

PRINCIPLES OF RECYCLING DAIRY MANURES THROUGH FORAGE CROPS

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ABSTRACT

In California's Central Valley, degradation of groundwater quality associated with dairies has been documented. Proper nutrient management is critical to protecting groundwater quality. Because surface irrigation on lighter soils often results in rapid leaching of nitrate out of the root zone, applying only the amount of available nitrogen that the crop can take up from one irrigation to the next is crucial to minimizing the amount of nitrate leaching to groundwater. To do this requires changes to the dairy infrastructure and development of a computer-based recordkeeping system, in addition to the practices associated with the actual application of nutrients.

Key Words: manure, nitrogen, lagoon, dairy, nutrient management

INTRODUCTION

The goal of nutrient management is to land apply nitrogen, phosphorus, and salt in such a way that there is minimal adverse effects on the environment. In California's Central Valley dairy region, the primary concern is for protection of groundwater quality. Significant impacts to groundwater quality been observed, especially in areas where dairies are situated on coarse textured soils and with shallow groundwater.

Prologue to Nutrient Management: Assessing Land Base

The first step in managing nutrients, then, is to assure that each dairy facility has an adequate land base for appropriate application of nutrients. There is no single "cows per acre" assessment because there are many factors that influence the relationship between cow numbers and crop uptake. These include the diet the cow is fed, the potential nitrogen uptake by the crops, losses in the soil, and the amount of loss that occurs between the back end of the cow and the application to the soil. These losses have been estimated to range from 20% to 80%. To assess if a dairy has adequate land base, we have found it best to calculate the amount of acreage needed based estimated excretion and adjusting for both a high and a lower loss rate. If a facility has enough land application area even at a low loss rates there can be reasonable confidence that the land base is adequate. If a facility does not have enough land base even at a high loss rate there is definitely too much manure being generated and there will need to be either off-site transport of nutrients or a reduction in cow numbers. Those facilities that fall in between will need to either do a more detailed assessment of the nutrients being applied compared with what is being taken off in the crop or they will just begin to measure application rates and eventually determine what their situation is. It is critical that some assessment of land base be made prior to beginning any other portion of a nutrient management plan, otherwise the facility may be making investments in improvements that have little hope of being successfully implemented.

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Once it is determined that a facility has the acreage needed to land apply the nutrients generated, then the process of developing a system to manage the nutrients can begin.

Introduction: The Three Components of a Nutrient Management System

In the Central Valley of California, as well as in other places, the foremost specific goal of a nutrient management program is to protect groundwater quality. Degradation of groundwater quality is the logical result of over application of manure and other nutrients and salts. In order to apply appropriate amount of nutrients, it is essential to know how much needs to be applied, when it needs to be applied, and to apply that amount. None of this can be done without a means of measuring and controlling application rates. Therefore, the starting point of any nutrient management strategy is to set up a system to measure, and apply, appropriate amounts of nutrients. While simple in principle, in practice this can be an enormously complex undertaking that involves nearly every aspect of a facility.

There are three major components of a functional nutrient management system, whether on a dairy or any other type of facility. They are equally important; if any of the parts are deficient, the entire system will not function. They are also interdependent, and each cannot be designed without consideration of the other parts. The components are:

Facility and land application infrastructure. These are the physical facilities on the dairy that collect, separate, transport, and store the manure, both liquid and solid.

Application of nutrients to cropland. This is the actual procedure of deciding when and how much manure and fertilizer to apply to the crops, and the process of working out that plan on the ground.

Recordkeeping: All other components may be in place, but without a practical means of keeping track of applications and crop uptake, a system that is actually used, it will still be impossible to determine if nutrients are being appropriately applied.

Each of these will be discussed in more detail. A fourth component of nutrient management is diet manipulation to avoid unnecessary excess excretion of nitrogen, phosphorus and salts. Although this can make a significant impact on the amounts of nutrients that need to be beneficially land applied, this topic is beyond the scope of this article.

FACILITY AND LAND APPLICATION INFRASTRUCTURE

Many manure management systems were not designed with agronomic application of nutrients as their primary objective. Most existing dairies therefore require at least some modifications to enable them to properly manage nutrients. Some of the areas that need to be addressed include storage capacity, sources of dilution water, adequate mixing of fresh and pond water, correctly sized pumps and pipelines, pipeline or spreader truck access to all application fields, solids separation, prevention of sludge buildup in ponds, metering systems and flow control, sampling ports and analysis of concentration, irrigation uniformity, and tailwater return systems.

