Manure Technical Bulletin Series
University of California Cooperative Extension

Nitrogen Budgeting for Irrigated Forage Crops Receiving Dairy Manure

This bulletin describes an approach to budgeting manure and fertilizer N applications in crop rotations typical of dairy farms in California's Central Valley.

Introduction

A crop nutrient budget is a plan, similar to a financial budget. It compares expected crop nutrient requirements to inputs of fertilizer and manure, and it may include a schedule of planned nutrient applications. Typically, it is only a partial budget, because it does not show all nutrient losses from a field or changes in nutrients stored in the rootzone. Crop N budgets are useful for the following purposes:

- Estimating the amount of manure that can be used at agronomic rates to fertilize crops on the farm generating the manure and the amounts that must be transported off the farm generating the manure;
- Flagging potential risks of under- and over-fertilization of crops;
- Assessing the need for improvements in the capacity to store liquid and solid manure and distribute it to crop fields;
- Developing nutrient budgets and annual reports for dairies in California's Central Valley where dairy producers must demonstrate compliance with regulatory nitrogen application limits[1].

Field-specific information needed to construct annual N budget

To construct N budgets, expected values for N inputs and harvest removals are required for each field and each crop harvested during the calendar year. For annual reports required of Central Valley dairies under waste discharge regulations, actual farm data rather than expected or literature values must be used. The following expected field-specific values are needed for the planning budget approach described here:

1. Yield of each crop in each field to be harvested during the calendar year
2. Concentration of total N in harvested material of each crop

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[1] Dairy waste discharge regulations in effect in the Central Valley of California since 2007 limit applications of N in liquid or solid manure, fertilizer, and irrigation water to each field during a calendar year to 140% of crop harvest N removal during the same time period. Additional applications of N are allowable if plant tissue testing has been conducted, and it indicates the need for more N in order to obtain typical crop yields. (California Regional Water Quality Control Board Central Valley Region. Order No. R5-2007-0035. Waste Discharge Requirements General Order for Existing Milk Cow Dairies, Attachment C.)

3. Concentration of total N in irrigation water applied during year
4. Total volume of fresh irrigation water applied to each field during year
5. Legume N credit (also known as "plowdown N credit") – an estimate of the residual above-background N credited toward the crop following alfalfa or other legumes in rotation. A recommended N credit to a crop following irrigated alfalfa in California is 40 to 80 lb N/acre, depending on the vigor of the alfalfa stand (Pettygrove and Putnam, 2009).

For more detailed N budgets, e.g., with monthly or weekly time intervals, the following information may also be useful:

6. Approximate volume of fresh water applied at each irrigation event (needed if fresh irrigation water contains significant levels of N)
7. Typical proportion of total N in inorganic and organic forms in dairy lagoon water (helpful in assessing risk of under- or over-supply of available N to crops).

In the following section, a sample N budget is presented for a hypothetical irrigated forage field receiving manure and lagoon water (liquid manure) on a dairy farm in the Central Valley.

Sample N budget for 40-acre double-cropped forage field

The following hypothetical example is for a 40-acre field planted to silage oats/wheat ("winter forage", which was planted in the fall of the preceding year) followed by silage corn. Following the N budget table are comments and the calculations associated with each numbered row in the table.

This sample N budget is set up to cover a calendar year, which is the time frame required of dairies for reports and plans submitted under the Central Valley waste discharge requirements (see footnote on page 1). Note that fertilizer/manure applied to the winter forage in the preceding year is not shown. Also, while in this example, no manure or fertilizer N is planned for the fall after corn harvest, if it were, we would include it in the October-December column, even though the crop it would benefit will not be harvested until the next budget year.

		January - April	May-September	October-December	Annnual Total
		lb total N/acre			
1	Winter lagoon water application	120			
2	Corral manure application		150		
3	Starter fertilizer N for corn		20		
4	Lagoon water #1		80		
5	Lagoon water #2		80		
6	Water run NH_3 fert. application		30		

7	Atmospheric N deposit		14	
8	Irrigation water nitrate N		41	
9	**INPUT TOTAL**	**120**	**415**	**535**
10	**HARVEST REMOVAL**	**150** (winter forage)	**240** (silage corn)	**390**
11			**Input:Harvest ratio**	**1.37**

Lines 1, 4, and 5 – Lagoon water N applications

The above sample budget should be considered a first draft that could be adjusted after considering the adequacy of infrastructure (especially for handling lagoon water) and for its ability to meet crop N demand. This first draft shows planned applications of lagoon water total N without regard to the volume of lagoon water that will be required. Application timings and amounts are those that (in the experience of the fictitious farmer and crop adviser) are believed to satisfy the crop N demand while drawing manure nutrients out of the storage lagoon.

