilization. However, the relative value of these nutrients depends on costs of alternative sources of nutrients, the relative costs of application, other beneficial aspects of manure use, and detrimental aspects of manure use. Calculation of relative costs requires comparison of application of manure nutrients to the application of commercial nutrients (which are typically more con-
centrated and therefore require less time in handling and application). In general, nutrients applied in excess of plant requirements should be given a value of zero. When nutrients are applied at detrimental rates they should receive a negative value.

Organic matter in manure can be beneficial to soil to improve tilth, porosity, and water holding capacity as well as microbial environment. Additionally, trace minerals present in manure can be beneficial to soil. Challenges associated with manure applications include regulatory constraints (consideration of prevailing wind, proximity to neighbors, odors, groundwater, and surface water concerns), social considerations, ratio and availability of needed nutrients, and detrimental effects of nutrients applied in excess.

The major emphasis on economic evaluations of land applied manure has focused on N, P, and K — elements having primary implications on crop productivity. Less emphasis has been focused on soil structure, water holding capacity, salinity, and weed seed viability. The economic impact of manure application in the context of these factors has seldom been evaluated.

C.2. Relative economic value of manure as fertilizer

In order to determine the gross dollar value of manure nutrients, three types of information must be collected: (1) nutrient concentrations based on laboratory analyses; (2) efficiency values for each nutrient; and (3) the value of alternative commercial fertilizer nutrients. The efficiency values of each nutrient will depend largely on the chemical form of the nutrient, the season and method of application, and soil tillage practices. These values represent the percent availability of specific nutrients. Efficiency estimates of incorporated manure are 70% N, 85% P, and 95% K (Segars, 1986). The actual economic value of manure nutrients is the sum of the individual values for N, P, and K in manure:

\[ $ = \text{Nutrient Content of Manure} \times \text{Efficiency Value (EV)} \times \text{Value of Commercial Nutrient in $ Per Pound} \]

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>lb/ton</th>
<th>EV</th>
<th>Commercial Value ($/lb)</th>
<th>Value ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>26.0</td>
<td>0.70</td>
<td>0.22</td>
<td>4.00</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>7.8</td>
<td>0.85</td>
<td>0.50</td>
<td>3.32</td>
</tr>
<tr>
<td>Potassium</td>
<td>15.3</td>
<td>0.95</td>
<td>0.50</td>
<td>7.27</td>
</tr>
<tr>
<td><strong>Total Value</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$14.59</strong></td>
</tr>
</tbody>
</table>

Total Gross Value (with no consideration for the value of the micronutrients) of one ton of the product is $14.59
The net economic value must consider differences due to application method between manure and commercial fertilizers. Equipment and labor requirements as well as timing of fertilizer applications with respect to plant growth stages must be considered. There continues to be some debate about the economic value of nutrients applied in excess of crop needs. Should a negative value be assigned to nutrients that are applied in excess of crop needs and are mobile in soil if the nutrient does not impair soil productivity or crop quality? As an example, irrigation water management currently utilizes deep percolation of salts beneath the crop root zone. This is done to minimize salt build-up that would impair crop production. The leaching of salts will eventually reach groundwater. Should a negative value be assigned to nutrients that are applied in excess of crop needs if the nutrient is not mobile in soil and soil nutrient reserves are low? The cumulative effect of continued over application (with no leaching) would result in soil saturation at some time. In cases where excess nutrient application results in negative effects on crop production or environmental impairment, negative values should be assigned to correctly quantify the value of the manure. The magnitude of the negative value should be determined long before environmental impairment is evident.

C.3. Agronomic value

Crop productivity can be used to quantify agronomic value of manure. This method measures the increased crop yields resulting from manure application. Application expenses associated with manure use are calculated. Crop productivity takes into account the effects of the nutrient as well as the manure’s beneficial amendment qualities (increased water holding capacity, improved soil tilth, and enhanced growth of soil microorganisms). This method is best suited to long-term studies.

C.4. Further consideration of manure use

In addition to nutrient value determination, added costs associated with manure use should be considered.

Transportation costs

Transportation costs may limit the use of manure as a source of fertilizer off-farm. Manure differs in water content depending on storage and handling methods. The weight and volume of additional water merely dilute manure and increase the volume. As the moisture content of the manure is decreased, the transportation of manure becomes more cost effective. Liquid manure is commonly transported on-farm through an irrigation system, thus application is limited to a two to three mile radius. However, air-dried manure or compost may be hauled much longer distances. Follett and Croissant (1990) discussed possible loading, hauling, and spreading costs approximating $15.00 per load for a 15 ton load if the hauling distance was less than ten miles. The cost for each additional mile over 10 miles was estimated at $1.00 per ton. A composting operation located in California estimated hauling costs for a finished product of about 30% moisture as $17.00 per load for a 25 ton load, with an additional charge of $1.50 per ton and $.08 per mile for distances in excess
of 10 miles. This rate did not include spreading charges that were approximated at $4.00 per ton. Transportation and spreading costs will vary by location and individual circumstances. Transportation costs should be all-inclusive and carefully evaluated for each operation. Costs should include, repair and maintenance, depreciation, permits and vehicle registration fee, labor, insurance, fuel costs, and interest on the capital.

Salt accumulation in soils

Manure’s salt content may pose a limitation to its use as a fertilizer for agricultural crops. Salt content of manure should be evaluated in the waste management strategy. For example, an average 1,400 pound dairy cow excretes 120.4 pounds of wet feces per day which contain about 1.3 pounds of soluble salts (ASAE, 1992). Potassium is the soluble salt most often associated with salinity problems. Salts can accumulate and create soil salinity problems resulting in reduction of crop yields.