Each of these infrastructure components is critical to the ability of an operator to apply appropriate amounts of nutrients. Additional information is available in Eric Swenson's presentation "Engineering Aspects of Managing Dairy Lagoon Water".

APPLICATION OF NUTRIENTS TO CROPLAND

Application amounts for season

In general, the amount of nitrogen that can be applied to a crop in a given season is calculated based on the amount of nitrogen that the crop is expected to remove. The most accurate way to determine nitrogen uptake is to measure this value directly when the crop is harvested. Since most forage crops involve harvesting the entire aerial portion of the crop, the yield and nitrogen content can be used to calculate crop removal. A representative sample can be taken and sampled for percent total nitrogen. Percent total nitrogen (divided by 100) multiplied by pounds of dry matter per acre will give pounds of nitrogen removal per acre. Nitrogen removal may also be determined from protein content. Multiply pounds of dry matter per acre by percent protein (divided by 100) to obtain pounds of protein per acre. Divide this number by 6.25 to obtain pounds of nitrogen per acre. An alternative method for silage at 70% moisture is to multiply tons per acre by percent protein (not divided by 100) and multiply the result by 0.96. In determining total application rates, there needs to be some allowances for unavoidable nitrogen losses such as denitrification (conversion of nitrate to nitrogen gas), inefficiencies in application, and imprecision in application measurement. The current state of science recommends that the total application should not exceed 120 to 150% of the amount of nitrogen taken off by the crop, and Harter, in the previous paper, suggests that even this amount may be too much in some situations.

Forms of Nitrogen

In order to understand how best to apply nitrogen so that it is taken up by crops and not leached to the groundwater, it is necessary to first understand the forms of nitrogen in manure and how they behave in the soil. Nearly all of the nitrogen in dairy nutrient water coming from anaerobic lagoons is either in the form of ammonium or is chemically bound in particles of organic matter. When applied in irrigation water, the ammonium, which has a positive charge, tends to be retained in the top foot or so of soil because the soil particles are predominantly negatively charged. Likewise, organic matter also stays in the upper part of the soil; mainly because the particles are larger than the soil pores. Nitrogen in dairy nutrient water, or in freshly incorporated dry manure, will therefore tend to stay in the upper part of the soil when initially applied, even if it is applied to wet soils. Ammonium is rapidly converted to nitrate in a process called nitrification. This process is facilitated by certain kinds of bacteria which are abundant in all soils. These bacteria convert ammonium (which resists leaching) to nitrate. The nitrate has a negative charge and does not stick to soil particles. It readily moves along with water moving through the soil. The process of nitrification occurs rapidly when soil temperatures are warm. It takes only a few days during summer for most of the ammonium in the soil to be converted to nitrate.

Nitrate Leaching

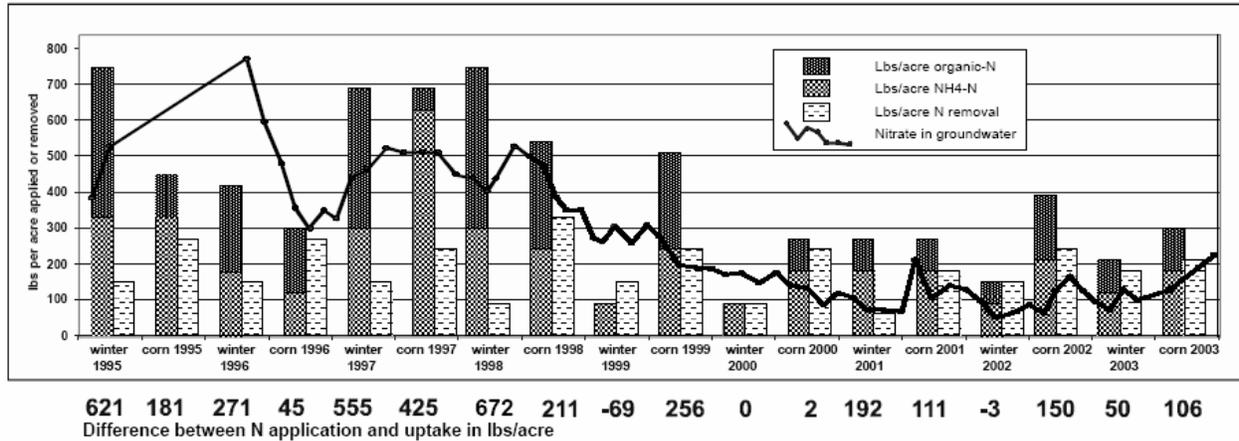
Most of the irrigation in the Central Valley is surface irrigation, either furrow or border check. It is often the case with a surface irrigation system that the amount of water that is applied in each