At this point, no consideration has been given to the form of N applied and the resulting amount of plant-available N vs. residual N that will remain in the soil beyond the budget year.

It is recommended that after the first draft of the budget is made using lagoon water total N, different scenarios be constructed using a farm-specific realistic range of lagoon water N form concentrations (total N, ammonium, and organic N) to estimate the potential range of lagoon water volumes required and the resulting plant-available N (PAN) likely to be applied. Mineralization coefficients should be considered to estimate PAN, and these are discussed in another bulletin in this series listed in the reference section (Pettygrove, Heinrich, and Crohn, 2009).

To estimate lagoon water volumes, a dairy lagoon water spreadsheet calculator is available, which can be downloaded from http://manuremanagement.ucdavis.edu. This can be used to calculate lagoon water volumes and resulting ammonium and organic N application rates per acre. The lagoon water application volumes can then be compared to lagoon pump and pipe capacity. Also, the ammonium/organic N application rates will be helpful in assessing the risk of crop N deficiency and nitrate N leaching loss.

Line 2 – Spring corral manure application

An application of 7.5 tons/acre of corral manure is planned after winter forage harvest and before corn is planted. Past analyses of corral manure on this farm show an average total N content of 20 lb N/ton. (Note, the manure typically contains 25% moisture and a total N content of 1.33% on a dry weight basis. This is equivalent to 20 lb N/ton @25% moisture). Total N applied will be 7.5 tons x 20 lb N = 150 lb total N/acre.

Line 3 – Starter fertilizer application

The normal practice in this field is to apply 180 lb/acre of 11-52-0 fertilizer just ahead of the seed, resulting in application of 20 lb N/acre and 95 lb P_2O_5/acre. (Question: Considering the large amount of manure and lagoon water applied, is this much starter P necessary? A soil test for P would be helpful in answering this question.)

Line 6 – Water run NH_3 fertilizer application

Following silking, after a short-lived decline in N uptake, corn again requires large amounts of N to maintain leaf chlorophyll during ear development. Water-run anhydrous ammonia (82-0-0) is a good choice for a mid- to late-season shot of N. Low-solids dairy lagoon water may also be a good choice for this purpose, but on many dairies in the Central Valley, pipes that transport lagoon water to fields are too large in diameter and lagoon pumps/valves are not able to throttle down sufficiently to deliver the small amount of lagoon water needed.

Line 7 – Atmospheric N deposition

This is a small credit of 14 lb N/acre per year for wet and dry atmospheric deposition of N-containing compounds that is a required input for all fields under the Central Valley dairy waste discharge requirements. It is small enough that it will not make much difference whether it is all "applied" at one point in the budget or is apportioned to each of the crops in the annual rotation. In the budget example here, it is arbitrarily assigned to the corn crop.

Line 8 – Irrigation water nitrate N

Some well waters and, less commonly, canal waters contain agronomically significant quantities of N, usually in the nitrate form. Freshwater irrigation N inputs in lb N/acre can be calculated as follows:

$$\mathbf{N_{iw}=I_{vol} \times N_{conc} \times 0.227}$$

where
N_{iw} = irrigation water N applied in lb N/acre
I_{vol} = volume of irrigation water applied in acre-inches/acre
N_{conc} = concentration of N in water in milligrams N/liter or ppm
0.227 = conversion factor specific to the units used for **N_{iw}, I_{vol}**, and **N_{conc}**

In the sample budget table, the following values were used

I_{vol} = 36 acre-inches/acre of well water will be applied to the corn, no well water will be applied to the winter forage

N_{conc} = 5 mg/L total N average for the well water applied to corn

This results in application of 41 lb N/acre in the irrigation water, as follows:

N_{iw} = 36 x 5 x 0.227 = 40.9 lb N/acre

If it is expected that fresh water would be added to the lagoon to facilitate the winter lagoon water application, or if the winter forage typically receives a spring irrigation using this water, estimates for those inputs should be included in the budget.