The negative effects of soil salinity are two fold. Short-term effects on plant growth of the current crop include poor seed germination and seedling vigor (Voss, 1973). High concentrations of salt increase the osmotic potential of the soil solution and desiccate seedlings as well as mature plants. The degree of crop devastation due to salinity differs depending on the climate, soil water, salt composition, plant species, and the plant’s stage of production (Singer 1987). Long-term effects on soil quality include changes in chemical composition. When large quantities of salt are present in the soil, sodium replaces other bases, especially calcium and magnesium in clay soils. This results in soil aggregation or granulation. Dispersion of soils causes:

- severely reduced infiltration of moisture leading to increased runoff and erosion or longer ponding after rains;
- slower drainage and drying because more water is held in the smaller pore spaces;
- poorer aeration as a result of smaller pores and slower drainage leading to poorer root development; and
- severe crusting making emergence of seedlings more difficult and the need for more frequent cultivation to break up the crust (Voss, 1973).

Although negative impacts of soil salinity, like beneficial amendment qualities, are difficult to quantify, negative values may need to be assigned to manures for long-term economic assessment. Manure management also must include salt management. The salt concentration of manures depends on the quantity of salt consumed in the feed and the manure collection, storage, and treatment methods. For example, pond effluent may have a more severe, immediate effect on salt load because the salt is soluble and the effluent contains less organic matter (Voss, 1973). Salt content of soils may differ depending on soil type and historical use. Care needs to be taken to prevent salt accumulation beyond crop tolerance levels. A table of salt tolerance for a few selected agronomic crops can be found in Appendix 4.
III. Manure As a Source of Energy Generation

Animal waste can be digested. Anaerobic digestion of animal waste yields methane for conversion to energy. Complete anaerobic digestion to the usable methane end-product is accomplished by the interaction of two entirely different bacteria populations, "acid formers" and "methane formers." Environmental factors such as pH, alkalinity, volatile acid concentration, temperature, nutrient availability, and presence of toxic materials affect bacterial function and efficiency (Morris et al., 1975). Under the appropriate environmental conditions, the bacteria populations will-flourish and methane production will be more efficient. The resulting methane end-product is converted to an electrical energy source. The electricity can be used for on-farm purposes such as lighting, heating buildings or water, and running small combustion engines. Electricity produced in excess of the farm's needs may be sold. A more detailed explanation of the energy generation process can be found in Appendix 5.

A. Benefits of Energy Generation through Anaerobic Digestion of Animal Waste

The process of energy generation through anaerobic digestion offers several other benefits to waste management. Morris et al. (1975) listed several important benefits from anaerobic fermentation: the stabilization of organic material; reduction of odor, and; production of a usable biogas product, methane. The fertilizer value of the manure is conserved, and end-product material can be applied to the land as fertilizer. Pigg and Yetter (1984) found that 93% of the nitrogen present in the manure added to a digester was still contained in the effluent at the time of application to the soil. Dahlberg et al. (1988) concluded that digester effluent, when utilized in wheat production, was as effective as fresh manure sources in stimulating dry matter production, grain yields, and grain protein content. They found that digester effluent had higher percentages of N as ammonium, a plant-available form of N, than did fresh or stored manure. This indicated that digester effluent was just as effective, if not more effective, as a fertilizer source than fresh or stored manures. Table 3 lists estimated nutrient concentrations (N, NH₃—N, P, and K) of digester effluent by species. In general, manure effluent of non-ruminant species contains higher nutrient concentrations than does manure effluent from ruminants.
Table 3. Estimated Fertilizer Content of Anaerobic Digester Effluent by Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Total N (percentage in digester effluent)</th>
<th>NH₃—N</th>
<th>Total P</th>
<th>Total K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry</td>
<td>1.0</td>
<td>0.8</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Swine</td>
<td>0.4</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Dairy</td>
<td>0.2</td>
<td>0.1</td>
<td>0.04</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: Sievers and Lannotti, 1982. Table 1.6.

Similar to raw manures, digester effluent is subject to nutrient losses due to storage and application practices. Pigg (1977) reported losses in dairy cow effluent of 4.5% and 17% for total N and P, respectively, from an open-topped slurry storage tank. Sampling effluent prior to application is necessary to determine appropriate application rates and promote adequate nutrient availability to growing crops.

Animal manures are well suited as a source of energy generation material compared to many other biomasses. Methane production from manure, as a percentage of total gas production, has been quantified by Taiganides (1969) as 60-80%, 55-75%, and 60-80% for laying hens, growing swines, and dairy cows, respectively. Table 4 identifies recommended digester volumes, loading rates, estimated retention times, and biogas yield rates by animal species on a per thousand pound standard. These figures are estimates and will differ depending on individual circumstances.

Table 4. Gas Production and Digester Size for Animal Wastes

<table>
<thead>
<tr>
<th>Waste</th>
<th>Retention Time (days)</th>
<th>Digester Size (ft³ / 1000 lb liveweight)</th>
<th>Loading Rate (lb/day/ft³ of digester volume)</th>
<th>Biogas Yield (ft³ / 1000 lb liveweight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laying Hen</td>
<td>22</td>
<td>79</td>
<td>0.13</td>
<td>75</td>
</tr>
<tr>
<td>Growing Hog</td>
<td>15</td>
<td>19</td>
<td>0.25</td>
<td>43</td>
</tr>
<tr>
<td>Growing Beef</td>
<td>15</td>
<td>20</td>
<td>0.3</td>
<td>31</td>
</tr>
<tr>
<td>Steer</td>
<td>15</td>
<td>20</td>
<td>0.3</td>
<td>42</td>
</tr>
<tr>
<td>Dairy Cow</td>
<td>20</td>
<td>28</td>
<td>0.3</td>
<td>42</td>
</tr>
</tbody>
</table>

