PRINCIPLES OF RECYCLING DAIRY MANURE THROUGH FORAGE CROPS

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ABSTRACT

In California's Central Valley, proper application of manure nutrients to cropland associated with dairies is critical to prevention of groundwater degradation of groundwater. Where leaching conditions are present, movement of nitrate with irrigation water can be minimized by applying only the amount of available nitrogen that the crop can take up between irrigations. Management of organic form nitrogen is also critical to avoiding groundwater contamination, but is complicated in that nitrogen mineralization rates are difficult to predict and may not coincide with crop demand. Controlling nitrogen applications of liquid manure requires changing the dairy infrastructure, establishing a computer-based recordkeeping system, and optimizing the actual nutrient application practices.

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

INTRODUCTION

The primary goal of nutrient management is to apply nitrogen, phosphorus, and salt in a way that results in minimal adverse effects on the environment while at the same time maintaining crop production. In California's Central Valley dairy region, a major environmental concern is protection of groundwater quality. Significant impacts to groundwater quality have been observed, especially in areas where dairies are situated on coarse textured soils with shallow groundwater. In this paper the term "nutrient water" is used for the mixture of manure, washwater, stormwater runoff, and drainage from feed storage areas. Such nutrient water is typically stored in lagoons or holding ponds and used a source of nutrients on cropland associated with a dairy. Since it has generally been managed to remove excess solids, it is commonly referred to as "liquid manure" or "nutrient water."

Prologue to Nutrient Management: Assessing Land Base

The first step in managing nutrients is to ensure that each dairy facility has adequate cropland for appropriate application of nutrients. There is no simple "cows per acre" assessment that identifies the needed cropland acreage because there are many factors that influence the relationship between cow numbers and crop uptake. These factors 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% of the applied nitrogen.

To assess if a dairy has adequate cropland, we have found it best to calculate the acreage needed based on estimated nutrient excretion and then to consider the effect of both a high and a low loss rate on the calculated acreage. If a facility has enough cropland even at a low loss rate, there can be

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reasonable confidence that the cropland acreage is adequate. If a facility does not have enough cropland even at a high loss rate, there is definitely excess 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 detailed assessment of the nutrients being applied compared with what is being taken off in the crop, or they will need to measure application rates and keep records of crop production and eventually use that information to more accurately determine their situation. It is critical that some assessment of cropland adequacy 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. Once it is determined that a facility has the acreage needed to land apply the nutrients generated, the process of developing a system to manage the nutrients can begin.

Introduction: The Three Components of a Nutrient Management System

Degradation of groundwater is likely to result from application of manure and other nutrients and salts at levels that exceed crop uptake. In order to minimize degradation of groundwater, it is essential to know the amount of nutrients to apply, when they need to be applied and to have the ability 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 establish 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:

<u>Facility and land application infrastructure</u>. These are the physical facilities on the dairy that are used to collect, separate, transport, and store nutrient water and solid manure.

<u>Application of nutrients to cropland</u>. This is the actual procedure of deciding the quantity of nutrients to apply, when to apply the nutrients, and how to apply the nutrients.

<u>Recordkeeping</u>: All other components may be in place, but without having and using a practical means of keeping track of applications and crop uptake, 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 reduce excretion of nitrogen, phosphorus and salts. Although nutrient management can make a significant impact on the amounts of nutrients that are excreted, the topic is beyond the scope of this article.

FACILITY AND LAND APPLICATION INFRASTRUCTURE

Many existing manure management systems were not designed with agronomic application of nutrients as their primary objective. Most existing dairies require some modifications to facilitate proper nutrient management. Some of the areas that need to be addressed include adequate storage capacity, reliable sources of dilution water, thorough mixing of freshwater and nutrient water, correct sizing of pumps and pipelines, the ability to apply manure to all cropland at desired intervals, effective solids separation, prevention of sludge buildup in nutrient water ponds, accurate metering systems and flow control, functional sampling ports, timely analysis of nutrient concentrations, good irrigation uniformity, and control of tailwater.

Each of these infrastructure components is critical to the ability of an operator to apply appropriate amounts of nutrients. Additional information on setting up a dairy for liquid manure applications is available on the UC Lagoon Nutrient Management website, http://groups.ucanr.org/LNM.

