Manure Quality Principles Applied to Lagoon Sludge: The Dairy's Forgotten Liability

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Introduction

Specialists in livestock waste management often remark how strangely amusing it is that the tough waste management rules pushed by environmental advocacy groups and agencies end up encouraging and accelerating the growth and concentration of confined animal feeding operations (CAFOs). Many of the advocacy groups, tacitly or otherwise, make clear their desire to see CAFOs revert to the small, family-owned, independent producers as the model for long-term sustainability. However, their pet policies — for example, the recent effort by the Environmental Protection Agency (EPA) to remove the 24-hour-storm exemption for permitted discharges, to require that lagoons be covered and to advocate phosphorus-based nutrient management plans — actually seem to drive the trend in the opposite direction. Under many circumstances only the largest, corporate entities can afford to implement the strict structural, management and monitoring schemes that the environmental groups demand. As a result, the small producers liquidate, not proliferate.

Perhaps such an explanation seems utterly simplistic. Obviously, more forces drive the growth trend than merely the rapid increase in regulatory pressure. Still, the regulatory trend anticipates a time when advanced treat-and-release systems for managing manure are the norm, and lagoons are but a quaint relic of an earlier, less sophisticated day. Unfortunately, the strict no-discharge policies of the past 30 years have given the animal-feeding industry little incentive to develop the advanced systems needed to sustain confined animal production in the absence of lagoons. We are making good headway, but we have yet to develop systems that are effective, widely applicable and economically feasible.

Producers of confined livestock and poultry need to be reminded of the underlying lesson in all of this: choices made principally to satisfy short-term objectives invariably return to cause long-term problems. In the case of the more aggressive environmental advocacy groups, the short-term goal was to eliminate lagoons as a treatment and storage option in a zero-discharge framework, and the result has been an acute growth in the very large-scale operations that such groups condemn as ecological disasters-in-waiting. Producers, as well as their land-grant advisors and private consultants, have often focused on short-term disposal options like nitrogen-based nutrient planning, relying on volatilization of ammonia and nitrogen oxides from liquid manure-handling systems to reduce drastically their annual land-area requirements for beneficial use of manure and wastewater. Among the unintended results of that short-term focus have been:

1. A buildup in soil phosphorus pools;
2. Localized enrichment in atmospheric ammonia (and, in some areas, an accompanying increase in secondary fine particulate matter, or $PM_{2.5}$; see Watson et al., 1998);
3. Unrealistically small land-application areas for long-term disposal of manure and wastewater; and
4. Accumulation of lagoon sediments.

All four phenomena are closely related because of a single axiom known as the Principle of Conservation of Mass: what goes in must either be discharged or stored. As discharge and disposal restrictions to air and soil have been added to the traditional effluent limitations, we have come to recognize that storage capacities are finite. As these storage pools reach their capacities due to short-term planning, the likelihood of discharges can only increase. Sustainability, on the other hand, demands a more long-term view in which storage pools are used to detain manure components rather than to sequester them (as in lagoon sediments), assimilate them (as in soil phosphorus pools) or waste them (as in ammonia volatilization).

Why is Lagoon Sludge Important?

The buildup of sludge in anaerobic lagoons is not a new phenomenon. Lagoon design standards published by the American Society of Agricultural Engineers (ASAE, 1995), the Natural Resources Conservation Service and other organizations have long provided for a sludge-accumulation layer in the design process because it is a technical necessity for efficient anaerobic treatment. Accounting for sludge buildup is vital to efficient lagoon operation because unchecked accumulation of sediments eventually encroaches on a crucial lagoon layer, the minimum treatment volume (MTV). The MTV is the minimum volume of free lagoon liquid required to permit complete digestion of volatile solids (VS) and is typically determined by referring to a figure such as Figure 1.