Source: NRAES, 1984 Table 1 and text.
B. Economic Considerations of Anaerobic Digestion

Similar to any enterprise, energy generation by anaerobic digestion should be evaluated in terms of its cost-benefit potential. Factors which need to be evaluated include: capital costs of the investment (including equipment, installation labor, and insurance); operation and maintenance costs, and; cost of on-farm energy generation in relation to current energy costs (Morris et al., 1975). Investment, operation, and maintenance costs are highly variable and will depend on the size and style of the system. Morse et al. (1996a) reported a range in investment costs for anaerobic digester equipment and installation of $100,000 to $950,000 for six California dairy operations. The single swine operation known to operate a capped-pond style anaerobic digester, Royal Farms (Sharp, 1996), showed an initial investment cost of $280,000 for their first and largest pond system. Although these figures represent substantial investments, the revenues realized from the energy generation can result in an economically viable system if operated and maintained cor-

| Investment:  | $280,000 |
| Maintenance: | $100/month |
| Production rate: | 67 kwh |
| Opportunity cost: | $0.08/kwh |

Income: 

\[ 67 \times \$0.08 \times 24 \text{ hrs/day} \times 30 \text{ days/month} \times 12 \text{ months/year} = \$46,310 \]

Expenses: Maintenance (yearly) \(-\) $(1,200)\]

Cash Flow: \$45,110

Payback Period: Investment/Cash Flow = 6.2 years

Figure 2. Determination of Payback Period

| Investment:  | $280,000 |
| Loan Amount: | $280,000 |
| Term:        | 10 years |
| Rate:        | 9% |
| Depreciation:| 20 year straight-line |
| Maintenance: | $100/month |
| Production Rate: | 67 kwh |
| Opportunity Cost: | $0.08/kwh |

Income: 

\[ 67 \times \$0.08 \times 24 \text{ hrs/day} \times 30 \text{ days/month} \times 12 \text{ months/year} = \$46,310 \]

Expenses: Maintenance & Depreciation \(-\) $(15,200)\]
Interest \(-\) $(14,563)\]

Profit: \$16,547

Return on Investment Profit/Investment = 5.9%

Figure 3. Determination of Annual Return on Investment
rectly. The Royal Farms covered-pond digester produces an average of 67 kilowatt-hours (kwh) from about one-third of the manure production on a swine farrow-to-finish operation housing a total of 12,000 animals. At the rate of 67 kwh, the digester system produces all of the energy necessary for the operation of the swine farm plus excess which is sold to the local utility company. This results in a savings of approximately $3,000/month in energy costs (using opportunity cost of $.08 per kwh) and an additional income from the sale to the utility at $.02 per kwh or about $650/month.

Capital budgeting methods should be utilized to evaluate the economic soundness of an investment. Return on investment, or simple rate-of-return, and payback period are two commonly used methods in investment analysis. Return on investment expresses annual profits projected from the investment as a percentage of the initial investment. Payback period estimates the length of time required to repay the investment from the cash flows. Using the Royal Farms' information, a sample return on investment and payback period can be determined (Figures 2 & 3). The results will differ for each system and financial situation. The annual profit, and ultimately the return on investment, will be affected by financing costs (determined by loan amount, term, and interest rate), depreciation method, system efficiency, and value of the energy.

In addition to income or savings obtained directly from the energy produced, economic value should be placed on the solid and liquid end-products as sources of fertilizer, potting mix, or feeding materials. These end-products can be used on-farm or sold resulting in a cost savings or additional revenue for the farming operation. Careful financial analysis of all factors should be undertaken prior to investment in an energy generation system. Only a limited number of producers have found on-farm energy generation profitable. However, under the correct management and economic situations, energy generation appears to be a viable means of increasing the value of manure.
IV. Alternative Uses of Manure

A. As a Compost Material

Manure can be used as a material source for compost. The C:N ratio of beef feedlot and dairy manures makes these manures more viable sources of composting material than either poultry or swine manures (Jurgens, 1996; NRAES, 1992). Various bulking agents (C source) or manure additions (C or N source) may be needed depending on the ability of air (i.e. $O_2$) to penetrate and the initial C:N ratio (Paul, 1996).

During the composting process, aerobic microorganisms actively decompose organic materials into humus and long chained molecules consisting primarily of carbon, hydrogen, and oxygen compounds (NRAES 1992). Humus is a chemically stable substance with almost 100% of its nitrogen in the stable, organic form. Fresh manure contains 10-50% of its nitrogen in the ammonium form that is not stable and volatilized (Lammers-Helps, 1991).

Although the decomposing process occurs naturally with time, it is accelerated when ideal conditions are maintained. Optimal conditions for composting include a carbon to nitrogen ratio between 25:1 and 30:1, a moisture content of 50-60%, and an oxygen concentration of greater than 5% (Paul, 1996). Composting conditions outside of optimal are less efficient. For proper decomposition, the temperature of the compost pile should be between 130° to 160° F. This range, referred to as the thermophilic range, is high enough to maximize the rate of decomposition without killing the microorganisms. To maintain temperatures within this range, piles must be kept moist and aerated to supply sufficient amounts of oxygen (Lammers-Helps, 1991). High moisture results in poor oxygen movement through the pile and ultimately results in anaerobic conditions, thus eliminating an environment for aerobic bacteria. Continued lack of oxygen further enhances the anaerobic
microorganism population. Anaerobic metabolism is not desirable in the composting process and results in foul-smelling compost piles (Paul, 1996).

