FINAL REPORT TO
CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

Period covered	October 1, 2007 – March 30, 2009
Contractor	Regents of the University of California
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Agreement No.	CDFA #07-0405
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Project Title:	Development of Certified Crop Adviser Specialty Certification and Continuing Education in Manure Nutrient Management
Cooperators	Robert Fry USDA/Natural Resources Conservation Service Davis, CA Michael Payne California Dairy Quality Assurance Program Davis, CA Luther Smith American Society of Agronomy Madison, WI

EXECUTIVE SUMMARY

In this project we collaborated with the California Certified Crop Adviser board and the California Dairy Research Foundation to train crop management professionals in the agronomic aspects of manure management to enable them to better serve the dairy industry in the Central Valley of California. Under waste discharge requirements adopted by the Central Valley Regional Water Quality Control Board in May 2007, all milk cow dairy producers in the region must implement Nutrient Management Plans (NMP), which must be developed and signed by Certified Crop Advisers or other certified professionals. The technical standards for the NMPs include unprecedented annual nitrogen loading limits for each field, and the regulation requires a detailed monitoring and reporting program including manure, plant, soil, and water sampling and analyses.

Project accomplishments were the following:

1. We conducted two series of workshops for crop management professionals on environmentally and agronomically sound manure management practices. These drew 205 individuals (spring 2008) and 110 individuals (fall 2008) and provided 3.5 units of CCA continuing education to 67 CCAs (spring 2008) and 10 units of continuing education to 40 CCAs (fall 2008).
2. We produced a manure and crop nutrient management curriculum in the form of handouts and educational modules. Workshop materials included approximately 50 handouts, of which about 20 were produced specifically for these workshops. Additional materials are in preparation as downloadable technical bulletins.
3. We supported the California Certified Crop Adviser program's new Specialty Certification in Manure Management, which is scheduled for roll out during early October 2009. A set of 32 Performance Objectives have been submitted to the CCA board, a website has been established for distribution of the aforementioned educational materials, and a set of exam questions is in preparation for use in the CCA program's February 2010 examination for the Specialty Certification.
4. From the sign-in lists, pre-registration lists, and names collected at several other crop management workshops, we have compiled a Dairy Manure Email Interest List of more than 350 individuals.

INTRODUCTION

Under waste discharge requirements adopted by the Central Valley Regional Water Quality Control Board (Order No. R5-2007-0035), all dairy producers must implement Nutrient Management Plans (NMP). The NMPs must be developed and signed by Certified Crop Advisers or other certified professionals. The technical standards for the NMPs include unprecedented annual nitrogen loading limits for each field, and the regulation requires a detailed monitoring and reporting program including manure, plant, soil, and water sampling and analyses. In this project we collaborated with the California Certified Crop Adviser board to train crop management professionals in the agronomic aspects of manure management to enable them to better serve the dairy industry. Additional financial and logistical support were provided by the California Dairy Research Foundation.

OBJECTIVES

1. Produce a manure and crop nutrient management curriculum in the form of educational modules to be made available on the internet in downloadable format. Additionally the modules will be formatted for use in short courses or workshops both initially and in continuing education.
2. Develop a set of multiple choice questions and an accompanying set of performance objectives on manure nutrient management suitable for use by the California Certified Crop Adviser program in the state CCA examination.
3. Conduct workshops for crop management professionals on crop nutrient management and dairy manure use in the Central Valley region. The workshops will target Certified Crop Advisers, NRCS Technical Service providers (TSPs) and NRCS staff who are Certified Planners of Comprehensive Nutrient Management Plans.

ACCOMPLISHMENTS

1. We have completed drafts of curriculum materials, with technical bulletins in preparation or completed on the topics shown in the following table:

1	USDA cost-share programs related to dairy manure recycling
2	Dairy manure properties
3	Estimating manure N availability **(Appendix F this report)**
4	N cycling and losses from the soil **(Appendix H this report)**
5	Soil testing and estimating soil N availability
6	Crop N Requirements and harvest removal
7	Legume N credit for crops following alfalfa **(Appendix F this report)**
8	Plant sampling for agronomic purposes
9	Nutrient management planning and budgeting

10	Lagoon water calculations

Additional topics were identified at an earlier stage of this project and listed in our earlier progress report. Those topics were subsequently addressed in documents produced by the California Dairy Quality Assurance Program in collaboration with the Central Valley Regional Water Quality Control Board and therefore are no longer on our list. These are available at the CDQAP website, cdqa.org. Topics that were on this initial list but are covered outside of this project are the following:

1	Regulatory requirements for Nutrient Management Planning	CDQA and CV Regional Board
2	Manure sampling and analysis protocols	CDQA and CV Regional Board
3	Plant sampling (for harvest nutrient removal estimation)	CDQA and CV Regional Board
4	Irrigation water testing	CDQA and CV Regional Board
5	Irrigation system basics	CDQA (potential for leaching) and UC ANR irrigation manuals
6	Dairy manure infrastructure requirements	In preparation by Stanislaus Co. UC Cooperative Extension under contract with USDA-NRCS

2. A half-day course was conducted at three locations (Tulare, Modesto, and Madera) in May 2008. (**See Appendix B and C this report**). The short course was advertised by the Western Plant Health Association, the Certified Crop Adviser program/California Association of Pest Control Advisers, the California USDA/NRCS and several units within the University of California. A total of 205 persons attended, including 67 Certified Crop Advisers and 18 USDA-NRCS staff members. Continuing Education Units (3.5 units in the nutrient management category) were awarded to the Certified Crop Advisers. A total of seven new handouts were produced for this workshop series, not including Powerpoint presentations. Handout materials were prepared by the UC Cooperative Extension (S. Pettygrove, C. Frate, M. Campbell Mathews) and were reviewed and in some cases revised by S. Pettygrove and project staff prior to the short course. Following the workshops, these materials were made available (by download from UC ANR filevault) in electronic format to those who had attended the workshops and other interested persons who are listed on the project database. Additionally, five CDQAP documents were reproduced for distribution at the workshops. The workshop agenda and list of handouts is attached.

3. A two-day short course was conducted in the fall of November 2008 at two locations – Tulare and Modesto. (**See Appendix D and E this report**.) This provided 10 units of Certified Crop Adviser continuing education. Lecturers included UC Cooperative Extension county farm advisors and specialists and Central Valley Regional Water Quality Control Board staff and Denise Mullinax of the California Dairy Quality Assurance Program (CDQAP).

These workshops distributed about 30 handouts, including a number prepared specifically for this workshop. Selected CDQAP guidesheets were included. Total attendance was 110, including 40 CCAs. Evaluations indicated overall satisfaction, but significant dissatisfaction was expressed with information presented on N mineralization, which involved a complicated budgeting exercise in which laptop computers were used by the workshop participants.

4. From the sign-in lists, pre-registration lists, and names collected at several other crop management workshops, we have compiled a Dairy Manure Email Interest List of more than 350 individuals.

5. Stuart Pettygrove made a related presentation ("Preparing a nitrogen budget that is consistent with both crop needs and regulatory requirements") at the USDA-NRCS Comprehensive Nutrient Management Planning workshop (75 attending) in Modesto on April 17, 2008.