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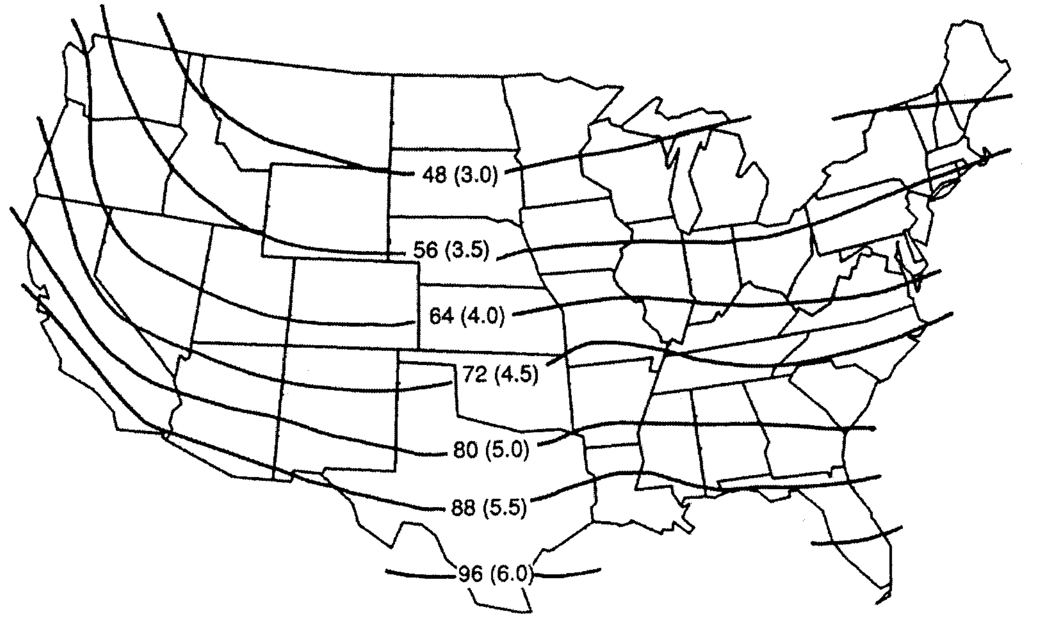
Figure 1. Recommended volatile solids loading rates for anaerobic lagoons in the United States (excerpted from ASAE, 1995).



A lagoon in which sludge accumulation has encroached on the MTV will often turn sour because the products of incomplete anaerobic digestion are tremendously odorous and offensive. (These intermediate compounds may also be toxic to plants.) A well designed, well maintained and conscientiously operated anaerobic lagoon system will provide an effluent that is rich in stable nutrients and only minimally odorous.

Lagoon Sludge and Principles of Manure Quality

If providing stable, relatively odor-free effluent for land application were the only critical objective of operating a lagoon system, it would be justification enough for attentive sludge management. As environmental regulations become increasingly strict, they reduce the number of permissible discharge pathways for manure constituents. Under those constraints, however, managing sludge takes on a new dimension of importance. The advent of phosphorus-based nutrient planning, which usually increases acreage requirements over the traditional nitrogen-based management plans, has forced many livestock producers either to purchase or lease new land-application fields or to market their manure to off-site users. Where acquisition of additional land is not feasible or is prohibitively expensive, this dynamic has highlighted the importance of producing manure of high quality and value. The further the manure has to be hauled for beneficial use, the higher its quality must be to justify the hauling expenses.

As authors and extension specialists have frequently noted over the past decade, the nutrient content of manure products is usually out of balance with respect to crop nutrient requirements. For grain crops and forages, the N:P ratio of the crop requirement may exceed the N:P ratio of manure by a factor between 3 and 6. That is particularly true of lagoon sludge because (a) phosphorus compounds are relatively insoluble and therefore accumulate in sediments and (b) ammonia nitrogen is continually lost from an anaerobic lagoon, effectively stripping it from lagoon solids.