A.1. Benefits from composting manure

The total nutrient concentration of manure can be enhanced through composting. The nutrients within the humus material are more stable. With good system management, environmental problems such as NH₃ volatilization resulting in foul odors for neighboring communities, nitrate leaching into groundwater, and phosphorus and nitrate runoff contaminating surface water are decreased (Paul, 1996). Furthermore, composting kills weed seeds and pathogens. The high temperature conditions of the microbial decomposition process decreases the impacts of these concerns which may impede plant growth and are commonly associated with fertilization with raw manure.

A.2. Economic considerations to composting manure

During the composting process the total volume of material is reduced by about one-third, potentially increasing nutrient concentration and enhancing product value. Handling and spreading costs are reduced through reduction in volume of material required to be hauled to the field and spread to satisfy the nutrient needs of the crop. The economic savings associated with the use of compost over manure will differ by individual situation, but any analysis must take into account added costs such as labor, land, and machinery. In addition, any financing costs for specialized equipment to be used in the composting operation should be included.

There are a number of accepted methods that can be used to evaluate the economic soundness of composting. Both the payback period and return on investment methods may be used when evaluating composting as a commercial venture (for examples see the preceding energy generation section). The benefit-cost ratio method can be used to determine the economic value of composting to the farming operation. A sample benefit-cost ratio can be determined for composting as follows:

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- savings from decreased hauling</td>
<td>- labor costs</td>
</tr>
<tr>
<td>- savings from decreased spreading</td>
<td>- equipment investment/amortization</td>
</tr>
<tr>
<td>- value of conserved nutrients</td>
<td>- opportunity costs of additional land</td>
</tr>
<tr>
<td>- value of compost</td>
<td>used for composting</td>
</tr>
</tbody>
</table>

Benefit-Cost Ratio = total $ value of benefits / total $ value of costs.

The composting process is considered economically justifiable for an individual case if the benefit-cost ratio is greater than 1.0. If the benefits outweigh the costs, then active composting of manure can be recommended.
B. As a Soil Amendment

Numerous studies support the use of animal manures as a soil amendment to improve the soil tilth. Stewart (1991) defined tilth as “the physical condition of the soil related to its ease of tillage, fitness as a seedbed, and impedance to seedling emergence and root penetration.” Manure used as a soil amendment, or humus, improves both the physical and chemical properties of soils. In particular, soils that are shallow, coarse textured, or low in organic matter benefit from the addition of manure. Manure’s high proportion of organic matter contributes to the soil’s ability to perform three vital functions — promote plant growth, regulate the flow of water, and attenuate wastes (Stewart, 1991). While commercial fertilizers add nutrients needed for crop production, manures can contribute to the overall health of the soil. The soil’s ability to perform is dependent on its content of organic material. The improved physical condition of the soil attributable to the organic matter in manure includes: increased water holding capacity, reduced water runoff, improved soil aeration, and increased growth of soil microorganisms (Segars, 1986). Increased water holding capacity can result in greater water availability to growing crops and ultimately higher crop production. Reduced water runoff minimizes soil erosion. Improved soil aeration promotes the growth of soil microorganisms and the establishment of plant root reserves. Increased growth of soil microorganisms increases the soil’s ability to decompose organic matter into plant available nutrients. Together these characteristics improve soil fertility and longevity.

Soil fertility and longevity are essential for long-term crop production, however, they are difficult to evaluate on an economic basis. The added soil amendment benefits of manure are relatively inseparable from its fertilizer value. This makes manure’s true value as a soil amendment difficult to quantify.

C. Feedstuff

Manure nutrients can be used as a feedstuff for animals. The animal can utilize the energy, protein, and minerals. The feed nutrients of manure can be recovered by direct re-feeding, or by processing, followed by re-feeding. Processing aids in the reduction of pathogenic organisms, facilitates easier handling and storage, and preserves manure nutrient content. Common processing methods include ensiling with addition of other feedstuffs or products, drying, solid-liquid separation, or chemical treatment with additives. A producer must be aware of any regulations pertaining to the feeding of animal manure products.

Lindley (1982) suggested that the ideal animals for consuming processed manure were ruminants because of the rumen microbes. Rumen microbes can utilize the fiber, non-protein nitrogen compounds, and nucleic acids more efficiently than the gastro-intestinal system of non-ruminants.

A least-cost ration formulation program can identify the economic value of a given manure product. Samples of the source manure should be collected and analyzed for nutrient and fiber content (crude protein, acid and neutral detergent fibers,
and minerals). The value will vary according to local feed costs, manure nutrient content, and nutrient requirements of the animals being fed.

D. Bedding Material

Recycled manure solids can be used as free-stall bedding material. Dairymen use dried manure solids recovered from solid-liquid separators or barnlot corrals as a source of bedding material. Manure solids can be stored in windrows or stacks, and can be handled similar to other bedding materials. Manure solids must be managed to minimize the incidence of mastitis (Allen et al., 1980). Allen et al. (1980) found that coliform mastitis incidence was significantly lower when manure solids were composted for at least six weeks (reaching temperatures of 130°F). They recommended that only manure solids that had coliform counts below 106/gm and dry matter above 60% be used as bedding material. Under these conditions, dried manure solids provide a convenient, on-site source of bedding material. However, important economic considerations of producing on-farm bedding material need to include equipment costs and operating expenses in comparison to the purchase cost of alternative bedding material.