6. We are providing support to the California CCA for its new Specialty Certification in Manure Management, which is to be announced to CCAs by the CCA board in early October 2009. This is a voluntary certification available only to California CCAs in good standing. It is being offered as a tool to build clientele in the dairy industry and to demonstrate additional CCA competency in a regulated category of nutrient management. The CCA board is offering an exam specifically for this certification on February 5, 2010 at the same time as the regular state and international CCA exams are being offered. In support of this exam and certification program, we have produced a draft list of 32 performance objectives (APPENDIX A), and these will be distributed to interested persons by the CCA program. The CCA board's decision to offer this specialty certification was made after the beginning of this FREP project, and therefore, the Performance Objectives (P.O.s) were not in the original project objectives; however, the exam questions and educational materials are aligned with the P.O.s, and therefore it made sense for us to work with the CCA in the development of this list.

7. A bank of approximately 40 questions on manure nutrient management is in preparation for use by the California Certified Crop Adviser program for the manure specialty certificate exam.

8. A website has been established for the distribution of manure technical information developed under the FREP project. This will be used in the fall of 2009 to make information available specifically for those CCAs interested in the CCA Manure Management. As this website is currently under construction, the URL is not reported here, but it is available upon request made by email to Stuart Pettygrove (gspettygrove@ucdavis.edu).

Appendix A

California Certified Crop Adviser
Proposed Performance Objectives for Specialty Certificate in Manure Management
DRAFT September 25, 2009

This draft is currently under review by the California Certified Crop Adviser Board. It is not an approved document of the California CCA or International CCA programs.

I Manure Properties and Production

1 For planning purposes, estimate the quantity of manure and manure nutrients (total N, P, and K) excreted annually by dairy cattle, beef cattle, poultry, and swine, and understand the main factors that affect this.

2 List materials, in addition to animal feces and urine, that may be present in manure collected in animal agricultural operations.

3 Compare relative amounts and forms of N in the following materials dairy farms: corral manure, lagoon water, sludge, solids separated by mechanical screen, and aerobically composted solid manure

II

Dairy Manure Collection, Storage, and Treatment

4 Describe methods used in California to collect and store animal excreta in milk cow dairies, beef feedlots, swine farms, and poultry farms.

5 Describe the importance of having secure and adequate storage capacity for manure.

6 Describe common physical and management safeguards used to assure illegal or reasonably avoidable seepage and surface discharge of stored manure does not occur.

7 Describe hazards and elements of worker safety in managing animal manure.

III Manure Sampling and Analysis

8 Identify the chemical and physical properties that should be measured for manure that will be applied to crop land.

9 Describe methods for sample collection and sample storage for both liquid and solid manures.

IV Crop Availability and Behavior of Manure-Derived Nutrients in Soil

10 Relate pattern of N mineralization and manure N availability to timing of application, type of manure, and crop N utilization.

11 Compare P availability of commercial inorganic fertilizers and animal manure.

12 Describe the potential for accumulation of salt and metals in manure-based cropping systems.

V Nutrient Balance

13 Estimate whole herd manure nutrient production and other nutrient sources for a dairy farm.

14 Estimate the N, P, and K balance for crop fields receiving manure on a dairy, including a composite balance for all fields together and for each field individually.

15 Describe alternatives potentially useful for achieving whole farm nutrient balance.

16 Prepare a preliminary field level dairy manure application plan following the format used either by the Central Valley Waste Discharge Requirements General Order (Order No. R5-2007-0035) or the USDA-NRCS Manure Management Planning procedure

VI Manure Application

17 Estimate the quantity of N, P, and K removed by crops in the harvested biomass.

18 Describe the function and use of devices for lagoon water sampling, flow control, and flow measurement, as dairy lagoon water (process wastewater) is pumped from storage to crop fields.

19 Describe in general the techniques used to ensure that dairy lagoon water is mixed adequately with irrigation water prior to application to fields.

20 Differentiate between total and actual acreage available for application due to setbacks and buffers.

21 Describe procedures for measurement and calibration of solid and slurry manure application.

22 Using laboratory analyses or published values for manure nutrient content, calculate the weight or volume of manure required to achieve a desired nutrient application rate.

23 Understand how to manage surface irrigation systems in order to control the rate and distribution uniformity of liquid manure.

VII Regulations and Cost-Share programs

24 Know what the EPA CAFO Rule is and list main elements of CAFO requirements.

25 Know which state regulations in CA govern livestock manure and which state agencies administer regulations. Know basic requirements of the regulations.

26 Know which government/public organizations can provide technical assistance to dairies on their waste management.

27 Know what the USDA NRCS Comprehensive Nutrient Management Plan is and for whom it is required.

VIII Potential Animal Manure Impacts on Water Quality, Air Quality, and Animal Production

28 Describe how manure N:P and N:K ratios and N applications create the potential for environmental, animal health, and agronomic problems.

29 List manure constituents that can degrade surface and ground water quality, their forms, and pathways to groundwater and surface waters, and the way in which they impair WQ.

30 Describe State of California system for classifying surface water impairment and know where to find the list of impaired waters.

31 Describe potential impacts of manure management on air quality and list manure constituents that are potential air pollutants.

32 Describe briefly common methods used to limit air quality impacts of manure management.

Appendix B

WORKSHOP — OPEN TO PUBLIC — NO CHARGE

Dairy Manure Nutrient Planning for Crop Management Professionals

8:00 a.m.—Noon
(Sign-in, coffee, rolls at 7:30 a.m.)

Tuesday May 20

Cooperative Extension
4437-B So. Laspina St.
Tulare

Thursday May 22

NEW LOCATION!

Vintage Gardens, 4342 Dale Rd. , Modesto

Thursday May 29

Madera Co. Social Services Classroom
700 E. Yosemite, Madera

Sponsors

- University of California Cooperative Extension
- CA Department of Food & Agriculture
- CA and International Certified Crop Adviser
- California Dairy Research Foundation

5/15/08

This free workshop will provide information and an opportunity to discuss dairy manure nutrient planning with fellow crop management professionals. We will present the latest crop nutrient-related updates of the Central Valley Waste Discharge Requirements General Order for Existing Milk Cow Dairies. This will include help with the July 1, 2008 deadline. Topics will include:

- Sampling and analysis methods for soil, plant tissue, irrigation water, and manure
- Estimating N mineralization from soil and manure
- Dairy lagoon water sampling and flow measurement
- Interpreting regulatory N loading limits (the "1.4X and 1.65X harvest N removal" limit)
- Agronomic options for addressing nitrogen application limits and inadequate storage pond capacity

Instructors:

Stu Pettygrove, UC Cooperative Extension Soils Specialist
Marsha Campbell Mathews, UC Cooperative Extension Farm Advisor
Carol Frate, UC Cooperative Extension Farm Advisor

For more information about the program, contact Stu Pettygrove at gspettygrove@ucdavis.edu

PRE-REGISTRATION — Please help us get a headcount!