APPLICATION OF NUTRIENTS TO CROPLAND

Seasonal Application of Nutrients

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 collected and tested for percent total nitrogen. Percent total nitrogen divided by 100 and 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 recommendation is that the total application should not exceed 140 to 165 percent of the amount of nitrogen taken off by the crop. In some situations, however, although this amount may be needed for optimal crop growth, it may not be completely protective of groundwater quality.

Forms of Nitrogen

In order to understand how to apply nitrogen for adequate crop uptake and minimal leaching to 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; primarily because the particles are larger then 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 that 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 in solution 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 significant amounts of the ammonium in the soil to be converted to nitrate.

Nitrate Leaching

Most irrigation on dairies in the Central Valley is either furrow or border check irrigation. To refill the root zone to three feet requires between two inches of water on a sandy soil and four inches on a clay soil, assuming a 75% irrigation efficiency. However, with surface irrigation systems, the amount of water that is applied in each irrigation is usually 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. The actual amount of water applied in a typical irrigation is often much greater than this amount, especially the slower pre- and first crop irrigations. This amount of water is capable of moving considerable amounts of nitrate completely out of a three-foot root zone in a single irrigation. This has been documented in a study where the amount of nitrate lost in a single irrigation event was measured. Soil samples were taken at 1 foot increments to a minimum of 3 feet immediately prior to a freshwater irrigation and again as soon as reentry into the field was possible (usually 1 to 3 days later) after 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 typical 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 it may be possible to apply most or all of the nutrients at the beginning of the season and have them available in suitable quantities when the crop needs them. However, it is likely that few dairy operators 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 nutrients in applied manure willh stay near the top of the soil profile because of the positively charged ammonium ions and relatively large particle size of the organic 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. 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 but only if the amount of organic nitrogen in the nutrient water is a low in relation to the total nitrogen applied. Figure 1 shows the effect of uncontrolled (before spring 1998) and improved (starting spring 1998) application rates of ammonium and organic nitrogen on shallow groundwater quality. Nitrate concentrations in shallow groundwater declined after improvements in nutrient application were implemented. The adverse affect of unintentional overapplication combined with unexpectedly low yields in winter of 2001 are evident, as is the trend towards higher nitrate concentrations in the years since the lowest levels in 2001.

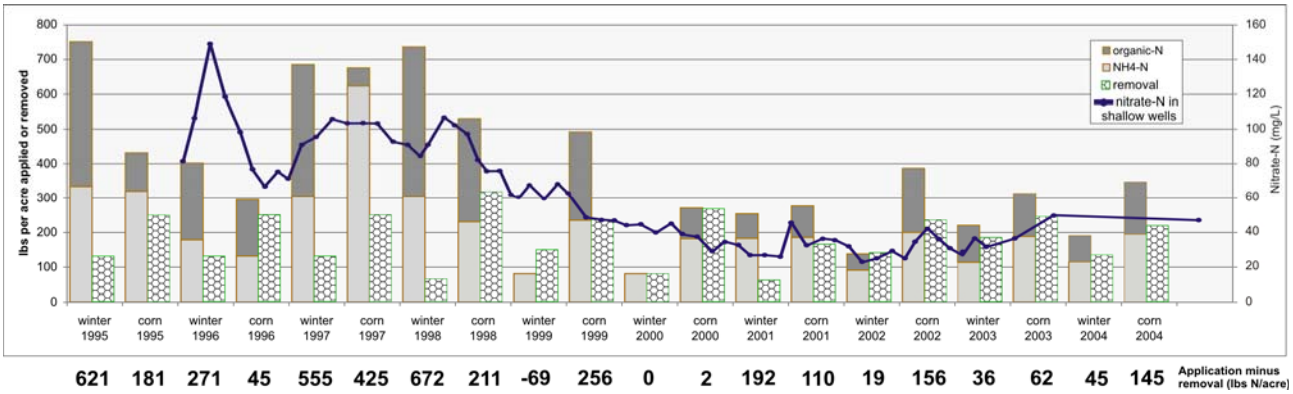
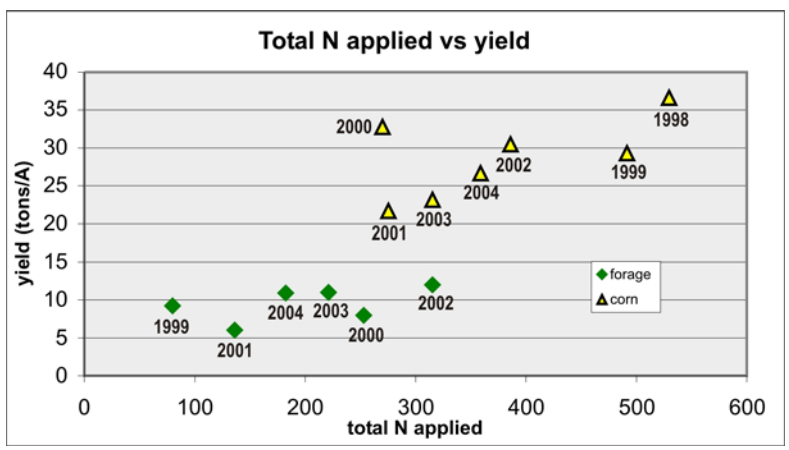