irrigation is determined not by how much water is needed to refill the soil profile, but by how long it takes for the water to move from one end of the field to the other. A typical irrigation requires 4 to 6 inches of water, and the slower preirrigation and first crop irrigations could require even more. This amount of water is capable of moving considerable amounts of nitrate completely out of a three foot root zone in a single irrigation. To measure the amount of nitrate lost in a single irrigation event, soil samples were taken at 1 foot increments to a minimum of 3 feet immediately prior to and again as soon as reentry into the field was possible (usually 1-3 days) after a freshwater irrigation on 12 sites (loam to loamy sand). An average of 117 lbs (40% of previous total) of nitrate-N (ranging from 8 to 445 lbs N/A) was not present in the root zone (top 3 feet) after a single freshwater irrigation event. An average of 123 lbs N/A of nitrate-N (67%) was missing from the top foot alone (range 46-458 lbs N/A).

Clearly, nitrogen applied far in advance of crop utilization is subject to being lost, most likely to groundwater, within a few irrigations under these conditions. There may be some instances where a soil does have excellent nutrient holding capacity and is not subject to excessive leaching. In this situation, it may be possible to apply most or all of the nutrients at the beginning of the season and still be assured that they will be available in suitable quantities when the crop needs them. However, it is likely that few soils in California's Central Valley have this flexibility. In most cases, the best way to apply nutrients to avoid leaching losses is to split the total amount of nitrogen needed into multiple targeted applications.

Synchronized rate nutrient application

With a synchronized rate nutrient application system, only the amount of nitrogen that can be utilized by the crop before the next one or two irrigations is applied at any one time. The practice of applying specific small amounts of nitrogen in multiple applications relies on the fact that lagoon nutrients will stay near the top of the soil profile when they are applied because of the positively charged ammonium ions and relatively large particle size of the organic form nitrogen. If the application rates are synchronized correctly to coincide with crop uptake, then most of the nitrogen that was applied will be taken up by the crop before the next irrigation event, and the nitrate that remains will be less subject to leaching than if the soil contained abundant excess nitrate. Using this technique, it has been demonstrated that leaching of nitrate to groundwater can be minimized under high water application rates on sandy soils--conditions that normally would be highly conducive to nitrate leaching. This has been demonstrated on a field where shallow groundwater nitrate has been monitored for the past nine years. In this case study, there was a marked improvement in groundwater quality when application rates closely matched to crop uptake.



Impact of nitrogen application compared to crop uptake on shallow groundwater quality, Hilmar, CA

Rates per irrigation

In a synchronized rate nutrient application system, typically about 50 pounds per acre, but no more than 65 pounds per acre, is applied in each of five to six corn irrigations. The irrigations in which the nitrogen is applied are selected to coincide with periods of peak corn nitrogen uptake. If dairy lagoon nutrients are used, this equates to a dilution with fresh water that varies but is commonly around ten to one. At these dilutions, growth inhibition from excess salts would not be expected to occur unless the dilution water itself was of poor quality. Also, because the concentration of ammonium in the irrigation water is relatively low at these application rates, volatilization of ammonia to the atmosphere during irrigation is expected to be minimal.

Lower amounts of nitrogen, around 30 lbs available nitrogen, may be necessary if the water is to be applied to very young corn (less than 15 inches) high in order to avoid ammonia toxicity to the leaves and/or to avoid salt damage.

It may be possible to apply a higher nitrogen rate on the winter crop if it is applied in the late winter-early spring just prior to the period of rapid uptake for the crop. A higher rate can be applied during this period than in the summer because the conversion of ammonium (which sticks to the soil) to nitrate (which leaches readily) occurs more slowly in cold soils than in warm ones. Another, more importantly, the potential for rapid leaching is lower in the spring than during the summer irrigation season because it is unlikely that the amount of water going onto the field during a spring rainfall event in the Central Valley would exceed the amount of water applied in a single typical summer irrigation. These factors, combined with the rapid uptake that typically occurs in the spring, provides some assurance that a single application of between 100 and 150 lbs N per acre, depending on expected crop uptake, can be applied just prior to jointing of the winter cereal crop with minimal negative impact on groundwater. If more nitrogen is needed, it should be split into two spring applications. In planning to irrigate in the winter to apply nutrients, the assumption is made that this can be done without water leaving the field or without damage to the crop by waterlogging. Lighter textured soils with good internal drainage are most conducive to winter applications, but heavier textured soils may require planting on raised beds to provide drainage. If a winter irrigation cannot be made, the crop will still likely need nitrogen to be applied during the winter if fall applied nitrogen is likely to be lost through either leaching or denitrification. If commercial fertilizer is applied, then additional land area

will be needed to accommodate land application to summer crops only, and additional storage capacity will also be necessary.

