

Eliminating Waste : Strategies for Sustainable Manure Management^a - Review -

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ABSTRACT : Modern livestock production facilities face both challenges and opportunities with respect to sustainable manure management practices. Nutrient recycling is constrained by the size of modern livestock operations, the low nutrient density of liquid manures, and the spatial and temporal variability of manure nutrient concentrations. These constraints can and must be addressed or farmers will be increasingly drawn to nutrient wasting strategies such as anaerobic lagoons, wetlands, and other systems designed to treat and discharge nutrients to the environment. Intentional discharge of nutrients is difficult to justify in a sustainable agricultural production system, since replacing those nutrients through chemical fertilization requires considerable expenditure of energy. In contrast, there are several currently viable technologies which provide the homogenization and stabilization needed to successfully compete against chemical fertilizers, including composting, pelletization, and anaerobic digestion. Some of these technologies, particularly anaerobic digestion and composting, also open up increased opportunities to market the energy and nutrients in manure to non-agricultural uses. Future advances in biotechnology are likely to demonstrate additional options to transform manure into fuels, chemicals, and other non-agricultural products. (*Asian-Aus. J. Anim. Sci.* 1999, Vol. 12, No. 8 : 1162-1169)

Key Words : Crop Farming, Livestock Farming, Livestock Manure, Waste, Nutrient Recycling

INTRODUCTION

Livestock production systems throughout the world struggle with a common challenge: manure. This natural and necessary byproduct of livestock production was traditionally a valuable part of the typical family or village agricultural enterprise. But changes in manure handling systems, the specialization of individual farms, the increasing size of livestock production facilities and the advent of chemical fertilizers have combined to greatly reduce both the incentives and the opportunities for recycling manures for crop production. This paper discusses strategies for re-capturing more of manures value for traditional agricultural production systems, as well as ways of transforming manure to develop alternative products and markets.

Before discussing some of the strategies that can lead to more sustainable manure management systems, it is important to understand the factors which led to the current situation. Perhaps principal among them is the simple fact that integrated crop and livestock production enterprises are becoming the exception rather than the rule. Specialization among farmers has reduced the number of integrated farms and divided producers among those who specialize in livestock and

those who specialize in crops. Long term trends of increasing number of animals per livestock farm (FAO, 1978; Gassman and Bouzahr, 1995; CAST, 1996) have been paralleled by increasing confinement of animals within housing or lots (FAO, 1978, Loehr, 1984). As a result, livestock farmers often have inadequate cropland on which to utilize all the nutrients in their manure. Farms which emphasize crop production prefer chemical fertilizers for their ease of use and timely application, and are reluctant to use manures which may bring odor complaints from neighbors.

In the new world of specialized agricultural production, an additional constraint on traditional strategies for manure utilization in crop production is the increasing amount of manure generated at individual sites. Large livestock facilities produce large amounts of manure, which must be hauled greater distances to reach cropland that can use those nutrients. A related constraint which exacerbates the problems of scale is the relatively low density of nutrients in many manures. For field crop applications, high density of nutrients allows greater efficiency in transportation and application costs. In much of the industrialized world we have seen several decades of increasing substitution of water (via flushing systems) for the labor or mechanical devices required for solid manure collection (Schmidt et al., 1996). Liquid manure handling systems can reduce costs of livestock production at several scales of operation (Hilborn, 1996), but above a certain size operation or in cases of limited land availability the reduced nutrient density results in greater transportation costs to move the manure to crops that can utilize its nutrients (Hilborn,

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^a This paper has been presented at Plenary Session III entitled "Environment, Biodiversity and Human Health" of the 8th World Conference on Animal Production on July 3, 1998 at Seoul National University, Seoul, Korea.

Table 1. A national nutrient balance for Korea

	Nitrogen (ton/yr)	Phosphorous (ton/yr)	Potassium (ton/yr)
Crop nutrient requirements			
Paddy field	162,978	38,416	202,908
Upland	284,886	24,249	102,042
Total	447,864	62,665	304,950
Chemical fertilizer utilization	435,469	185,806	213,480
Livestock manure production			
Cattle	156,229	78,113	171,716
Swine	113,713	124,374	103,762
Poultry	72,990	61,260	39,102
Total	342,932	263,747	314,580
Nutrient deficit (Excess)	(330,537)	(386,888)	(406,050)

Sources: Han and Jung, 1995; Korean Agriculture and Fisheries Statistics Bureau, 1994.