Economic assessment of manure as bedding material can be accomplished using the replacement cost of alternative bedding materials. Investments that would be made in any case, such as solid-liquid separators, should be considered sunk costs, or unrecoverable costs, and should not affect the decision making process. However, extra labor hours required to manage the composting process should be subtracted from the manure’s value. This assumes that the typical routine for bedding free-stalls is not altered by changing bedding materials. For example, if bedding needs to be changed more frequently or excess amounts of manure solids need to be applied to achieve sufficient success, these factors should be accounted for in the analysis. If manure solids require hauling to alternate areas of use, the transportation costs must be considered.

E. Vermicompost

Another proposed use for manure is as a material for vermicompost. The vermicomposting process is the composting of nitrogen and organic materials by earthworms into castings or “earthworm dirt” (Albanell et al., 1988). Earthworms are housed in manure windrows or slurry beds approximately 1.5 feet deep. The earthworms rapidly decompose manure nutrients into more stable end-products when managed correctly. During the process, volatile nitrogen, odor, and total tonnage are reduced.

Three types of earthworms are active during vermicomposting: epigeic, endogeic, and diageic. Epigeic earthworms are responsible for the reduction of offensive odor commonly associated with manure. These worms ingest the anaerobic microbes responsible for the foul odors during manure decomposition. In contrast, the endogeic and diageic earthworm species are responsible for the reduction of manure tonnage. By burrowing networks of tunnels throughout the compost,
these worms introduce oxygen conditions favorable for aerobic microbe decomposi-
tion of organic materials and ultimate reduction in manure volume (Hartenstein
and Bisesi, 1989).

Studies have examined the viability of the process to aid in the reduction of
animal manures and the conversion of manures into more usable materials. Fosgate
and Babb (1972) stated a conversion rate of raw feces to live earthworms as 2:1
(weight basis) using *Lumbricus terrestris* earthworms and "barnlot" feces. Albanell
et al. (1988) found that vermicomposting accelerated the mineralization rate and
increased the nutritional value and degree of humification in the final product when
sheep manure was used. They found that the chemical make-up of the castings
produced by *Eisenia fetida* earthworms over a 12-week period differed from the
original sheep manure sample. Specifically, the percent salinity; organic matter;
total N; and C:N ratio were reduced from week two to week twelve by 46%, 84%,
88%, and 85%, respectively. In addition, P, K, and N percentages were increased
by 137%, 136%, and 200%, respectively. These changes may increase the value of
manure as a fertilizer source by improving the ease of handling (less bulk), decreas-
ing the salinity, and narrowing the gap between N, P, and K percentages. The closer
N, P, and K values may aid in determining application rates that satisfy the nutrient
requirements of the crop without over application of any one nutrient.

The use of manure as a vermicomposting material is considerably less popular
than other uses. The relatively large land area required and the need to develop a
market for the product may contribute to its lack of popularity. Although experi-
mental data suggest that vermicomposting is a possible method to reduce manure
volume and produce useful end-products, little research has been done to assess the
economic feasibility of the process. Effort needs to be spent to determine the cost
of investment, maintenance costs (including total labor hours allocated to up-keep
of the system), and the market value of end-products. As with any manure manage-
ment alternative, these will differ by individual conditions, and will ultimately de-
terminate the economic viability of the system.
V. Conclusion

Animal manure, if managed properly, can be a valuable commodity to California producers. Although this paper has not attempted to list the many manure management tools available in the literature to assist in proper management, it has attempted to show how the nutrient content and chemical nature of manure contributes to its value. Manure's varied uses range from a source of fertilizer nutrients to an electricity generation medium and include uses as compost material, animal feed, and a soil amendment. Manure should be viewed as an economic resource that may be used on-farm or off-farm, contributing to operational efficiency and profitability. In today's business environment, any advantage, no matter how slight, can determine the difference between a profitable or unprofitable operation. Proper use and management of manure may be one opportunity for producers to improve efficiency and cope with tighter margins created in today's market.
# Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic</td>
<td>Pertaining to life in free oxygen or conditions requiring the same.</td>
</tr>
<tr>
<td>Ammonia nitrogen (NH₃—N)</td>
<td>The nitrogen component of the gas ammonia (NH₃) released by the microbiological decay of plant and animal proteins. (The term sometimes refers to the total of NH₃ and the ammonium ion, NH₄⁺.)</td>
</tr>
<tr>
<td>Ammonia volatilization</td>
<td>The loss of ammonia to the atmosphere.</td>
</tr>
<tr>
<td>Ammonium (NH₄⁺)</td>
<td>An ion (NH₄⁺) derived from ammonia (NH₃).</td>
</tr>
<tr>
<td>Anaerobic</td>
<td>Living in the absence of free oxygen; the opposite of aerobic.</td>
</tr>
<tr>
<td>Animal Unit (AU)</td>
<td>One thousand pounds of animal.</td>
</tr>
<tr>
<td>Anion</td>
<td>Negatively charged ion that can adsorb to positively charged particles. Common soil anions are nitrates and orthophosphates.</td>
</tr>
<tr>
<td>Available nitrogen</td>
<td>Form of nitrogen (NO₃⁻ or NH₄⁺) that is immediately available for plant growth.</td>
</tr>
<tr>
<td>Cation</td>
<td>Positively charged ion; can adsorb to soil particles. Common soil cations are ammonium, calcium and potassium.</td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td>The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value.</td>
</tr>
<tr>
<td>Cation exchange</td>
<td>Ion exchange process in which cations in solution are exchanged for other cations from an ion exchanger.</td>
</tr>
<tr>
<td>Demineralization</td>
<td>The total removal of all ions.</td>
</tr>
<tr>
<td>Denitrification</td>
<td>The chemical or biological reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen (N₂) or as an oxide of nitrogen (N₂O).</td>
</tr>
<tr>
<td>Inorganic nitrogen</td>
<td>Nitrogen that is not bound to organic material (example commercial fertilizer).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Ion</td>
<td>A charged element or compound that has gained or lost electrons so that it is no longer neutral electrically.</td>
</tr>
<tr>
<td>Mineralization</td>
<td>The microbial conversion of an element from an organic to an inorganic state.</td>
</tr>
<tr>
<td>Nitrification</td>
<td>The biochemical transformation by oxidation of ammonium (NH$_4^+$) to nitrites (NO$_2^-$) or nitrates (NO$_3^-$).</td>
</tr>
<tr>
<td>Nitrate nitrogen</td>
<td>The nitrogen component of the final decomposition product (NO$_3^-$) of the organic nitrogen compounds; expressed in terms of the nitrogen part of the compound.</td>
</tr>
<tr>
<td>Nitrogen fixation</td>
<td>The biological process by which elemental nitrogen is converted to organic or available nitrogen.</td>
</tr>
<tr>
<td>Nutrient, animal</td>
<td>Food constituent or groups of food constituents of the same general chemical composition required for support of animal life.</td>
</tr>
<tr>
<td>Nutrient, plant</td>
<td>Element essential to plant growth used in the elaboration of food and tissue.</td>
</tr>
<tr>
<td>Organic matter</td>
<td>Chemical compounds of carbon combined with other chemical elements and generally manufactured in the life processes of plants and animals. Most organic compounds are a source of food for bacteria and are usually combustible.</td>
</tr>
<tr>
<td>Organic nitrogen</td>
<td>Nitrogen bound to or in organic matter.</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen (TKN)</td>
<td>The sum of the organic and the ammonia nitrogen in a material. This method does not account for nitrogen in the form of azide, azine, azo, hydrazone, nitrate, nitrite, nitrile, nitro, nitroso, oxime, and semi-carbazone.</td>
</tr>
</tbody>
</table>