Available Nitrogen

When determining the amount of nitrogen to apply in a targeted nutrient management system, only mineral nitrogen – either nitrate or ammonium – is considered to be available nitrogen to meet crop needs during the targeted period. When determining application rates, all ammonium form nitrogen in lagoon nutrient water is counted as being immediately available, and the portion of the organic form that is expected to become available during the current crop season is also counted as available. The remainder of the organic nitrogen must not be disregarded, however, because when it does mineralize, if it is not taken up by crops, it becomes subject to leaching to groundwater. The amount of nitrogen that is mineralizing from organic nitrogen that was applied during previous seasons thus needs to also be considered and subtracted from the amount that is being applied. Determining the amount of nitrogen that is mineralizing is difficult and injects considerable uncertainty into nutrient management planning. This topic is covered in more detail in David Crohn's presentation "Nitrogen Mineralization and its Importance in Organic Waste Recycling".

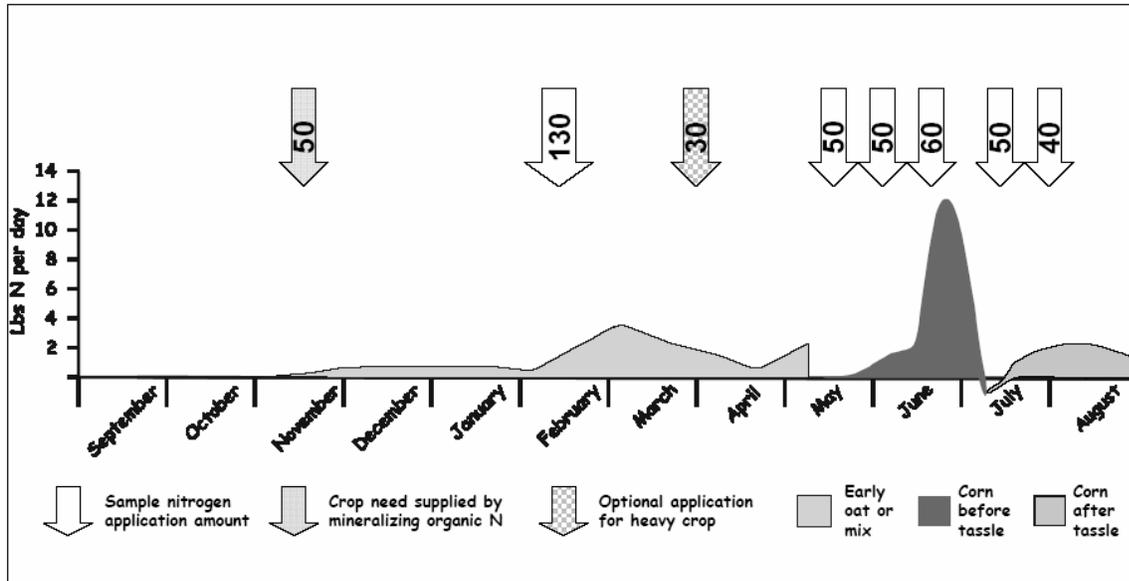
It is especially difficult to grow crops using only dry manure as a nitrogen source because of the uncertainty in predicting when the nitrogen will become available, and the short but intense duration of peak periods of nitrogen uptake by annual forages. An appropriate strategy to utilize these materials would be to apply only small amounts to each field and use water-run commercial fertilizer or very low solids lagoon water to supply available nitrogen during periods of peak crop uptake.

Other sources of nitrogen inputs also need to be considered when determining application rates. These include irrigation water that contains significant amounts of nitrate, plowdown of leguminous crops, and commercial fertilizer in addition to liquid and dry manure.

It is usually not necessary to consider the amount of nitrogen needed to supply root growth. Total application rates are usually based on the amount of nitrogen removed with the crop and it is assumed that the amount of nitrogen needed to grow roots is already in the soil from the breakdown of previous season's crop roots. There are times, however when that nitrogen (or its equivalent) is not available at the right time or has been lost. Supplemental nitrogen may need to be applied in these cases in order to maintain crop production.