1996; Fleming and Babcock, 1997; Massey et al., 1998). This dis-economy of scale is exacerbated by the large volumes of dilution water necessary for proper operation of anaerobic lagoons (USDA, 1992; Fleming and Babcock, 1997), and may be one of the factors influencing some farmers to over apply manure to fields close to the barn.

Two other important constraints are the variability of manure nutrients (both in space and in time, depending on how they are treated and stored) and the related variability during application to soil. The resulting difficulties estimating manure nutrient content, availability, and rate of application combine to encourage farmers to over apply nutrients even when they are attempting to credit their manure nutrients in a nutrient management plan (Nowak et al., 1998). Over time the soils ability to absorb these excess nutrients can become saturated and overwhelmed (Wood and Hattey, 1995). In many areas of intensive livestock production, nutrient losses have reached a scale where air and water pollution are a serious environmental problem, and farmers are under intense social, political, and regulatory pressure to come up with a better approach.

These constraints, which influence manure management decisions on individual farms, can aggregate to generate a serious nutrient imbalance for livestock producing regions and even an entire country. Table 1 compares 1993 nutrient data developed for livestock manure (Han and Jung, 1995) with crop requirements and fertilizer use based on statistics from the Korean Agriculture and Fisheries Statistics Bureau (1994). When comparing the total agricultural crop

nutrient requirements to the current fertilizer use plus the total nutrient production by livestock, one sees that the total nutrients available significantly exceed crop requirements. Crop requirements were calculated based on highest yield crop uptake figures for rice (for paddy land) and soybean (for upland) from the USA, but may still be somewhat low given the intensive nature of Korean agriculture. Nonetheless, the reality is that many farmers in Korea and throughout the world currently use chemical fertilizers to supply essentially all their crop nutrients. This analysis suggests that on-farm use of manure is not just neglected in crop fertilizer calculations, but in many cases may represent the excess nutrient application which often leads to environmental problems.

There is widespread recognition that the current situation of over-application and under-utilization of manure is not environmentally or socially sustainable. But to evaluate alternative approaches it is necessary to define some criteria for sustainable manure management. Definitions of sustainable agriculture and sustainable livestock production include environmental, economic, and social and community components (National Research Council, 1991; Honeyman, 1991). Explicit in most definitions are goals of energy efficiency and reducing inputs of petrochemicals, pesticides and synthetic fertilizers (National Research Council, 1991). Livestock production includes as a major input the animals feed a concentrated source of nutrients and energy. The manure represents the imperfect efficiency of the animal in utilizing those nutrients. Although considerable research is underway to improve that efficiency (Voermans, 1990; Bonazzi,