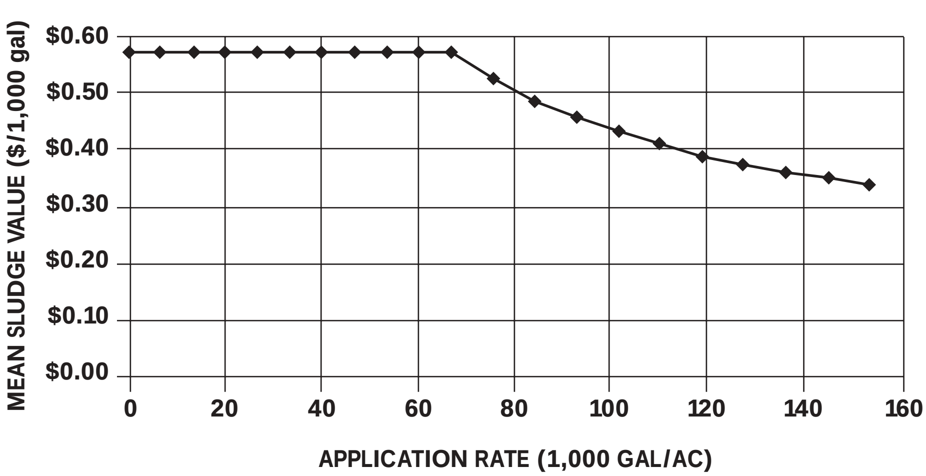
Sweeten et al. (1980) studied the buildup, composition and cost of removal of lagoon sediments on two dairies and a cattle feedyard in Texas and Tennessee. They determined that sludge accumulation from a free-stall dairy averaged 5.9 m^3 hd^{-1} yr^{-1} (1,560 gal hd^{-1} yr^{-1}). When removed via an open-impeller pump into an irrigation ditch for land application, the sludge contained about 5.5% solids. The solid fraction of the sludge contained 62% volatile (digestible) solids (VS), 0.7% nitrogen (N) and 0.6% phosphorus (expressed as P_2O_5). Extrapolated to a modern, 1000-cow dairy, the sludge accumulation rate estimated by Sweeten et al. (1980) corresponds to nearly 5,000 lb yr^{-1} of N and 4,300 lb yr^{-1} of P_2O_5, or 5 lb N hd^{-1} yr^{-1} and 4.3 lb P_2O_5 hd^{-1} yr^{-1}. Lindemann et al. (1985) estimated that the total fertilizer value of sludge removed from dairy lagoons in Erath County, Texas, would offset only 30 to 50% of clean-out costs.

Because it depends on soil type and cropping regime as well as manure composition, manure quality for land application is a relative attribute, not an absolute one. In other words, manure quality for a particular use depends on (a) how well matched the nutrient ratios in the manure are to the nutrient ratios required by the crop based on a soil test and (b) how much water and ash are contained in the manure. Thus, the historical method of computing manure value — computing the inorganic fertilizer equivalents of the manure nutrients and adding them all up — fails to recognize the concept of the "limiting nutrient," which can be defined as follows:

The limiting nutrient for land application of manure and/or effluent is defined as the crop-essential nutrient that results in the lowest recommended application rate during a particular year when all soil-test requirements, availability fractions and regulatory restrictions have been considered.

Note that this definition of the limiting nutrient includes provisions pertaining to, for example, soil-test phosphorus thresholds (e. g., "regulatory restrictions"), cropping regimes and soil types (e. g. "soil-test requirements"). To illustrate, suppose that the lagoon sediments analyzed by Sweeten et al. (1980) are to be applied to a field where irrigated corn will be grown with a yield goal of 220 bushels per acre (bu ac^{-1}). The soil test, which reflects the character of many alkaline soils of the western United States, calls for 200 pounds per acre (lb ac^{-1}) N, 75 lb ac^{-1} P_2O_5 and no potassium (K, often expressed as K_2O). Assuming that 50% of the N and P_2O_5 in the sludge is available during the first year, an application rate of 67,000 gallons per acre (gal ac^{-1}), or 2.5 inches, will satisfy the soil-test phosphorus requirement; however, that application rate will provide only 88 lb ac^{-1} or 44% of the soil-test nitrogen requirement. Below the 67,000 gal ac^{-1} application rate, both N and P contribute to the sludge's value as a replacement for inorganic fertilizer. Above the 67,000 gal ac^{-1} rate, however, because the P requirement has been met, any additional sludge applied can be credited only to the crop's N requirement. At this point, the phosphorus in the sludge adds no additional value. (In a conventional fertility program, no additional phosphorus would have been applied once the 75 lb ac^{-1} P_2O_5 recommendation had been met.) Figure 2 shows how the average fertility value of the lagoon sludge changes with application rate as the soil-test requirements are met.

Figure 2. Average value of dairy lagoon sludge ($1,000 gal) as a function of application rate, computed on the basis of inorganic fertilizer equivalence. Note how the average sludge value begins to drop once the soil-test requirement for the limiting nutrient (in this case, phosphorus) has been met. Figures assume that inorganic fertilizers cost $200/ton (82-0-0) and $250/ton (10-34-0) for anhydrous ammonia and liquid superphosphate, respectively.