References


Appendix 1. Manure Production and Characteristics

The most commonly cited values describing manure production and nutrient composition are: Table D384.1 (American Society of Agricultural Engineers, 1992), Table 2-1 (Midwest Plan Service, 1985), and Chapter 4 (Soil Conservation Service, 1992). The initial ASAE manure production and characteristics table cautioned users that median values were presented and that actual values could vary widely (by as much as 50%) due to differences in ration, animal age, and management practices (ASAE, 1977).

Table 2-1 (MWPS, 1985) was established with data from Table D384 (ASAE, 1979). Values for beef cattle (cow) and various swine production stages were added to the MWPS table. Table D384 was revised in 1988 to Table D394.1. During this revision, split entries for dairy, beef and swine were reduced to singular entries for each species. The average values for the single entry value were altered slightly. For example, the current value of manure production for dairy is 120.4 lb/AU. This replaced the previous dairy cow value of 82 lb/AU and the previous dairy heifer value of 85 lb/AU. Pounds of N excretion per AU were 0.34 (previous dairy cow), 0.31 (previous dairy heifer) or 0.45 (current dairy cow). Multiple stages of production are itemized in the NRCS tables in Chapter 4 (SCS, 1992). The reader is unable to determine the origin of these numbers. They do not clearly delineate from the ASAE or MWPS values. A comparison of Standard Values indicates there is variation in estimating such values. All calculations from such estimates are also estimates. As a result, it is not uncommon to find a disclaimer that Standard’s data, while beneficial for general planning, are not applicable to specific farming situations. A comparison table of the commonly cited values can be found in Table 1A.

Table 1A. Commonly Cited Daily Manure Production Characteristics by Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Total Manure Production (lb/day)</th>
<th>N (lb/day)</th>
<th>P (lb/day)</th>
<th>K (lb/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy Cattle</td>
<td>ASAE 86</td>
<td>0.45</td>
<td>0.094</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>MWPS 82</td>
<td>0.41</td>
<td>0.073</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>NRCS (LC) 80.0</td>
<td>0.45</td>
<td>0.07</td>
<td>0.26</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>ASAE 58</td>
<td>0.34</td>
<td>0.092</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>MWPS 60</td>
<td>0.34</td>
<td>0.11</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>NRCS (BC) 65.0</td>
<td>0.33</td>
<td>0.12</td>
<td>0.26</td>
</tr>
<tr>
<td>Swine</td>
<td>ASAE 84</td>
<td>0.52</td>
<td>0.18</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>MWPS 65</td>
<td>0.45</td>
<td>0.15</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>NRCS 65.4 (grower)</td>
<td>0.42</td>
<td>0.16</td>
<td>0.22</td>
</tr>
<tr>
<td>Poultry (Broiler)</td>
<td>ASAE 64</td>
<td>0.84</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>MWPS 52.5</td>
<td>0.73</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>NRCS 45</td>
<td>0.27</td>
<td>0.05</td>
<td>0.17</td>
</tr>
</tbody>
</table>

ASAE source: Table D384.1, 1992; MWPS source: Midwest Plan Service Table 2-1, 1985; NRCS source: SCS Handbook Chapter 4, 1992.

LC=lactating cow; BC=beef cow.
Differences in manure nutrient composition result from initial concentration of nutrients in excreted manure, losses during storage, handling, and utilization, and climatic conditions. From an environmental perspective and from the perspective of the land manager the differences in manure composition from a table value to those calculated from mass balance can be large and significant. Therefore, use of "Standard Values" from tables may grossly underestimate actual quantity and nutrient concentration in excreted manure (Morse, 1994; Morse et al., 1996; Tomlinson, 1996). As a result, more emphasis is now placed on calculating manure nutrients from mass balance.