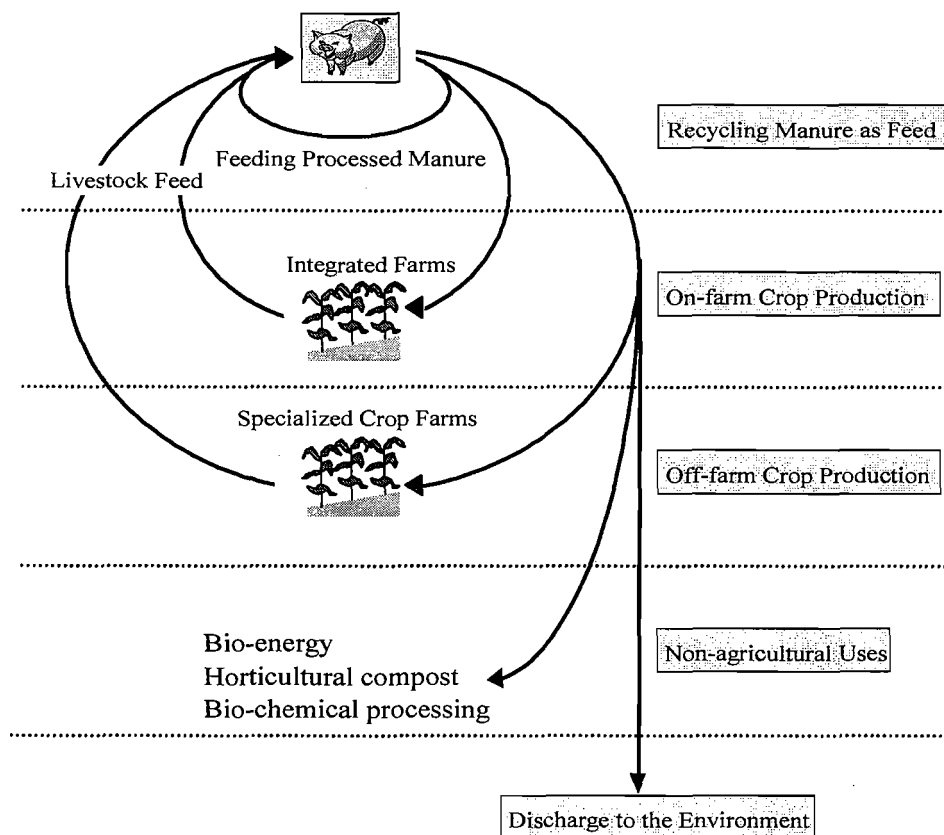


Figure 1. Options for manure management

1991; Jongbloed and Lenis, 1992; Pell, 1993; Paik et al., 1995), it is probably safe to assume that manure will continue to represent a relatively significant investment of energy and nutrients. Sustainable manure management should attempt to recover that investment, reducing other inputs needed for livestock and crop production and minimizing both local and global environmental impacts.

Figure 1 provides a conceptual framework for considering possible solutions to the current situation. The figure illustrates five possible options for manure management: 1) direct recycling of manure as a livestock feed ingredient, 2) on-farm and 3) off-farm recycling of nutrients for crop production, 4) export to non-agricultural uses, and 5) discharge to the environment. If the agricultural sector itself is to achieve a nutrient balance, much more manure must be used in crop production that occurs at present, and chemical fertilizer as well as feed imports must be dramatically reduced. If this is to occur voluntarily on farms, many of the constraints to efficient manure utilization must be addressed. Alternatively, the agricultural sector can market nutrients and/or energy off the farm, ideally in the form of value-added products. While the first three options of agricultural utilization implement relatively narrow recycling loops,

the fourth group of non-agricultural uses can still be viewed as efficient recycling of nutrients and/or energy when we consider human society as a whole. But before discussing strategies to implement these sustainable manure management options, it is important to recognize that for many farmers today the most attractive option has been to export nutrient not to the marketplace but to the environment, by treating manure as a waste.

TREATING MANURE AS A WASTE

There are several manure treatment systems which intentionally or unavoidably discharge most of the nutrients in manure to the environment, including anaerobic lagoons and constructed wetlands. In light of the previously mentioned constraints, these practices are oriented to high volume wastes which include considerably quantities of dilution water, and thus have a low nutrient density. The nutrient losses can from these systems can either be environmentally benign or problematic. Relatively benign losses include plant uptake and denitrification to N_2 gas that occurs in wetland treatment systems (Hunt et al., 1995; Reed et al., 1988). More problematic are such losses as NH_3 volatilization from storages and anaerobic lagoons

(USDA, 1992), which can be transported downwind and returned to earth via atmospheric deposition such as acid rain (ApSimon et al., 1987; Cahoon et al., 1998).

The increased prevalence of liquid manure handling systems and the similarity of particularly the heavily diluted manures to municipal and industrial wastewaters has renewed interest in advanced municipal wastewater processes such as activated sludge treatment (Tchobanoglous and Burton, 1991) and autothermal aerobic digestion (Jewell and Kabrick, 1980). Activated sludge systems, while expensive relative to conventional manure management systems, have recently been implemented for a few large livestock operations. Although the sludges from these systems can be recovered and used in agricultural crop production, total nutrient recovery in the sludge is typically only 15-40% for nitrogen and 10-25% for phosphorus in a conventional activated sludge wastewater treatment plant (Tchobanoglous and Burton, 1991). While considered acceptable for municipal wastewater treatment where the primary concerns are pathogens, solids, and biochemical oxygen demand (BOD), these systems release most of the influent N and P to the environment through the effluent discharge. Even when these effluent losses meet regulatory requirements, they can contribute to nutrient excesses in aquatic systems downstream.

Whether or not they are environmentally benign in terms of their immediate effect, these systems are the antithesis of agricultural sustainability. By dissipating the concentrated nutrients captured in the crop and livestock production process, they necessitate continued reliance on high rates of synthetic fertilizers and the energy embedded in them. Anhydrous ammonia production requires about 950 m³ of natural gas per

metric ton produced (Jones, 1982), with corresponding contributions to greenhouse gases and global warming. Although anhydrous ammonia is the greatest energy consumer, other forms of fertilizer also require considerable amounts of energy for production and transportation (Jones, 1982). Recycling nutrients for livestock, crop, or other uses is thus an important component of sustainable livestock production systems.