If the irrigation water N content were much higher than the 5 mg/L in this example, it would be helpful in the planning process to break this input into multiple applications over the season, i.e., showing the projected amount applied at each irrigation. The resulting plan would give a more accurate picture of the fertilizer/manure input timing that will be required to match the changing crop N demand during the season.

Additional sample calculations and procedures for estimating volume of water applied (I_{vol}) are presented in Appendix A of this bulletin.

<u>Line 9 – Input total</u>
This is the total N removed in the two crop harvests during the calendar year.

<u>Line 10 – Harvest removal</u>
The winter forage (wheat/oats cut at soft dough stage for silage) is expected to yield 9.5 tons/acre at 70% moisture content with a total N content of 15.8 lb/ton, for a harvest N removal of 9.5 x 15.8 = 150 lb N/acre.

Silage corn yield for this field is expected to be 26.7 tons/acre at 70% moisture containing 9 lb N/ton, for a harvest nitrogen removal of 26.7 x 9 = 240 lb N/acre.

The calculation can also be carried out if plant N content is expressed as percent protein or if it is on a dry weight basis – see Appendix B for the equations. Literature values of N content of harvested material are provided in another bulletin in this series (Pettygrove and Bay, 2009).

<u>Line 11 – Input:Harvest removal ratio</u>
In this first draft N budget, the ratio of N input to harvest removal is 1.37. This complies with the technical standard contained in water quality regulations (see footnote on page 1 of this bulletin) which state that N inputs from all fertilizer, manure, and irrigation water applied to each field in each calendar year shall not exceed 1.4 times crop N harvest removal.

Managing Risk and Improving Crop Nitrogen Use Efficiency
Following is a brief discussion of risks inherent in the planned N budget. Suggested risk-reduction measures or approaches are underscored.

1. Crop nutrient management plans that depend on small, frequent applications of dairy lagoon water N will be defeated if the lagoon water distribution system (pump, throttling valve, and piping to fields) is not designed to handle low flows. Small applications will also be impractical if dairy lagoon water has a high solids content or a highly variable solids content. A smaller number of large doses may get around this problem but may result in lower crop N recovery due to mismatch with crop N demand and consequent excessive N leaching losses.

    - <u>Assess the risk of nitrate leaching loss by comparing applied irrigation water volume to crop evapotranspiration.</u> A procedure for this assessment is described in two technical guides (Schwankl et al. – see references section of this bulletin).

- Improve homogeneity of dairy lagoon water by effective solids separation, proper placement of lagoon inlets and pump outlets, mechanical stirring of dairy lagoons, strategic additions of fresh water, and other design and operation approaches

2. In fields with a long history (>5 years) of regular manure or lagoon water applications, a significant portion of the crop's nitrogen comes from mineralization (decomposition) of residual manure and crop residues from past years. Nitrate from this process is generated during the year, including during times when plants are small or not present, such as after corn harvest and in the spring immediately following harvest of winter forages. Heavy winter rains, pre-irrigation of corn fields, and the post-plant first irrigation when plants are still small can flush the accumulated nitrate from the root zone, especially in coarse-textured soils. What can be done to ensure that crops recover most of this mineralized N?
   - Consider irrigating corn up instead of pre-irrigating.
   - Conduct an irrigation system performance evaluation and make improvements that will allow less water to be applied at each irrigation.
   - Consider adding a late summer/fall "triple crop" -- sudangrass or sweet sorghum – which will take up nitrate, reducing soil nitrate levels going into the winter rainy season.
3. Uncertainty in the fertilizer value of both corral manure and lagoon water organic N creates risk. The uncertainty may not matter during much of the year, but presents risk during periods of rapid daily crop growth and high N uptake, e.g., from stage V8 to tasseling in corn.
   - To reduce risk, transfer more corral manure and lagoon solids off farm and use small, strategically timed doses of water-run ammonium fertilizer or low-solids lagoon water to bump up the available N during periods of greatest crop need.
   - Use nitrate soil testing and plant tissue analysis to evaluate the need for additional N in early and mid-season. Delay applying fertilizer or dairy lagoon water when high nitrate-N levels (>20 ppm in top foot) are present or when tissue samples indicate very high plant N status
4. Non-uniform stand emergence, planter skips, pest problems, salinity, etc. can limit yields, as nearly everyone understands. It should also be appreciated that these problems reduce crop nitrogen use efficiency (NUE) and may increase groundwater nitrate contamination, as N is applied but is not taken up by crops growing at less than full potential. Reaching full yield potential is important both for protecting groundwater quality and in complying with regulatory N application limits.