Mass balance calculations have been used to more precisely predict quantity of nutrients excreted. Safley et al. (1984) summarized data from collection of feces and urine on seven North Carolina dairy farms. Their data indicated that mass balance calculations (manure N = feed N - milk N) more closely reflected measured manure N than did table values. They found approximately 30% more manure N than suggested by Table D384.

Recently, Tomlinson et al. (1997) validated the use of the mass balance technique to estimate N excretion. These studies were accomplished in lactating Holstein cows. Nitrogen consumption, and N produced in milk and manure were quantified. The mass balance technique is most precise in mature cows. Realizing N accretion will occur in growing animals, this technique will overestimate manure N. This technique has been validated for P in dairy cows (Morse et al., 1994) and for monogastrics.
Appendix 2. Manure Management Flow Chart

- **Collection**
  - **Flush**
  - **Scraper**

- **Separation**
  - **Settling basin**
  - **Solid separator**
  - **Evaporation pond**

- **Storage**
  - **Above ground tank**
  - **Anaerobic lagoon**
  - **Aerobic lagoon**

- **Value Increasing Method**
  - **Composting**

- **Utilization**
  - **Sprinkler irrigation**
  - **Flood irrigation**
  - **Furrow irrigation**
  - **Soil injection**

- **Plant Up-take**

**Excretion from Animal**

**Solids**

**Drylot stacks**
Appendix 3. Calculating Application Rates

A number of different methods and tools exist for determining manure application rates. Wallingford et al. (1975) estimated availability of organic—N (decay series), coupled with the N usage of the crop and potential salt toxicity as a possible method to determine the application rate. The decay series was used to describe N mineralization. The complex reactions necessary for organic—N to be mineralized to plant-available N vary by soil type, climate, and manure N content. The decay series concept is something to consider in the overall manure application scheme as all organic—N applied is not available during the year of application. However, some individuals would prefer to account for organic—N mineralization through actual soil testing. Such a method would provide the land manager with the net effect of nitrogen mineralization and water management.

Recently, Follett and Croissantl (1990) developed conversion factors to allow feedlot operators to more precisely land-apply manure. Manure samples were evaluated for nutrient content. Data were expressed on air-dried manure-weight basis. A calculation can be made to convert wetter manures to an air-dried basis. A sample of manure can be weighed, then allowed to air dry on a sheet of plastic and reweighed. The percent moisture can be calculated as:

\[
\text{Percent Moisture} = \left(\frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}}\right) \times 100;
\]

and a conversion factor can be determined for application on an air-dry basis (Table 3A). For example, if the application rate for air-dry manure is 25 tons per acre, the application rate for manure with 15% moisture is \(1.18 \times 25 = 29.5\) tons per acre (Follett and Croissantl 1990).

Table 3A. Multiplication Factors to Convert High Moisture Manure to an Air-Dry Basis

<table>
<thead>
<tr>
<th>Percent Moisture</th>
<th>Multiplication Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.11</td>
</tr>
<tr>
<td>15</td>
<td>1.18</td>
</tr>
<tr>
<td>20</td>
<td>1.25</td>
</tr>
<tr>
<td>25</td>
<td>1.33</td>
</tr>
<tr>
<td>30</td>
<td>1.43</td>
</tr>
<tr>
<td>35</td>
<td>1.54</td>
</tr>
<tr>
<td>40</td>
<td>1.67</td>
</tr>
<tr>
<td>45</td>
<td>1.82</td>
</tr>
<tr>
<td>50</td>
<td>2.00</td>
</tr>
<tr>
<td>55</td>
<td>2.22</td>
</tr>
<tr>
<td>60</td>
<td>2.50</td>
</tr>
<tr>
<td>65</td>
<td>2.86</td>
</tr>
<tr>
<td>70</td>
<td>3.33</td>
</tr>
<tr>
<td>75</td>
<td>4.00</td>
</tr>
<tr>
<td>80</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Organized and well kept data are essential to maintain a historic and current view of manure nutrient application. Tedious record keeping is necessary. Often, results of laboratory analytical analyses are received sporadically. Soil and tissue samples are typically evaluated prior to and during the initial stages of plant growth. Both solid and liquid forms of manure should be evaluated at least twice yearly. Additionally, nutrients may be applied to crops through commercial fertilizers. Crop yield data and nutrient analyses are also generated. All forms of input and output nutrients should be accounted for in a nutrient management plan. This is a time consuming and cumbersome task.

A simple balance sheet of nutrients supplied to crop (soil, manure, fertilizer, etc.), nutrients utilized by crops (crop yields), and nutrients remaining in the soil can be accomplished for each crop field. This requires repetitive calculations and inputs that may well be more easily accomplished by computer software. Various computer programs have been developed to assist with determining nutrient application rates and maintaining nutrient management records. Collectively, these programs are known as Decision Support Systems (DSS).

Twelve of the more useful manure DSS were reviewed (Thompson et al., 1997). DDS for manure application ranged in complexity from single field application rate determination, to multiple field application rate determination, to automatic allocation of manure, to designated fields and calibration of manure spreaders (Table 3B).