- Online—go to https://ucce.ucdavis.edu/survey/survey.cfm?surveynumber=2710
- By email or phone: Contact Victoria Pakhomov, UC Davis Department of Land, Air & Water Resources, vpakhomov@ucdavis.edu, 530-752-1406

CCAs — 3.5 CEUs in Nutrient Management approved

Appendix C

Dairy Manure Nutrient Planning for Crop Management Professionals

May 20 Tulare, May 22 Modesto, May 29 Madera

Workshop agenda

7:30	Doors open, sign-in, coffee & rolls
8:00	Introduction
8:15	Review of N budgeting and current situation
8:30	Plant sampling & analysis
	Irrigation water sampling & analysis
9:10	Soil sampling
	Estimating N from soil N mineralization
10:00	Certified Crop Adviser program update
10:10	***Break***
10:30	Manure organic N and mineralization
10:45	Lagoon water measurement, sampling
	Infrastructure, agronomic strategies for meeting N loading limits and lagoon water storage inadequacy
Noon	***Adjourn***

Instructors

Stu Pettygrove, Cooperative Extension Soils Specialist, UC Davis

Marsha Campbell Mathews, UC Cooperative Extension Farm Advisor, Modesto

Carol Frate, UC Cooperative Extension Farm Advisor, Tulare

Handouts - Partial List

California Dairy Quality Assurance Program

1. Tips for Completing the 2007 Annual Report (Due July 1 2008)
2. Example Sampling and Analysis Plan for Nutrient Management
3. Sampling Protocol for Plant Tissue Corn and Winter Forage Silage
4. Irrigation (Fresh) Water Sampling Protocol
5. Optimizing capacity of existing process wastewater holding ponds

UC Cooperative Extension

1. The End-of-Season Cornstalk Test for Excess Nitrogen
2. Soil Sampling in Fields Receiving Dairy Manure

3. Illinois Soil Nitrogen Test and UC Davis Modified Alkaline Hydrolysis Procedure for Estimating Potentially Mineralizable Soil Nitrogen
4. Legume Credits for Crops Following Alfalfa
5. Dairy Manure Nutrient Content in California
6. Mineralization of Nitrogen in Liquid and Solid Dairy Manure Applied to Soil
7. Nutrient Content of the Harvested Portion of Crops

Appendix D

FALL 2008 UC COOPERATIVE EXTENSION SHORTCOURSE FOR CROP MANAGEMENT AND DAIRY DESIGN PROFESSIONALS

Crop Nutrient Management for Central Valley Dairies

Wednesday-Thursday

November 19-20

Stanislaus Co. Ag Center, Room D-E
3800 Cornucopia Way
Modesto

December 10-11

International Agri-Center
4500 Laspina St.,
Tulare

Sponsors

- CA Department of Food & Agriculture
- CA and International Certified Crop Adviser
- California Dairy Research Foundation
- California USDA-NRCS

University of California Cooperative Extension

This two-day UC Cooperative Extension shortcourse is aimed at Certified Crop Advisers and other crop management and dairy design professionals working with dairy producers to improve crop nutrient management. It will expand on topics covered in the half-day workshops held by UCCE in May and the agronomy/irrigation portion of the fall workshops conducted by the California Dairy Quality Assurance Program. The shortcourse will include lectures, discussion, and hands-on exercises. It will help participants integrate the many components needed to develop a crop nitrogen budget, including

- Manure collection
- Manure conveyance
- Irrigation system performance
- Crop nutrient requirements
- Manure/soil/plant tissue sampling and analysis

PRE-REGISTRATION REQUIRED — enrollment limited

Registration deadline — two weeks before shortcourse

- Online—go to https://ucce.ucdavis.edu/survey/survey.cfm?surveynumber=3083
- By email or phone: Contact Victoria Pakhomov, UC Davis Department of Land, Air & Water Resources, vpakhomov@ucdavis.edu, 530-752-1406

For more information about the program, contact Stu Pettygrove. (gspettygrove@ucdavis.edu), Cooperative Extension Soils Specialist, Department of Land, Air & Water Resources, UC Davis

10 CCA Continuing Education Units — request pending

Appendix E

AGENDA -- CROP NUTRIENT MANAGEMENT FOR CENTRAL VALLEY DAIRIES

Tulare -- December 10-11, 2008

Wednesday	Topic
8:30-9:00	Sign-in, refreshments
9:00-9:10	Welcome
9:10-9:25	Nutrient balance and Central Valley Dairies: An overview
9:25-10:00	Overview of Central Valley WDR General Order
10:00-10:30	Introduce dairy N budget planning exercise
10:30-10:45	Break
10:45-11:00	The N Planning Process: Overview of steps for evaluating and designing dairy N applications
11:00-11:45	Evaluating irrigation system risk of deep percolation and fixing the problem
11:45-Noon	Matching N application to crop uptake
Noon-1:00	Lunch on site
1:00-1:30	Exercise: Planning crop N uptake
1:30-1:45	Manure N mineralization
1:45-2:00	Exercise: Crediting mineralized N to crops in budget
2:00-2:15	Developing the budget based on leaching risk
2:15-3:00	Exercise: Develop the budget for your dairy
3:00-3:15	Break
3:15-3:45	Matching mineralization and crop uptake
3:45-4:05	Discussion: How much risk is associated with assumed mineralization? How do you minimize risk of low yields while staying within the 1.4X limit?
4:05-4:45	Manure transfer systems, pipelines and pumps
4:45-5:00	Feedback, lead-in to next day

Thursday

8:30-9:00	Sign-in, refreshments
9:00-9:15	Intro to Day 2

9:15-9:45	CV Regional Water Quality Control Board update
9:45-10:30	Infrastructure information and tools (continue)*
10:30-10:45	Break
10:45-Noon	Infrastructure information and tools (continue)*
Noon-1:00	Lunch on site
1:00-1:25	Sampling & analysis update
1:25-2:30	Continue infrastructure topics*. Data collection and recordkeeping
2:30-3:00	Evaluation, certificates of participation, adjourn

Appendix F

UC Manure Technical Guide Series
for Crop Management Professionals

Legume N Credit for Crops Following Alfalfa

Corn and other crops following alfalfa require lower rates of N as fertilizer or manure than when following a non-legume forage or grain crop. This is due to the residues left in the soil by alfalfa being richer in N than those of non-legume crops. An estimate of this “legume credit” is needed for N budgets developed by dairy producers to comply with waste discharge regulations adopted by the Central Valley Regional Water Quality Control Board in 2007.

What is the amount of this legume credit? No recent field studies have been carried out in California to answer this question. Field experiments conducted by Williams in the 1950s at lower yields than currently are obtained by farmers suggest a legume credit of 60 lb N/acre (Williams, citation). A University of California, Davis, researcher who specialized in biological N fixation by legumes, D.N. Munns, reviewed the circumstantial evidence and research conducted outside California. He noted that although alfalfa takes up prodigious amounts of nutrients and usually obtains a large proportion of its N from the atmosphere, under the climatic conditions and intense management in the Central Valley, much of this N is removed in the harvested forage. He concluded that the likely contribution of alfalfa residues to a following crop is 40-80 lb N/acre higher than that provided by the residual soil organic matter and crop residues following non-legume crops in the rotation (D.N. Munns. 1975. Alfalfa as a soil builder. pp. 89-92 in Proceedings, California Alfalfa Symposium).

This is consistent with an informal survey of six UC and industry experts conducted in 2004 by the authors of this guide. All six recommended that under Central Valley and desert conditions in California, the legume credit should be no more than 60-80 lb N/acre. Those surveyed cited personal observations of corn and other crops following alfalfa, and one person had observed very low soil nitrate levels in several fields following alfalfa.

Based on the older research, the review by Munns, and the informal survey of experts, we recommend a legume credit of 40-80 lb N/acre depending on alfalfa stand density during the last year. This legume credit is somewhat lower than that recommended by other land grant universities in the US, especially at the high end of the recommended ranges (see table below). Research under irrigated California conditions is needed to confirm the recommended range.