Many of the highly leached soils of the eastern United States would have a potassium requirement for corn production, which immediately adds value to the lagoon sludge. Sweeten et al. (1980) did not publish the potassium content of the lagoon sediments, but it is reasonable to assume that their K_2O content would have been about 0.75% of the total solids. Assuming a soil-test K requirement of 150 lb ac^{-1} K_2O, potassium is the limiting nutrient whose economic threshold is reached at an application rate of 53,500 gal ac^{-1}. Even though the potassium limit is reached at an application rate well below that of the phosphorus limit, the marginal value of the sludge's potassium content increases the maximum manure value (i. e., $ per 1,000 gallons) by 70%, from $0.57 to $0.97 per 1,000 gallons. As before, the marginal value of phosphorus in the sludge vanishes at application rates above 67,000 gal ac^{-1}.

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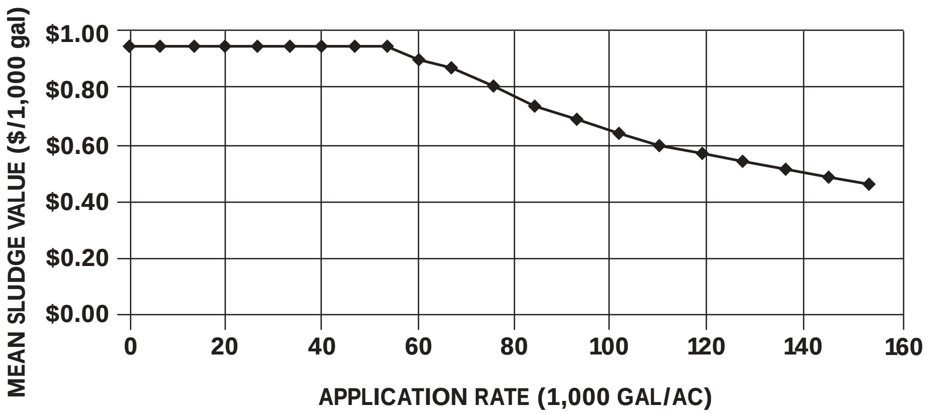
Figure 3. Average value of dairy lagoon sludge ($1,000 gal) as a function of application rate, computed on the basis of inorganic fertilizer equivalence. In this case, with a soil-test potassium (K) requirement, the average sludge value first decreases as the K requirement is met, then more steeply after the phosphorus requirement is met. Figures assume that inorganic fertilizers cost $200/ton (82-0-0), $250/ton (10-34-0) and $175/ton (0-0-60) for anhydrous ammonia, liquid superphosphate and potash, respectively.



As Figures 2 and 3 have shown, manure value is closely tied to nutrient content, nutrient ratios, soil-test fertilizer requirements and the fluctuating prices of inorganic fertilizers. As such, manure quality depends on too many external factors (cropping regime, natural gas prices, soil types) to be considered an absolute (or intrinsic) characteristic. Furthermore, to this point we have not considered the two major components of lagoon sludge that reduce its economic value: water and ash.

Water and Ash: The Manure Contaminants

Manure quality goes far beyond nutrient content, especially in the context of liquid or semi-solid manure. Water and ash both reduce manure value because of the high cost of transporting them to the field as compared to their agronomic value when they are applied. In most cases, the amount of water applied to the field in the form of lagoon sludge (e. g., 2.5 inches in the example above) is quite small compared to the amount of water required annually to meet the yield goal. Moreover, ash, which is the functional equivalent of adding mineral soil to the manure, would not ordinarily be applied to crops by any reasonable farmer. Still, both water and ash contribute significantly to the weight of the sludge bulk, and with hauling costs and application rates typically based on tonnage, water and ash reduce the value of the manure tremendously.