Table 3B. Summary of Decision Support Systems by General Function

<table>
<thead>
<tr>
<th>Function</th>
<th>Software Available*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application rate determination for a single field</td>
<td>AMANURE; Vermont Manure Nutrient Manager; UGFERTEX; OHIO-Crop Nutrient Management; Virginia; Texas A&amp;E 585; Intpro; and Smartpitchfork</td>
</tr>
<tr>
<td>Application rate determination for multiple fields</td>
<td>Manure Application Planner v3.0; WSU-Manure Nutrient Balancer; NCALC Manure Resource Balancer; Texas NMP67-8</td>
</tr>
<tr>
<td>Whole farm management plans - manure application rates and allocation</td>
<td>WISPER; Pennsylvania State University-Nutrient Management Plan; Michigan State University-Nutrient Management v1.1; and FERTREC</td>
</tr>
<tr>
<td>Whole farm management plans - nutrient monitoring on whole farm scale</td>
<td>Maine; FRW (Scotland)</td>
</tr>
<tr>
<td>Amounts of manure in storage records with application through time</td>
<td>MBUDGET</td>
</tr>
<tr>
<td>Determination of quantity of stored manure, only</td>
<td>Vermont: EMP</td>
</tr>
<tr>
<td>Whole farm simulation</td>
<td>DAFOSYM; CROP; DAIRY MANURE PLANNER</td>
</tr>
</tbody>
</table>

Source: Thompson et al., 1997.
Appendix 4. Salt Tolerance of Selected Agronomic Crops

Salt tolerance differs among plant species. Table 4A lists salt tolerances of a few selected plant species commonly grown for agricultural purposes. Manure application rates to prevent salt build-up should be based on the soil type, the salt content of the manure being applied, and the salt content and amount of the irrigation water being applied (Wallingford et al., 1975).

Table 4A. Salt Tolerance of Selected Plant Species

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Botanical Name</th>
<th>Threshold</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oats</td>
<td><em>Avena sativa</em></td>
<td>2.0-4.0</td>
<td>MT</td>
</tr>
<tr>
<td>Corn</td>
<td><em>Zea mays</em></td>
<td>2.0-4.0</td>
<td>MT</td>
</tr>
<tr>
<td>Clover, sweet</td>
<td><em>Melilotus, indica</em></td>
<td>2.0-4.0</td>
<td>MT</td>
</tr>
<tr>
<td>Alfalfa</td>
<td><em>Medicago sativa</em></td>
<td>4.0-6.0</td>
<td>T</td>
</tr>
<tr>
<td>Vetch, purple</td>
<td><em>Vicia, benghalensis</em></td>
<td>4.0-6.0</td>
<td>T</td>
</tr>
<tr>
<td>Sorghum</td>
<td><em>Sorghum bicolor</em></td>
<td>6.0-10.0</td>
<td>VT</td>
</tr>
<tr>
<td>Cotton</td>
<td><em>Gossypium hirsutum</em></td>
<td>6.0-10.0</td>
<td>VT</td>
</tr>
</tbody>
</table>


*a* Threshold equals maximum concentration, dS/m in soil water without yield reduction.

*b* Tolerance rating based on reductions in vegetative growth. MT= moderately tolerant, T=tolerant, and VT= very tolerant.
Appendix 5. The Methane Generation Process

Energy generation from animal wastes is accomplished through anaerobic decomposition by naturally occurring bacteria populations. Complete anaerobic digestion to the usable methane end-product has been described as a two-stage process (Sievers and Lannotti, 1982; Morris et al., 1975; Jewell, 1976; NRAES, 1984). Although the two stages actually occur concurrently, the two processes are accomplished by two entirely different bacterial populations and are most easily described as separate stages. In the first stage, “acid formers” degrade cellulose, lipids, and proteins to volatile acids. In the second stage, “methane formers” convert volatile acid end-products from the first stage to methane and carbon dioxide (Sievers and Lannotti, 1982).

The methane-producing bacteria involved in the anaerobic degradation require specific pH, alkalinity, volatile acid concentration, temperature, nutrient concentrations (Morris et al., 1975). The bacteria are adversely effected by small changes in pH or moderate changes in temperature and nutrient availability. System pH is determined by the relative concentrations of bicarbonate, carbon dioxide, and volatile acids in the system (Morris et al., 1975). The Northeast Regional Agricultural Engineering Service (NRAES) identified the optimum pH range for methane generation as 6.6 to 7.6. Temperature determines the growth rate of the microorganisms and the relative efficiency of the digester. The two temperature ranges under which optimal anaerobic fermentation occurs are the mesophilic range (85°F to 104°F) and the thermophilic range (120°F to 140°F) (NRAES, 1984). Higher temperatures generate increased methane production, while lower temperatures slow reaction rates, and require longer retention periods for complete decomposition. Nutrient availability is a function of nutrient loading rate, the amount of volatile solids or digestible organic material fed into the digester per day per unit volume of the digester (NRAES, 1984). A constant loading rate is based on appropriate retention times for organic material where breakdown is determined to maximize digestion efficiency and prevent digestion cessation.

Two general types of digester systems are commonly utilized for methane generation from animal manure. Digester systems can be batch loaded or continuously loaded. Batch loaded systems are fed with one batch of slurry which is contained within the digester until the energy generation process has completed, after which the digested material is removed and a new batch is added. This system requires relatively little attention and works well in conditions where material availability is sporadic, however, the rate of energy generation is uneven which may cause problems if generated energy is used for daily fuel needs. Continuously loaded systems are fed more frequently (typically 1-2 times each day) and in smaller amounts to replace only digested effluent that has been displaced from the system. This system requires significantly more management, however, it is more efficient than the batch loaded system.
Continuously loaded systems are further categorized as continuously mixed systems and plug flow systems (NRAES, 1984). Continuously mixed systems keep slurry organic matter in constant contact with bacteria and result in the most efficient degradation. The continuous mixing aids in preventing surface scum formation, reducing solid settling, and distributing heat evenly through the digestion material. However, it requires energy that can be costly. Plug flow systems eliminate the need for additional energy for mixing. The generators are long and horizontal in design, and material is degraded as it makes its way down the length of the digester. Although they consume larger areas of land, plug flow digesters are generally less expensive to construct and mechanically simpler to operate than continuously mixed systems.