Credit*, lb N/acre	Adjustment within range based on:	Source of information
40-140	Alfalfa plant density	Michigan State U. (1997)
0-120	Alfalfa plant density	Kansas State U. (2007)
0-150	Alfalfa plant density	South Dakota State U. (1998)
40-150	Plant density, soil texture	U. of Nebraska, Lincoln
40-150	Corn yield goal	U. of Minnesota (1990)
0-140	% stand	Colorado State U. (2003)
40-190	Plant density, regrowth after last cut, soil texture	U. Wisconsin A3591
40-80	**Stand density, yield**	**Recommendation for Central Valley of California (this publication)**

*Amount by which applied N should be reduced following alfalfa vs. full rate applied to crop following corn or other high yielding, non-legume crops

References

Kansas State University, 2007, pub L-778
University of Wisconsin, pub A3591
Colorado State University 2003 Pub XCM574A

Legume N Credit for Crops Following Alfalfa. 2009. University of California Cooperative Extension Manure Technical Bulletin Series. http://manuremanagement.ucdavis.edu

Authors: G.S. Pettygrove, Cooperative Extension Soils Specialist, Department of Land, Air & Water Resources and D.H. Putnam, Cooperative Extension Forage Agronomist, Department of Plant Sciences, University of California. Davis.

DRAFT SEPTEMBER 29, 2009

University of California Manure Technical Guide Series
for Crop Management Professionals

Sponsors
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California USDA Natural Resources Conservation Service

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Appendix G

Manure Technical Bulletin Series
University of California Cooperative Extension

Manure Nitrogen Mineralization

Most of the nitrogen in animal manure exists in two forms -- organic N (proteins, for example), which is not plant-available, and ammonium (NH_4), which is plant-available. Of the total N in manure, organic forms may account for as much as 95% (cattle manure in corrals) or as little as 30% (dairy lagoon water).

Key Points

- *__Mineralization__ is the microbial conversion of organic N to ammonium, a plant-available form of N*
- *In the first year following manure application, mineralization of organic N can range from 0 for mature composts to more than 50% for poultry manure.*
- *Under California conditions, mineralization values are useful for the first year following application, but for the longer term this approach is not useful*
- *To protect groundwater and meet N loading limits, imposed by government on dairies, the crop and irrigation system must be managed to maximize recovery of residual manure N as it is mineralized over a period of years.*

When manure is applied to land, a portion of the organic N is converted by soil microbes to ammonium. This process is called ***mineralization***. To calculate the N fertilizer value of manure and to construct crop N budgets, an estimate of the rate of mineralization is needed. Rate of mineralization is usually expressed as a fraction or percentage of the initial organic N that will be mineralized during a specified time period, usually a year or "season".

Calculating Plant-Available Nitrogen (PAN) for Animal Manure

Plant-available N (PAN) of manure is defined as the sum of inorganic N (ammonium) and the portion of the organic N that will be mineralized during the time period of interest. The values in Table 1 below provide suggested values of N mineralization that can be used to estimate PAN from manure. Following that, examples of PAN calculation are provided.

Variability of Manure N Mineralization

Mineralization is influenced by several factors – mainly the following:

- animal species, age, and diet
- manure collection and storage method
- manure age and degree of weathering in storage
- degree of incorporation in soil
- soil temperature and moisture
- other soil properties

As a result of the many factors and their interactions, no simple list of manure properties and environmental conditions can be used to precisely predict manure N mineralization. Furthermore, differences in research methods sometimes make it difficult to compare mineralization values reported by different researchers.

The results of a study of 107 solid and liquid dairy manure samples (Van Kessel and Reeves, 2002) gives us an idea of the magnitude and range of mineralization rates that can occur even under uniform conditions. The samples were mixed with soil at realistic application rates and incubated in the laboratory for 8 weeks at 77° F. For the majority of the samples, net mineralization over this time period ranged from 10 to 20% of the initial organic N. However, the range for the entire group of 107 samples extended from more than 50% down to negative values, i.e., net immobilization, in which inorganic N levels dropped below that observed in the unamended soil. The researchers did not find a relationship between the observed mineralization rates and any of the manure properties that they measured.

However, other researchers (for example, Gale et al. 2006) have shown that for prediction of N mineralization, manures and other organic wastes can be grouped into categories based on the conditions under which they were produced, treated, and stored. In research at UC Davis, Heinrich (2009) found some consistency in N mineralization within types of dairy manure -- e.g., solids separated by mechanical screen, windrow compost, corral manure, etc. These results and others provide some confidence that N mineralization values can be predicted within a useful range based on storage and handling prior to land application.

There is less research published on N mineralization of dairy lagoon water N than for solid manures. The values for lagoon water in Table 1 are consistent with the results of a four-year study at a Central Valley dairy in which shallow groundwater samples were collected from beneath an irrigated field (Harter et al., 2002). The researchers concluded that the observed levels of nitrate could only be explained by a relatively high rate of mineralization of the lagoon water organic N that had been applied. Also, the Table 1 lagoon water values are supported by a recent laboratory study (Heinrich, 2009) in which mineralization was measured on dairy lagoon water samples from which most of the ammonium had been removed.

Prediction of Manure N Mineralization for Other Time Intervals

Farmers in California – especially dairy producers – do not apply manure just once a year or once a season as is the practice in some other parts of the US. How can N mineralization patterns be predicted continuously over a year and for any desired time interval? UC scientists are developing a calculation tool that incorporates temperature effects and allows for choice of any application date and manure type (i.e., solid vs. liquid). This tool also includes (for a limited number of crop species and planting dates) the crop N uptake pattern, which then can be compared to the predicted pattern of manure N mineralization. The principles of this tool are described by Crohn (2006). It currently is in the development stage for use by the public.

Accounting for Long-term Mineralization of Manure N

The procedure described here for estimating short-term (12 months and less) mineralization is useful regardless of the history of past manure applications. But how can N budgets accommodate mineralization of organic N applied in previous years? In some states, growers are advised to include in N budgets credits for mineralization of manure applied in preceding years. Table 1 includes a Year 2 mineralization value to allow such a calculation. Beyond the second year (i.e., manure applied more than 1-2 years earlier), it is doubtful that such an approach will be helpful in constructing N budgets. Dairy producers in California typically apply both solid and liquid manure to crop fields year after year, leading to a build-up of organic N until a new "steady-state" mineralization is reached. The time required to reach this steady state depends on manure properties and climate, but it is likely to be on the order of 3-7 years under irrigated Central Valley conditions (Chang et al., 2007).

Two approaches for managing long-term mineralization are suggested here.

1) Steady-State Mineralization Approach

After enough time has passed (i.e., after a steady-state has been reached), the amount of N mineralized annually from the residual of all past years' manure applications will approach the total manure N applied each year. If approximately the same total and organic N quantities are applied each year, then the plant-available N will equal the total N applied (Chang, 2007; Crohn 2006) during the same one-year period. The short-term procedure based on Table 1 is still useful for providing some idea of the timing of N mineralization of manure applied in the current year.

In several situations, there will not be a steady-state, at least not one that can be identified, and the assumption that available N = total N applied will be questionable. This includes situations where (1) fields are receiving manure for the first time or have received manure infrequently, (2) manure application rates and timing have varied greatly from year to year, (3) fields are in a variable or long crop rotation, and (4) fields that in the past have received very high rates of manure are now receiving lower rates in order to comply with regulatory N loading limits. In these situations, it is necessary to use monitoring (e.g., soil testing and plant analysis) to determine the magnitude of the residual or "background" mineralization.