- Compare yields to the best achieved in nearby fields with similar soils and adopt practices that will improve stands and result in better-than-average yields.
- Scout fields in mid-season to locate significant areas of poor growth. Mark these with GPS or with reference points on field maps and follow up after harvest with soil sampling (nutrients, EC) of those areas. Irrigation non-uniformity (due to low spots, sand streaks, hardpan, gopher holes) is more difficult to map and correct, but can contribute to low yield and low crop nitrogen use efficiency.

References and Additional Information

Murrell, T.S. 2008. Measuring nutrient removal, calculating nutrient budgets. p. 159-182. *In* S. Logsdon et al. (ed.) Soil science step-by-step field analysis. Soil Science Society of America, Madison, WI.

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The following documents are distributed by the California Dairy Quality Assurance Program and are available at http://www.cdqa.org (verified October 2009)

California Regional WaterQuality Control Board Central Valley Region. Annual Dairy Report. July 1, 2008. Available at http://www.cdqa.org/docs/14_Page_2007_Annual_Report_Form.pdf

Frate, C. and M. Campbell Mathews. 2008. Irrigation (fresh) water sampling protocol. Tab 5.6 WDR General Reference Binder Materials.

Schwankl, L., A. Fulton, and T. Prichard. 2008. Determining whether nutrients are leaching from your fields. Tab 11.5 WDR General Reference Binder Materials.

Schwankl, L., A. Fulton, and T. Prichard. 2008. Determining crop evapotranspiration. Tab 11.6. WDR General Reference Binder Materials.

APPENDIX A
Estimating N Applied in Fresh Irrigation Water Applications

Estimating or forecasting volume of irrigation water applied to crops

Forecasting N applied to fields in fresh irrigation water requires an estimate of the volume of water to be applied and of the N content of the water. Farmers often do not measure the volume or depth of water applied to a field at each irrigation. *Beginning in July, 2011, dairies in the Central Valley will be required by waste discharge regulations to record the volume of water applied to each land application area (field) at each irrigation event*. For surface (canal) water volumes, water district records may be useful, but often it will not be possible to use these values for estimating volumes applied to individual fields. For fields irrigated from wells where flow meters are not in place, farmers may know the typical number of hours of pump run time and can estimate pumped volume from this; however, pumped volume estimated by this method is often very inaccurate.

In many instances, a better method for forecasting irrigation application volume is to use published normal-year crop evapotranspiration (ET) corrected for precipitation and combined with an expected value for irrigation application efficiency – an approach outlined as follows: ET values and calculation procedure are published for many locations in the state by the California Department of Water Resources (see www.cimis.water.ca.gov). Crop ET (ET_{crop}) values should be corrected for normal-year effective rainfall values (P_{eff}). This is especially important for winter forages. The resulting value of ET_{crop} minus effective rainfall should then be multiplied by a reasonable factor to account for irrigation system application losses to leaching and runoff. For Central Valley surface gravity irrigation systems, this factor will typically fall in the range of 1.25 – 1.43, mathematically equivalent to an irrigation application efficiency range of 70-80%. Finally, this must be corrected for (reduced by) the amount of dairy lagoon water that will be applied. (N contributed from dairy lagoon water is considered separately.) The volume of lagoon water to be applied in the future may be unknown, but except where fresh water N concentrations are very high, the error introduced by using an incorrect application volume of lagoon water will not be significant compared to other uncertainties in the budgeting process. The net amount of freshwater to be applied -- estimated here as (ET_{crop} minus effective precipitation) x (efficiency factor) minus (anticipated dairy lagoon water volume) -- may then be combined with N concentration of the water to estimate N applied in fresh irrigation water in lb N/acre.

Sampling and analysis of irrigation water: Irrigation (fresh) water sampling protocols acceptable for Central Valley dairies in compliance with waste discharge regulations are described in a California Dairy Quality Assurance bulletin (Frate and Mathews, 2008).