STRATEGIES FOR NUTRIENT RECYCLING

If manure nutrients are to be more efficiently used in agricultural crop production, some or all of the constraints previously identified must be addressed. Table 2 summarizes those constraints and suggests some possible remedies for each.

The challenges of specialization and scale in livestock production become a constraint when individual livestock farms are unable to economically utilize the nutrients in their manure. However, these same challenges can be transformed into opportunities. Concentrated sources of manure tend to generate environmental, social, or political problems, which often help clarify for producers the need to create and market manure products for off-farm uses. There are also economies of scale in some of the treatment and processing technologies, which reduce the costs of those technologies for larger operations. Groups of smaller farms can also achieve similar economies of scale by cooperative manure management efforts, as currently occurs in the US, Korea, and doubtless other countries with some agricultural composting operations. These later approaches more closely conform with aspects of sustainability related to equity and community, encouraging networks of cooperation among independent producers.

Table 2. Constraints and strategies to increase sustainable manure management

Constraints	Strategies
Specialization	Promote integrated crop and livestock farming. Market manure products to specialized crop farmers.
Scale	Decentralize livestock production facilities. Utilize scale (for large farms or aggregations of smaller farms) to capitalize manure treatment and processing facilities.
Low nutrient density	Concentrate nutrients using solid manure collection, liquid/solid separation, composting, drying and/or pelletization. Install pipelines for efficient transport of liquid manure.
Spatial variability	Homogenize during processing, treatment, and application.
Temporal variability	Stabilize nutrients in organic forms using composting, anaerobic digestion, drying and/or pelletization. Characterize bioavailability for different processes and products.
Application variability	Develop improved application technologies.

Nutrient density is a particular problem when liquid manure must be hauled over a distance. For highly dilute systems, pipeline delivery via umbilical cords or buried lines reduces application costs considerably. Nutrient concentration can also be increased through design of collection systems, by minimizing use of flush water in liquid systems and bedding in solid manure handling systems. A particularly effective nutrient concentration technique for swine manure is the fecal-urine separation developed in Japan, which concentrates 55% of the N and 95% of the P in the fecal matter, which represents only 27% of the total mass (Person, 1997). Further concentration of nutrients in this and more conventional solid manure collection systems, along with homogenization to promote uniformity and stabilization to facilitate storage and handling can be accomplished through such established technologies as composting and pelletization.

These later approaches, while they facilitate efficient nutrient utilization on an integrated crop and livestock farm, can also provide an attractive way to market manure from livestock farms to specialized crop farms or even non-agricultural markets. Compost is already being marketed this way by a number of facilities, and the value of this product as a fertilizer and soil amendment for horticulture is well established. Specially processed compost is now also being used as a pesticide substitute, providing plant pathogen suppression equal or better than chemical pesticides for several common soil borne diseases (Hoitink and Fahy, 1986; Hoitink and Grebus, 1994), while compost extracts are being used for foliar fungal disease control (Weltzien, 1992; Brinton et al., 1996).

Composting has proven very attractive for livestock producers for a variety of reasons, including the ready availability of proven technology (Richard and Walker, 1990; Richard, 1992), the high value and ready acceptance of the product, and the ease of adaptation to many different sizes and types of livestock operation (Rynk et al., 1992; Carr et al., 1995). The primary disadvantage to traditional batch composting is the high cost of a dry, carbonaceous bulking amendment, such as sawdust or straw, to absorb excess moisture present in the manure. Liquid - solid separation technologies can aid with this problem, particularly with dairy and cattle manures where the solids fraction has a relatively large particle size (Zhang and Westerman, 1997). Biodrying systems use the heat generated by composting to allow sequential additions of manure, effectively recycling the bulking amendment for multiple batches of manure (Richard and Choi, 1996; Richard, 1998). The other potential concern with composting is the possibility of market saturation, as the high price currently received for the product may drop as many more compost production

facilities are built. Market development, especially for such added value characteristics as pathogen suppression, will prove important for this technology's future success.

Another option for turning manure into a marketable product is through drying, with or without pelletization. Pelletization has seen increasing use in the USA for sewage sludge, and has received good farmer acceptance. In the Netherlands, where pollution from excess manure nutrients is also a serious concern, a government initiated program is pelletizing manure for both domestic and export markets (Voorburg, 1993, cited in Gassman and Bouzahr, 1995). Pellets are easy to store and can be applied with conventional fertilizer equipment. The disadvantages to this method are the high energy costs associated with drying the manure, and the need for large centralized facilities to achieve economies of scale.