2) Crop Management and Monitoring Approach

Because mineralization continues year round (not only during periods of high crop N uptake), there is the potential for this N to be lost to leaching, runoff, or the atmosphere. It is important to maximize crop recovery of this residual manure N as it is mineralized. Because the pattern of mineralization cannot be predicted with adequate accuracy in many situations, monitoring and improved water management are required. The following strategies are suggested:

- Optimizing irrigation system performance (application efficiency and distribution uniformity) to reduce N leaching losses;
- Applying manure and dairy lagoon water uniformly to fields. Some field research suggests that repeated non-uniform application of dairy lagoon water can lead to build-up of organic N, e.g., at the upper end of fields where particles tend to settle out during lagoon water irrigation events.
- Using crop rotations that will result in crop N uptake during periods of rapid mineralization, i.e., when soil temperatures are higher. In on farm trials in the San Joaquin Valley conducted by UC Cooperative Extension, sudangrass planted following corn in the late summer and early fall has been shown to take up substantial amounts of N that would otherwise remain in the soil, posing an increased risk of leaching loss during the winter.
- Soil nitrate testing after crop harvest and during other periods of low crop N demand. This can be useful for assessing the background soil N supply capacity;
- Using soil testing and plant tissue analysis during the crop season to identify opportunities for eliminating, reducing, or delaying N fertilizer or dairy lagoon water applications;

Table 1. Guidelines for animal manure N mineralization in California.

	Year 1	**Year 2**
	-- % organic N mineralized---	
Dairy lagoon water	**40-50**	**15**
Dairy lagoon sludge and slurry; corral manure	**20-30**	**15**
Dairy mechanical screen solids	**10-20**	**5**

Aerobically composted cattle or horse manure (finished or mature)	**0-10**	**5**
Solid poultry manure	**50**	**15**

Notes to Table 1.

1. Mineralization values are based on limited research in California (Heinrich, 2009) and Oregon State University bulletin EM-8954e (Sullivan, 2008).
2. 50-80% of mineralization value will occur within the first 4-8 weeks following application (Andrews & Foster, 2007; Gale et al., 2006). It is suggested that the lower value (50%) be used for winter applications.
3. Dairy lagoon water N mineralization may be delayed if a significant proportion of solid particles remains on the surface of the soil, as may occur when lagoon water is applied during an irrigation without sufficient dilution with fresh water.

Sample Calculations: Plant-available Nitrogen (PAN) of Manure:

Example 1. Dairy corral manure with 30% moisture content, 1.8% total N and 0.05% ammonium N (both on a dry weight basis) is applied in early fall and incorporated by discing. How much plant-available N is applied per ton?

Ammonium content is low enough to ignore. Use 25% for Year 1 mineralization, which is the middle of the range shown in Table 1 for corral manure.

Each ton of manure at 30% moisture (i.e., 70% dry matter) contains 2000 x 0.70 = 1400 lb dry matter x 1.8% N = 25.2 lb N/ton x 25% mineralized in the first year = <u>6.3 lb PAN/ton manure at 30% moisture.</u> For example, a 10 ton/acre application would provide 252 lb total N/acre (10 x 25.2) and 63 lb/acre (10 x 6.3) of plant-available N during the first year. According to footnote 2 of Table 1, approximately 50-80% of this or 32-50 lb N/acre would become available during the fall and winter period, with the remaining 13-31 lb N becoming available later in the following spring and summer.

Example 2. Dairy lagoon water with a total N content of 500 mg N/liter and ammonium N (NH_4-N) content of 260 mg/liter is applied to silage corn during an irrigation. What is the plant-available N (PAN) content of this lagoon water?

Organic N content is total N minus ammonium N or 500-260 = 240 mg/liter. Assume that all of the ammonium is plant-available. From Table 1, the mid-range mineralization for dairy lagoon water is 45%, thus 0.45 x 240 = 108 mg/liter. <u>First year PAN for this lagoon water is 260 + 108 = 368 mg N/liter</u>. Note that this amounts to 74% (=368/500) of the total N in the lagoon water.

Because dairy lagoon water is usually applied during the crop growing season, crop managers will be more interested in the PAN during the weeks following the application than over a 12-month period. Based on the suggestion in Table 1, footnote 2, 50-80% of first year mineralization is equal to 54-86 mg N/liter (= 50% to 80% of 108); and this results in a short-term PAN estimate of 314-346 mg N/liter. Note that of this amount, 74-84% is ammonium N, and the remainder is the mineralized portion of the organic N.

If the lagoon water analysis is available to the crop manager prior to application, the estimated value of PAN can be used to calculate the number of gallons of lagoon water required to apply a desired rate of plant-available N.

References

Andrews, N. and J. Foster. 2007. User guide: Organic fertilizer calculator. EM 8936-E. Oregon State University. Corvallis, OR.

Chang, A. et al. 2007. Managing dairy manure in the Central Valley of California. Publication 9004, Division of Agriculture and Natural Resources. University of California. Oakland, CA.

Crohn, D. 2006. Optimizing organic fertilizer applications under steady-state conditions. J. Environ. Qual. 35:658-669.

Gale, E.S., D.M. Sullivan, C.G. Cogger, A.I. Bary, D.D. Hemphill, and E.A. Myhre. 2006. Estimating plant-available nitrogen release from manures, composts, and specialty products. J. Environ. Qual. 35:2321-2332.

Habteselassie, M.Y., J.M. Stark, B.E. Miller, S.G. Thacker, and J.M. Norton. 2006. Gross nitrogen transformations in an agricultural soil after repeated dairy-waste application. Soil Sci. Soc. Am. J. 70:1338-1348.

Harter, T., H. Davis, M.C. Mathews, and R.D. Meyer. 2002. Shallow groundwater quality on dairy farms with irrigated forage crops. J. Contaminant Hydrology 55:287-315.

Heinrich, A.L. 2009. Nitrogen fertilizer value of solid and liquid dairy wastes produced in California's San Joaquin Valley. M.S. thesis. Soils & Biogeochemistry. University of California, Davis. 139 pages.

Sullivan, D. 2008. Estimating plant-available nitrogen from manure. EM 8954-E. Oregon State University. Corvallis, OR.

Van Kessel, J.S., and J.B. Reeves III. 2002. Nitrogen Mineralization potential of dairy manures and its relationship to composition. Biology and Fertility of Soils 36:118-123.

Manure Nitrogen Mineralization. 2009. University of California Cooperative Extension Manure Technical Bulletin Series. http://manuremanagement.ucdavis.edu

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Appendix H

Manure Technical Bulletin Series
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Nitrogen Cycling on Dairies in California's Central Valley

Efficient use of nitrogen, more than for any other nutrient, is the key to profitability for dairy-forage production in California's Central Valley. Nitrogen also has the most potential of any nutrient to harm air and water quality, and therefore it is the target of government regulations. Although other nutrients in the crop-animal-soil system take on different chemical forms, the nitrogen cycle is the most complicated. Throughout the cycle, there are opportunities for gains and losses of N, many of which have the potential to cost money (by increasing fertilizer or feed costs) or degrade air and water quality (e.g., ammonium volatilization and nitrate leaching). A good understanding of N cycling can help farmers and other practitioners choose management techniques that will improve the whole-farm nutrient balance, by conserving nutrients and reducing losses.

Key Points

- *Typical N losses on Central Valley dairies range from 42 to 69% of total N excreted*
- *Reducing losses by 20% of excreted N could save $34,600/yr for an average sized Central Valley dairy*
- *The ONLY way to meet regulatory requirements and prevent crop N deficiency is to minimize field N losses.*
- *The N cycle is complex, with transformations into different forms and various points for N loss or gain*
- *Excess N in surface and groundwater can seriously impact human and environmental health*

NITROGEN TRANSFORMATIONS

A dairy farm is best seen as a system whose components all are linked, with nitrogen flowing between constituent parts and leaving or entering at various points (see Fig. 1). Feed N is transformed into milk protein (and meat protein in growing animals), with the remainder excreted as urine and manure. Approximately 35% of excreted N is urea[1] with the rest in more complex organic forms. Urea is converted very quickly (within hours) into ammonium by the enzyme urease, which is ubiquitous in soil and manure. The ammonium (NH_4^+) and remaining organic N then enters manure treatment and/or storage, with some losses along the way. Depending on its form, organic N is mineralized into NH_4^+ over a period of days to years. From manure storage, where the N is in both inorganic and organic forms, it is applied to fields on the dairy or exported from the farm.