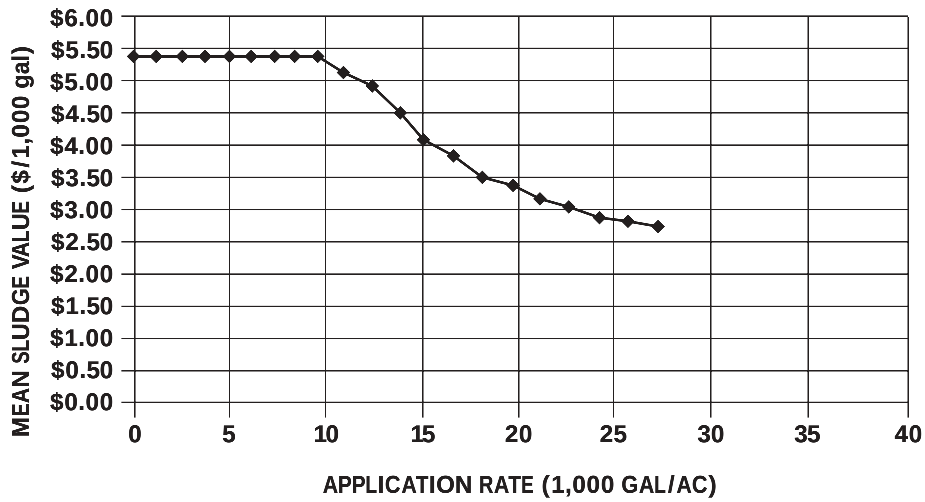
To illustrate the negative value of water, assume that we are able to harvest the same amount of sludge dry matter as above, but that we harvest it at 75% moisture instead of 96%. Figure 4 shows that the maximum value of the sludge or manure increases from $0.97 to $5.37 per 1,000 gallons — a staggering 450% increase in value achieved simply by reducing the water content from 96% to 75%.

In addition, the threshold application rate has been reduced from 53,500 to 9,600 gal ac^{-1}, which potentially reduces the number of trips across the field by a tank wagon. Where compaction is a concern, the lower moisture content indirectly increases the manure value by reducing fuel costs and decreasing compaction or added tillage requirements. Incidentally, a moisture content of 75% is well within the typical range for fresh manure, so these manure values closely approximate the potential value of manure handled mechanically rather than hydraulically.

A comparison of Figures 3 and 4 indirectly shows how the potential value of manure is drastically reduced through the use of hydraulic manure handling. Interestingly, the free-stall dairy studied by Sweeten et al. (1980) was equipped with a two-chamber settling basin. Under optimum conditions of design and management, settling basins can reduce total solids loading to the lagoon by up to 60% (Moore, 1989), but few settling basins actually achieve that separation efficiency. Mechanical separators like inclined screens and hydrocyclones typically remove 20 to 25% of the solids.

Ash is another manure contaminant, reducing manure quality. In the example represented by Figure 3, however, decreasing the ash content from 38% to 25% (dry basis) does not change the sludge value in $ per 1,000 gallons; it only reduces the hauling costs. The decrease in value associated with high ash content is most significant in the context of dry products like as-collected or composted manure.

Figure 4. Average value of dairy lagoon sludge ($1,000 gal) as a function of application rate, computed on the basis of inorganic fertilizer equivalence. The sludge represented here is the same as in Figure 3, but has been dried from the original 96% moisture to the 75% moisture that is typical of freshly excreted manure.



Summary

Hydraulic manure handling is popular in the dairy industry because of its relatively low management costs, its ease of automation and its potential to reduce odors associated with residual manure in the barns and on feed aprons. A properly designed and operated flush system maintains clean feed alleys and, with recycling systems, need not use tremendous amounts of expensive fresh water. Still, because solids separation is an inefficient process, most of the manure solids generated in the feed alleys and the milking parlor ends up in the bottom of the lagoon. That will be increasingly true as the trend from open-lot to free-stall production persists. According to figures published by Sweeten et al. (1980) and others, sediments accumulating in an anaerobic lagoon can induce periodic dredging costs ranging from $5 to 10 or more per head per year of accumulation. For a 1,000-head dairy whose lagoon system is designed with 10 years of sludge capacity, dredging costs could exceed $50,000 per dredging event. The extremely low economic value of lagoon sediments virtually ensures that they will be preferentially applied to land owned by or immediately adjacent to the dairy. Adding water to manure is, as a practical matter, an irreversible process, and in light of water's negative effect on manure value, manure quality considerations as applied to lagoon sediments argue against hydraulic manure handling for the long-term sustainability of the industry.

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