Sample calculation

During a season, it is expected that a field will be irrigated 8 times, each time with 5 inches of fresh water containing an average of 6 milligrams per liter (mg/L) of total N.

Using the equation $\mathbf{N_{iw} = I_{vol} \times N_{conc} \times 0.227}$

Where N_{iw} = lb/acre of N applied in the irrigation water, I_{vol} = irrigation water volume in acre-inches/acre, N_{conc} = N concentration in the water in mg/L, and 0.227 is a conversion factor specific to the units of measurement used here.

I_{vol} = 40 acre-inches/acre (= 8 irrigations x 5 acre-inches/acre for each irrigation)
N_{conc} = 6 mg/L

N_{iw} = 40 acre-inches/acre x 6 mg/L x 0.227 = **54.5 lb N/acre**

Useful conversion factors for water volume calculations

1 acre-ft = 12 acre-inches = 43,560 cubic ft = 325,850 gallons = 1233.5 cubic meters = 1.234 million liters

1 acre-inch = 3,630 cubic ft = 27,154 gallons = 102.8 cubic meters = 102,792 liters

Projecting irrigation water N application in situations with multiple water sources

Fields may be irrigated from a mixture of surface and well water sources with different N contents, and it will often be impossible to predict the mix of sources ahead of time. Keeping track of this for annual report purposes can be challenging. Unless fresh water N contents are significant (> 5 ppm N), inability to include these complications will not result in large errors in a planning budget. For farms operating under the regulatory N loading limits or where there is a high risk of harm to groundwater quality, a conservative approach is to err on the high side, i.e., use the higher end of the range of expected N applied in fresh irrigation water. This will reduce the allowed N applied (as manure and fertilizer) in the planning stage, but will allow for more flexibility during the season, if it turns out that N concentration in the irrigation water is high.

APPENDIX B
Estimating N Removed from a Field in the Harvested Crop Material

N harvest removal is less than crop N uptake and is not necessarily the same as crop N requirement. Harvest N removal in lb N/acre for each crop is calculated with one of the formulas below, depending on how the N content of the harvested plant material is expressed. Analytical laboratories may report plant N content (i) as percent N on an as-received moisture content, (ii) as percent N on a dry matter basis, i.e., essentially at zero moisture content, or (iii) as lb per ton at a specified moisture content. In each equation, **EY**=Expected Yield in units of wet weight at a specified moisture content.

Equation 1: PlantN is N content of the harvested material expressed as lb N per harvest weight unit and at the same moisture content as specified for the yield

Harvest N removal = EY x PlantN

Equation 2: EY is in tons/acre. %protein is protein content of the harvested material expressed as a percent on the same moisture basis as the yield. 0.16 is the factor to convert protein to a nitrogen basis

Harvest N removal = EY x 2000 x 0.16 x %protein/100

Equation 3: EY is in tons/acre, %N is N content of harvested material expressed as a percent on a dry weight basis

Harvest N removal
= EY x 2000 x %N/100 x [1-(%Moisture content/100)]

An example for a "triple crop" dairy rotation and using equation 1 is shown in the following table. Plant tissue N content is expressed in lbs/ton of harvested material adjusted to 70% moisture content.

Table 1. Example of N removed in harvested crop

	Expected yield, tons/acre @ 70% moisture	Crop N content, lbs/ton @ 70% moisture	Harvest N removal lb/acre
Triticale/oats for silage	12	12	144
Silage corn	27	9.5	257
Sudangrass, 1st cut	3	30	90
Sudangrass, 2nd cut	2	20	40
	Expected annual N removal		**531**

Expected yield values used for this calculation should be average or typical yields, rather than the most optimistic values. Use of realistic value for expected yields can make a big difference in accuracy of projected budget.

Plant N content should be based on samples taken from past harvests in the same field or from fields of the same variety grown at similar yield levels. Harvest plant sampling protocols required under the Central Valley Waste Discharge Requirements are available for download at the California Dairy Quality Assurance Program website (cdqa.org). For planning purposes, where on-farm or other reliable values are not available, literature values can be used, e.g., the Pettygrove and Bay bulletin in this series. Actual values may differ significantly from literature values.

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