Ammonium, either already present in the manure or as it is produced during mineralization of organic N, is available for plant uptake. However, it is more likely to be converted into nitrate (NO_3^-) by nitrifying bacteria in the soil before absorption by plants. Field losses of N can occur through volatilization of NH_4^+ and denitrification or leaching of NO_3^-. Nitrogen utilized by forage crops then completes the cycle when harvested for animal feed.

WHY MINIMIZE N LOSSES?

From a whole-farm perspective, minimizing N losses is associated with lower feed and fertilizer expenditures. N conserved on the facility or in the fields directly reduces the need for imports to the system. Feed N conversion to milk and N excretions depend on feed characteristics, milk production level, and animal health, with an average excretion rate for lactating cows in California of 1.0 lb N/head/day [1, 2][2]. Prior to any losses, a typical Central Valley dairy of 1000 cows[3] will generate 337,000 lbs of manure N each year. If recycled and used by crops with the same efficiency as commercial fertilizer N, it has a value (early 2009 prices) of approximately $173,000[4]. Reducing losses by 20% of excreted N therefore has a potential value of $34,600/yr[5]. For the same size dairy, over 62,000 lbs of phosphorus (142,000 lbs P_2O_5) are also excreted, although the full fertilizer value is not generally realized because N is more limiting in most cases. Potassium (K) and other nutrients in the manure may further increase the fertilizer value of the manure, if needed for the specific field or crop. Therefore, even if air and water quality were not environmental concerns, these benefits alone should warrant management changes to reduce nutrient losses. Obviously, where manure nutrients are applied to cropland beyond the point of agronomic benefit, the actual economic value will be non-existent; however some future benefit may be obtained if nutrients are "banked" in the soil.

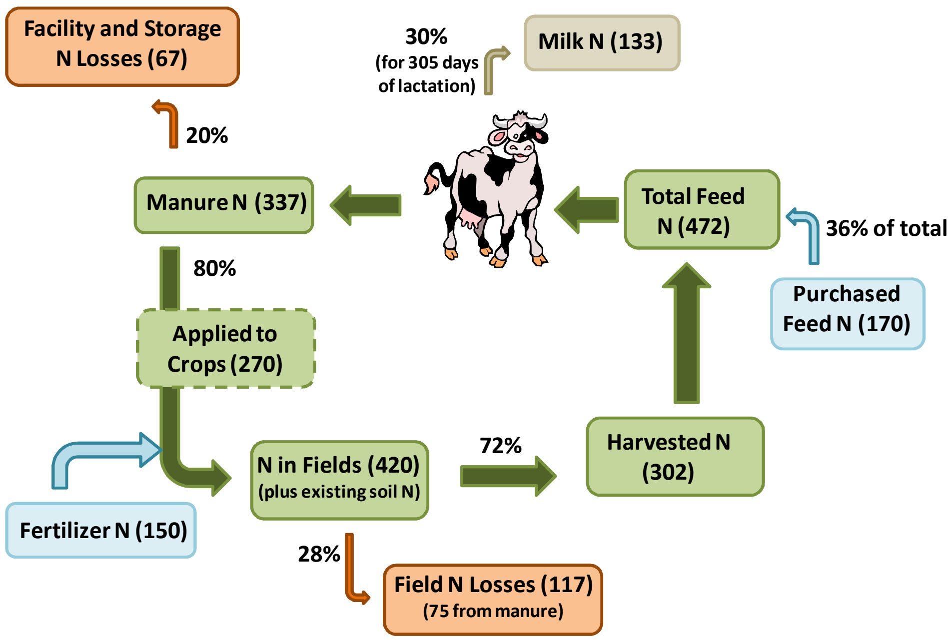

Figure 1. Hypothetical nitrogen cycle for a Central Valley dairy herd[6]. Units are lbs N/yr/cow.

Note: The indicated values assume high feed N conversion efficiency to milk as well as low facility, storage, and field losses. For simplification, the following flow pathways are not illustrated: imports or exports of animals and manure, legume associated N fixation, atmospheric N deposition, crop exports, changes in soil N reserves, and N in irrigation water.

On the other hand, regulations controlling N applications to fields receiving dairy manure are primarily in response to concerns over the public and environmental health effects of N losses to ground- and surface-water. Human health and quality of life is adversely affected by elevated N in drinking water. High ammonium (NH_4^+) concentrations in drinking water interfere with disinfection processes, and elevated nitrate and nitrite (NO_3^- and NO_2^-) concentrations are a potential health hazard for infants and pregnant women. When nitrate is transformed into nitrite and taken into the bloodstream, it prevents proper oxygen absorption, causing methemoglobinemia or "blue baby" disease. Excessive amounts of N and other nutrients in surface water also increase aquatic weed and algae growth, killing fish, causing offensive odors, and otherwise damaging natural ecosystems. While the main product of denitrification is nitrogen gas, it can also release nitrous oxide (N_2O), a key greenhouse gas that has 300 times the warming capacity of CO_2. Therefore, reducing N losses from the dairy/forage system can have diverse benefits – to the dairy's financial balance, drinking water, broader air quality, climate change, and wetland health.

WHOLE FARM N EFFICIENCY

The largest inputs of N to the dairy N cycle are purchased feed and fertilizer (see Fig. 1), with additional contributions from atmospheric deposition (rain), irrigation water, imports of bedding and animals, and biological N fixation by microbes in root nodules of alfalfa and other legumes. Unless a large proportion of manure or feed is transferred off the dairy, milk constitutes the single greatest intentional export of N (amounting to 25–30% of feed N). However, when feed production is out of balance with ration requirements or exceeds animal needs or (on the other hand) if crop acreage is insufficient for recycling of manure, dairy producers may transfer significant amounts of N off the dairy in the form of manure or feed/forage. Unplanned or unintentional losses of N to air and water can be considerable and are significantly impacted by management decisions.

Table 1 contrasts the N balance for four hypothetical dairies, including the example from Figure 1. All harvested N is assumed to be fed to animals, though in reality some losses can occur here as well. For purposes of simplicity, legume N additions and animal exports are not included, although in many cases legumes can significantly reduce the need for imports of feed or fertilizer N. Dairy A is the base case, with efficient feed N conversion, low N loss rates and sufficient land availability. The other three dairies demonstrate the impact of reduced feed N efficiency (Dairy B), higher N losses from facility and the land (Dairy C), and insufficient land for manure application and forage production (Dairy D). All of these issues require additional purchases of N, as fertilizer or as feed components. Feed N conversion varies from 25% to 30%, facility N losses vary from 20% to 40% of that excreted, and field N losses vary from 28% to 48% of that applied [2, pp. 20, 34, 48]. The land limitation of 0.28 acres/cow in Dairy D is the median non-alfalfa forage land availability for a sample of dairies in the Central Valley in 2002. At 2008 prices, Farms B, C, and D face additional N purchase costs of approximately $165, $117, and $330/cow/yr, respectively.