FIGURE 1 Impact of nitrogen application compared to crop uptake on shallow groundwater quality, Hilmar, CA

Starting in 2000, a portion of the organic form nitrogen was attributed to the current crop. Since during the latter years, up to half of the total nitrogen applied was in the organic form, only 20-30% of the organic nitrogen applied was presumed to be available to the current crop. Despite the overapplication of total nitrogen that occurred because of the, corn yields have not returned to levels achieved during the early years of the project, when it is likely that large amount of mineralizing nitrogen for previous year's overapplications provided supplemental nitrogen. Figure 2 shows the correlation between the last 4 years of corn yields compared to the total amount of nitrogen applied. Yields improve as more total nitrogen is applied ($r2 = .90$). This implies that, although the groundwater is being adversely impacted by excess nitrogen, the crop itself is not getting enough to maintain optimum yields. The winter forage crop yields appear to be limited mainly by factors other than nitrogen availability.

FIGURE 2. Total nitrogen applied and yield of winter forage and silage corn, corrected to 70% moisture, compared to total nitrogen applied. 1999 - 2004, Hilmar CA.



It is evident that the organic nitrogen that was not attributed to the crop is mineralizing and impacting the groundwater in subsequent seasons. Because of the difficulty in accurately predicting the mineralization of organic nitrogen, excellent solids separation will necessarily be an essential component of effective dairy nutrient management.

Rates per irrigation
In a synchronized-rate nutrient application system, typically about 50 pounds nitrogen per acre, but no more than 65 pounds nitrogen 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 nitrogen uptake by the corn crop. If dairy nutrient water is used, this equates to a dilution with fresh water that varies but is commonly around ten to one (fresh water to nutrient water). 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 pounds of available nitrogen per acre, 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 nutrients are 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. 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 pounds of nitrogen per acre, depending on expected crop uptake, can be applied with minimal negative impact on groundwater just prior to jointing of the winter cereal crop. If more nitrogen is needed, it should be split into two spring applications. In planning to apply nutrients in a winter irrigation, it is assumed that the irrigation 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. Heavier textured soils may require planting on raised beds to provide drainage. If a winter irrigation with nutrient water cannot be made, the crop will still likely need commercial nitrogen to be applied during the winter if nitrogen applied in the fall has been lost through leaching or denitrification. If commercial fertilizer is applied, then additional cropland and additional storage capacity will be needed to hold the lagoon nutrients until they can be applied in modest amounts to finish off the spring crop and supply the summer crop.

Available Nitrogen
When determining the amount of nitrogen to apply in a targeted nutrient management system, only mineral nitrogen – either nitrate or ammonium – and the portion of the organic form that is expected to become available during the current crop season is considered to be available to meet crop needs during the targeted period. The remainder of the organic nitrogen must not be disregarded because when it does mineralize, if crops do not take it up, it becomes subject to leaching to groundwater. The amount of nitrogen mineralized from organic nitrogen that was applied during previous seasons should therefore be considered and subtracted from the amount that is being currently applied.

Determining the amount of nitrogen that has mineralized is difficult and injects considerable uncertainty into nutrient management planning.