Whole year targeted plan

Below is a chart of crop nitrogen uptake in pounds per day and a sample plan of how the crop needs might be met using a targeted system. With this scenario, corn is grown in the summer and a forage blend that is predominantly early maturing oats is grown during the winter. Applications of lagoon nutrients are made five times during the summer and once or twice in the late winter and early spring. No applications are made during the preirrigation of either crop because the crop needs, which are low for young crops, are presumed to be met by mineralizing organic nitrogen from previous applications. In this sample, there is no crop on the ground during most of September and October. During this period, there could be mineralization occurring which would be subject to leaching during the preirrigation for the fall crop. Planting a crop of sudangrass as a third crop would be one way to capture and recycle that nitrogen.



Sample targeted nitrogen application plan for forage oats and silage corn.

Procedure for measuring and targeting synchronized nutrient application rates

In practice, the following steps are used to target applications of lagoon nitrogen to a particular field:

1. Determine number of acres to be irrigated. Some growers keep track of nutrient application according to each field, and others prefer to track application on every irrigation check or set within a field. Since often the only nutrients the crop will receive come from the lagoon, crop performance will be affected by the accuracy of the application. More management is needed in situations where each check irrigates differently, and less when each irrigation set within a field is essentially identical.
2. Estimate the time the irrigation will run, e.g. how many hours will it take it irrigate a given number of acres.
3. Decide on the amount of nitrogen to apply in this irrigation. Factors involved in this decision include the amount of nitrogen expected to be needed by the crop in the immediate future and further into the cropping season, the sensitivity of the crop to salt or ammonia injury, the ability of the soil to retain nutrients, the rate at which the ammonium and organic nitrogen in the nutrient water will be converted into nitrate and ammonium, and the supply of nitrogen expected to come from mineralizing organic nitrogen applied in the past.
4. Take a sample of the same lagoon water that will be applied. Often, a sample taken from the flush will not adequately predict the concentrations of nitrogen in the nutrient water actually being used during irrigation, especially if the flush pump is drawing from near the surface of the pond and the irrigation pump draws from the bottom. Samples dipped from the pond, or estimated from previous sampling, may be better in this instance to provide a preliminary estimate, which will later need to be confirmed during irrigation.
5. Determine the concentration of the sample using a quick test for ammonium and organic form nitrogen. Because the nitrogen in the organic form must be mineralized before being available

for crop use, only a portion of this form is considered when determining the concentration of nitrogen in the nutrient water. The available nitrogen concentration to use for calculating application rates is the sum of all the ammonium nitrogen plus the percentage of the organic form nitrogen that is presumed to become available during the cropping season.

6. Calculate the volume of lagoon water needed that will contain the amount of nutrients needed based on the concentration and expected run time. Consult a chart, calculator or computer spreadsheet to calculate a target pond water flow rate.

7. If using a flow meter, record the starting gallons on the meter totalizer and record the starting time of the irrigation. If using a pond drop method, record the depth of water in the pond at the beginning of the irrigation.

8. Begin the irrigation, adjusting the valve until the flow meter flow rate (gallons per minute) display matches the target flow rate.

9. Periodically check the lagoon water nitrogen concentration if there is reason to suspect that the lagoon water nitrogen content is not uniform, and adjust the target flow as necessary. The target flow rate should also be readjusted if the irrigation runs significantly longer or shorter than expected.

10. At the completion of the irrigation, record the ending time and the total number of gallons applied through the meter.

11. Using confirmed nitrogen concentrations and run times, calculate the actual amount of nitrogen that was applied per acre.

12. Adjust the target nitrogen application rate in the next irrigation according to crop needs.

These steps are repeated for each subsequent irrigation where nutrient water is applied.

RECORDKEEPING

The third critical component of a nutrient management system is recordkeeping. Growers will need to record volume and concentration of lagoon water applied to each field, as well as other information such as date, time, and source. Calculations will then be necessary to determine the amount of nutrients applied. A record keeping system that allows the operator to track the amount of crop nutrients as soon as they are applied to each field in each irrigation will enable them to make informed decisions about subsequent applications. Because of the huge amount of data that must be tracked in a synchronized rate nutrient management system, a computer based system is essential in most cases. Ideally, the recordkeeping software should be easy to enter data into, and provide such information as how much of each nutrient has been applied, from what source the nitrogen came from, the total gallons applied for the season, calculate how much nitrogen is plant available, and many other parameters. An Excel-based recordkeeping system is currently being developed by UCCE.