TYPICAL LOSS RATES AND INFLUENTIAL FACTORS

Dairy operations in the Central Valley differ significantly in animal housing, feed ration composition, manure treatment and storage, irrigation water flow rates, and manure distribution and application methods. All of these factors influence the variation in whole-farm N losses that typically range from 42% to 69% of the total N excreted in manure [2]. Table 2 summarizes current research on the range of N losses at different points and the impacts of different controlling factors.

Table 1. Nitrogen cycling on four hypothetical dairy farms with equal levels of milk and forage production, assuming 305 days lactating and 60 days dry. Dairy A is as shown in Figure 1.

	Dairy A	**Dairy B (↓feed efficiency)**	**Dairy C (↑losses)**	**Dairy D (↓land available)**
N in Cycle (lbs N/cow/yr)				
Feed N	472	561	472	472
Excreted N	337	426	337	337
Manure N applied to fields	270	341	202	170
Harvested N	302	302	302	123
Exports and losses (lbs N/cow/yr)				
Milk N	133	133	133	133
Calves born[a]	1	1	1	1
Manure exported	0	0	0	100
Facility losses	67	85	135	67
Field losses – from manure	75	95	97	48
Field losses – from fertilizer	42	22	182	0
Total N exported or lost	**320**	**337**	**548**	**349**
N imports (lbs N/cow/yr)				
Feed purchases	**170**	259	170	349
Fertilizer purchases	**150**	79	378	0
Total N imported [cost[b]]	**320 [$462]**	**337 [$628]**	**548 [$580]**	**349 [$793]**
Applied N : Harvested N Ratio	**1.4**	**1.4**	**1.9**	**1.4**
Assumptions[c]				
Feed N conversion efficiency (% feed N converted to milk in lactating cows)	30	25	30	30
Facility N losses (% of excreted N)	20	20	40	20
Field N losses (% of all applied N)	28	28	48	28
Feed N purchased (% of total)[d]	36	46	36	74
Forage land (acres/cow)[e]	0.69	0.69	0.69	0.28

[a] Assumes calves are exported from dairy directly after birth. Actual practice may impact feed and manure N.

[b] Cost of N imports is based on feed N of $2.27/lb and fertilizer N of $0.513/lb – calculated from available fertilizer and feed cost reports for 2008.

[c] The ranges used in N efficiency assumptions are based on ANR publication 9004 [2].

[d] Assumed and set at 36% for Dairy A [see 8]. Dairies B and C are assumed to have same amount of cropland and crop productivity and Dairy D has limited land – % of feed N purchased is then calculated.

[e] Calculated based on total annual harvested N removed of 440 lbs N/acre (average from BIFS project). Set at lower value for Dairy D.

Facility and Storage Losses

Up to 60% of excreted N can be lost by ammonia volatilization before the manure is even removed from the animal living quarters [9, 10], with highest loss rates observed where cattle are in dry corrals or large loafing areas and manure is left on the ground for days or weeks. However, research in California suggests that for a dairy with all manure entering an uncovered storage pond via flush lanes, the facility and storage N losses range from 20 to 40% [2].

Losses are also influenced by the design and operation of manure treatment and storage systems. More N is conserved when using manure water ponds – rather than solid systems – to handle the majority of manure. Under Central Valley conditions, within the commonly used freestalls and flushlanes, the maximum atmospheric N loss rate is approximately 35% [2, p. 31]. Estimated ammonia (NH_3) volatilization rates from storage ponds range between 2% (pH = 7.0, 25 ft depth) and 38% (pH=7.8, 10 ft depth) of total N excreted [2, p. 32], and are also impacted by the proportion of N in ammonia versus organic forms. Composting of manure can release large amounts of N (up to 50%) as volatilized NH_3 [11], and carbon-rich materials are sometimes added to immobilize N and reduce losses. Where nutrient recycling using nearby cropped fields is severely limited, systems have been designed to remove N by conversion into N_2 gas through alternating aerobic and anaerobic treatment reactors [12]. However, most anaerobic biogas reactors have negligible losses of N and convert much of the organic N into mineralized – and thus plant-available – forms [13].

Field Losses

Sufficient dilution of manure water reduces volatilization losses during field application, and experts suggest that NH_4^+ concentrations below 100 ppm in the irrigation water will result in minimal losses [2]. When applied to a field with a closed crop canopy, the crop can also absorb much of the NH_3 gas that does escape. Although NH_4^+ is adsorbed to soil and organic matter particles during infiltration, much of it does enter the soil profile, where it is converted into NO_3^- over a period of days. This initial adsorption prevents immediate leaching with excess irrigation water.

A greater concern is NO_3^--N leaching, since after conversion to NO_3^-, the N is readily soluble in the soil solution and susceptible to leaching with subsequent irrigation events. In the gravity flow irrigation systems common to the Central Valley, the best achievable irrigation application efficiency (amount of water that remains available to the crop) is 70 to 85%; the remaining 15 to 30% of the water leaches beyond the root zone [2, p. 43], taking soluble NO_3^- and other salts with it. Some leaching is necessary to move excess non-nitrate salts below the root zone and prevent crop damage. Rain may achieve this in some locations and in some years. Intentional leaching for the purpose of salt removal should be timed for periods when soil nitrate is low.

While some build-up of organic N in the soil can occur with regular manure additions, most fields on or near dairies are already at an equilibrium condition, with a constant level of organic N. This means that total N applied equals crop removal plus losses (denitrification and leaching). The proportion of losses due to leaching versus denitrification varies with soil characteristics, amount of irrigation water, amount of carbon in the soil, and other factors [14]. Studies in other regions have found total leaching losses to be 5 to 35 times greater than denitrification losses of N [15, 16]. In well-drained soils with relatively low organic matter content (typical of the Central Valley), leaching losses are the main concern. The timing of these nitrate-N losses is directly related to irrigation and precipitation and when NO_3^- is present in the soil solution, and applications targeted to crop uptake needs reduce losses. Cooler weather also slows mineralization and volatilization rates, reducing losses.

FARM-LEVEL ACTIONS TO REDUCE LOSSES

While producers cannot eliminate N losses, adaptations in facility design and operation can improve efficiency, save money, and reduce the transfer of N to air and water. Table 2 outlines the typical range of losses at various points in the dairy-forage system and the main factors that affect loss rates. Dairies will generally wish to address losses from facilities and losses from fields for different reasons. Attention to losses from the animal production and manure storage facilities will primarily impact the need for imports of N in feed and fertilizer and thus have a considerable financial impact. However, with the Central Valley regulatory limit on N applications, losses in the field are more critical. If field losses are not addressed, complying with the regulatory N loading limits will lead to crop N deficiencies and yield loss.

Farm-level actions to reduce N losses vary according to cost and efficacy (see Table 3). Nitrogen losses in animal housing facilities are significantly reduced when cattle spend the majority of their time in free stalls and the manure is flushed regularly [or "frequently"? How frequent?] into storage ponds. Most experts assume that manure excretion is distributed according to the amount of time cattle spend in each location. Therefore, increasing the time animals spend in areas where manure can be quickly removed will conserve N in the system. Loss rates in manure water storage ponds can be significantly reduced with dilution (lower NH_4^+-N concentrations), increased pond depth (reducing surface area to volume ratio), and lower pH (acidification).