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 nutrient 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 nutrient water and solid 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
Figure 2 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. There is a third crop of sudangrass following the corn. Applications of nutrients are made four to six times during the summer and once or twice in the late winter and early spring, and twice in the fiall. Some applications, such as applying light rates of nutrient water in preirrigations, and the final application close to harvest, are dependant on the amount of mineralized nitrogen from previously applied

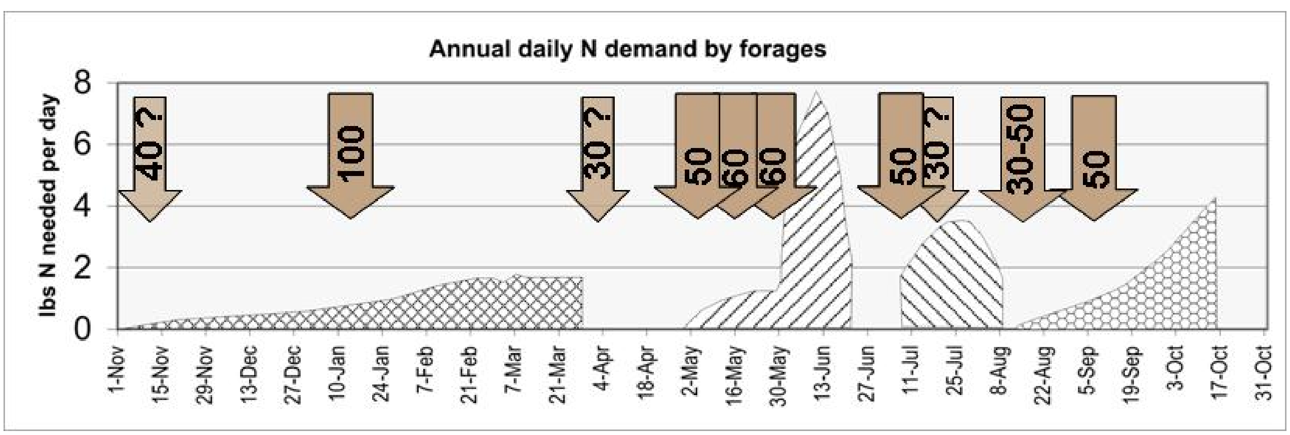
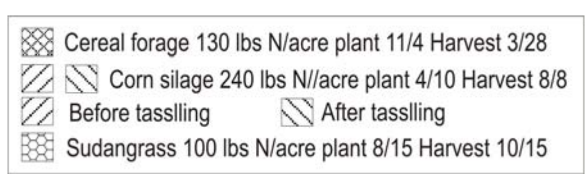


FIGURE 2 Sample targeted nitrogen application plan for forage oats, silage corn, and triple cropped sudangrass.



organic nitrogen that is likely to be present in the soil and the amount of leaching that could have occurred prior to planting. The number of applications between planting and tasselling is dependant on the number of irrigations during this period. Between 70 and 80% of the total nitrogen should be applied prior to tasselling. Available forms of nitrogen will need to be applied in order to meet the large demands for nitrogen by the crop between about knee high and peaking at the 12 leaf stage.

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. If there was no third crop, there would have been no crop on the ground during most of September and October. During this period, mineralization could produce nitrate that would be subject to leaching during the preirrigation for the fall crop.

Procedure for Measuring and Targeting Synchronized Nutrient Application Rates
In practice, the following steps are used to target applications of nutrient water 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 applied nutrient water, crop performance will be affected by the accuracy of the application. More intense management is needed in situations where each check irrigates differently, and less management is needed 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 nutrient water that will be applied. Often, a sample taken from the housing flush system 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 nutrient 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 nutrient 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 nutrient water nitrogen concentration if there is reason to suspect that the 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 or depth in the pond.

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 and the criteria listed in step 3.

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 nutrient 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 nutrients as soon as they are applied to each field in each irrigation will enable the grower 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 provide for easy data entry, and contain information such as how much of each nutrient has been applied, from what source the nitrogen came from, the total gallons applied for the season, how much nitrogen is plant available, and many other parameters. A prototype Excel-based recordkeeping system is available from UCCE which provides estimates of crop requirements and mineralized nitrogen, in addition to performing basic recordkeeping functions.

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