ALTERNATIVE USES FOR MANURE

While recycling manure nutrients via crop production makes a great deal of sense, an even more efficient strategy can be to process the manure directly into animal feed, as indicated by the innermost circle in figure 1. The nutrient content of manure has been shown to be 3 to 10 times more valuable as animal feed than as plant nutrients (Smith and Wheeler, 1979). While the ability of ruminants to utilize non-protein nitrogen gives them an advantage over other livestock (Smith and Wheeler, 1979; Zinn et al., 1996), refeeding has also been successful with poultry and swine (Day, 1980; McCaskey, 1995). The principal concern with refeeding has historically been animal health concerns, but the use of drying, ensiling, heat and chemical treatment have all been shown effective at eliminating disease transmission (McCaskey and Anthony, 1979). However, the costs of processing combined with lower nutrient values from some processing approaches (such as drying and heat treatment) have limited the application of this strategy primarily to the refeeding of poultry manure and litter to poultry and ruminants (Hauck, 1995).

A somewhat less direct means of converting manure into high protein human foods is through the use of aquaculture and fish ponds. Waste treatment in ponds has been an established practice for centuries in parts of Asia and are also currently found in Europe and North America (Edwards, 1980; Polprasert, 1989). Fish have a high feed efficiency ratio and with proper design the biological treatment processes in ponds can effectively address most odor and water quality issues, although pathogen survival and transmission can still be a concern with untreated manure (Polprasert, 1989).

The other important product which can be derived

from livestock waste using currently available technology is energy. Anaerobic digestion converts much of the energy in manure to methane gas, which can be burned for space and process heating and/or converted into electricity with an engine generator (Hashimoto and Chen, 1981; Polprasert, 1989; Badger et al., 1995). In addition to the recoverable energy produced, anaerobic digestion also reduces the odor content of the manure. While anaerobic digestion has been demonstrated as effective with a wide variety of manures throughout the world, the relatively high capital costs and management skills required have limited its application. Because anaerobic digestion converts manure solids to gas, the moisture content of the manure increases during digestion. On farms where land application of digester effluent is constrained by limits on land availability, liquid-solid separation followed by further treatment of both the liquid and solid streams would probably be required.

While the previously described approaches to livestock waste management are available today, there are a number of other promising strategies which should be considered for the future. Of particular interest are those that use applied biotechnology to generate value-added products from manure. Composting and anaerobic digestion are two current examples of this approach, and in both cases advances in processing efficiency and product value are likely benefits from additional research. While composting biologically utilizes the energy in manure for drying, minimizing or eliminating the need for liquid treatment and disposal, anaerobic digestion biologically converts that energy into a combustible gas. In the future we may see manure converted into even more valuable products, including proteins for animal feed through algal or other microbial conversion processes (Calvert, 1979; Polprasert, 1989; Hauck, 1995), and enzymatic conversions to alcohols or other chemical feedstocks (Spellman, 1994). While such systems may seem difficult to imagine today, with future research the concentrated energy and nutrients found in livestock manure are certain to be seen as a valuable resource rather than a waste.

HOLISTIC MANURE MANAGEMENT IN LIVESTOCK PRODUCTION SYSTEMS

The strategies described in this paper assume a fundamental change in the way many livestock farmers view their manure. To address the important challenges of pollution and odor, manure must be viewed as part of an integrated livestock production system. As farms are improved and new facilities built, manure management must be considered in everything from livestock watering systems to feed rations. Fundamental decisions about manure handling and treatment systems

must be integrated in other decisions about housing type, site selection, and scale of operation.

As livestock production systems continue to evolve, basic research into waste treatment, applied biotechnology and integrated systems analysis can draw much from research in other sectors, but must also focus on the unique aspects of the livestock industry. This is particularly true as technologies are adapted for use on farms, where field demonstrations and farm scale economic analysis are critical to farmer acceptance and success. And, since off-farm product sales are likely to play an important role in improving the agricultural nutrient balance, development of markets for compost, fertilizer, energy, and other manure products will be increasingly important. With a combined program of research, teaching, and demonstration that effectively addresses these challenges, the future of animal manure utilization can be a positive opportunity for the livestock farmers throughout the world.

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