Effective control of N losses in the field is essential in order to achieve good environmental stewardship, regulatory compliance, and healthy crop production. Field N losses can be most effectively controlled through measurement and control of manure application (again, see Table 3). The lessons learned by pioneering farmers and researchers suggest that applications should be spread out through the growing season where possible, especially in irrigated conditions and coarse-textured soils (e.g. sandy loam). Solid manure applications between crops can be used to bring nutrients further from the manure storage than is possible through the irrigation system. Timing and controlling manure water application during the growing season to coincide with crop N uptake needs can prevent build-up of excess NO_3^- in the soil and significantly reduce N leaching losses. Even distribution of manure nutrients is also essential to prevent crop nutrient deficiency.[7] While not directly related to loss prevention, both improvements in feed N utilization efficiency and increasing on-farm N production with legumes can also reduce N input costs.

Table 2. Nitrogen losses in dairy/forage system and factors impacting loss rates

Location in System	Range of Losses	Factors Impacting N Loss
Facility and Storage Losses of N to atmosphere		
Manure in corral/feedlot	Can lose 15 to 60% of total N [9, 10]	Temperature – N loss (mostly volatilization of NH_4^+) up to 60% higher with temp increase from 10°C to 25°C [9]
		Sprinkling with water to remove and dilute urine can reduce volatilization [17]
		Regular removal of manure from corral reduces losses: daily scrape and haul – 15 to 35% loss, versus open lot scraped quarterly – 40 to 60% loss [10]
Manure in freestalls, flush lanes and storage ponds	20 to 40% lost to atmosphere (primarily as NH_3) [2]	Increased flushing frequency and increased depth of storage pond reduces surface area for NH_3 volatilization [2, p. 30]
		Fresh water used for flushing and dilution in storage reduces NH_3 concentration and volatilization rates [2, 17]
		Inlet/loading system – ponds loaded from the bottom have significantly lower losses (3-8% of total N) than those loaded from top (29-39% of total N) [18]
		Lower pH in storage – losses can be reduced by six times when pH lowered from 7.8 to 7.0 [2, 17]
		Reduced residence time in storage pond reduces losses [2, p. 30]
Manure treatment systems	Up to 50% loss of total N with composting [11]	Low intensity (very little mixing) and anaerobic composting methods experience lower N loss than their alternatives. Total N losses in aerobic or high intensity manure composting reached 50%, while anaerobic and low intensity composting losses were only 26% and 5%, respectively [19] [11].
		Reduced pH and a higher C:N ratio are also associated with fewer losses [11, 19]
	Up to 95% of NH_4^+-N loss by conversion to nitrogen gas in batch reactors [12]	
Field Losses		
Ammonia volatilization after field application of manure water	Range from 3% to 33% of NH_4^+-N volatilized [2, 20, 21]. With typical diluted manure water in Central Valley, losses are near lower end of range.	Soil water content – greater losses in dry soil, e.g. NZ study with similar manure water to Calif. found 32% N loss in dry soil and 22% N loss in wet soil [22]
		Soil and air temperature – lower temperatures are associated with less volatilization
		pH – lower soil and manure water pH reduced volatilization rates [2]
		Nutrient concentration – dilution with fresh water significantly reduces losses [2, 23], e.g. less than 10% losses if diluted below 100 ppm NH_4^+-N [2], versus 24% to 33% lost with manure application of 2800 to 3100 ppm Total N [20]
		Increased frequency of applications – effectively the same as dilution
		Low wind conditions reduces volatilization
		Crop canopy can absorb gaseous NH_3 [2, p. 41]

Nitrate N in fields – leaching	Range from 10-15% loss to more than 50% of total N applied (all of excess N)	Volume of irrigation water – increased irrigation water application by 33% over that required by crop resulted in 3% to 8% increase in proportion of excess N lost by leaching, for liquid manure applications 400 to 1250 lbs N/acre in excess of crop needs [14] Improved irrigation efficiency (shorten check length, use torpedoes to speed water flow in furrows) and delayed introduction of manure into long irrigation times results in even distribution and reduced overall losses – useful where irrigation set times are at least four hours. Manure application frequency – more frequent applications with lower N concentrations results in less NO_3^--N in the soil, less to leach [2, p. 9] Time applications to meet crop N uptake needs – less NO_3^--N remains in the soil for leaching during following irrigation event
Nitrate N in fields - denitrification	Negligible in recent Central Valley experiments [2] 11 to 25% of applied manure N in other in year-round irrigated forage systems [14, 24-26]	Amount of N in excess of crop uptake – more excess N results in greater proportion lost to denitrification (versus leaching), e.g. up to 62% of excess N when applications were more than 1200 lbs N/acre greater than crop uptake [14] and from 32 to 114% of excess N with applications up to 230 lbs N/acre greater than crop uptake [25] Soil type – clay soil will have more denitrification than sandy soil, sandy soil will have higher leaching rates Soil moisture content – higher soil moisture increases denitrification [25] ; soil with high water table showed more denitrification than a well-drained soil [26] Available carbon – Central Valley soils have low C content and thus little energy source for denitrifying microbes

Table 3. Farm-level actions that may reduce N losses and N purchases/inputs for California dairies

Action	Comments
Animal Feeding and Housing	
Adjust feed composition	For dairies with excess feed N, reducing N intake to NRC recommendations can significantly decrease N excretion. Protein level reduction of 7 to 11% in a typical dairy cow diet can lower total N excretion by 5 to 18% without impacting milk production [27, 28]. Costs can be minimal, because of reduced feed purchases.
Bovine growth hormones, 3X/day milking or artificial light	While controversial for animal health and other reasons, rBGH/rBST, 3X/day milking or artificial light to extend photoperiod can improve feed N use efficiency by up to 8% (15% with all three actions combined) [27, 29].
Convert from corrals to free stalls with flush lanes	This can reduce N losses in animal housing facilities by 20 to 40%. Construction costs may be justified if the fertilizer N savings are sufficient (assuming land is available for nutrient application).
Manure Storage	
Increase depth of storage pond	An increase in depth from 10 to 25 ft can prevent the losses of from 1 to 15% of the N excreted [2], with greater impact at higher pH levels. Costs are significant, but could fit into already planned improvements or storage expansions.
Line storage ponds to limit leaching	This generally has minimal impact, and is quite costly or not practical with established ponds.
Reduce pH level of pond	Treatment to reduce pH from 7.8 to 7.0 could prevent losses of 9 to 31% of the N excreted [2].
Forage Fields	
Install flow meter and control valve, collect and analyze samples, control manure water application rates.	While also helping dairies to fulfill regulatory requirements, monitoring (and adjusting) manure N applications can improve distribution and reduce field losses by 20 – 70%. Costs include flow meter and valve installation, sample collection and analysis, and management; these are quite quickly covered by fertilizer cost savings.
Change timing of manure N application	Apply manure N to coincide with crop needs (i.e., pay attention to high growth periods). This likely requires dilution of manure water and increased application frequency.
Shorten check length, use torpedoes, or increase flow rates	These methods may improve irrigation efficiency and provide more even distribution of manure nutrients. Impact is greater in sandy texture soils, with possible reductions in deep percolation of up to 77% for shorter furrow lengths [30]. Increasing water flow rates or using torpedoes have less effect.
Delay manure injection into irrigation flows	Provides more even distribution of manure nutrients, fewer losses at the head of the field. This may be useful when it takes more than four hours for one irrigation set. Main cost is management of irrigation system.
Increase N fixation by legumes	Allows on-farm production of more high protein and N fixing forages such as alfalfa; deep roots of alfalfa also serve to "catch" nitrate that has leached downward [31]

TERMS

Absorption – being taken up by plants
Adsorption – clinging to organic matter or mineral materials in the soil
Denitrification – microbial process that converts nitrate (NO_3^-) or nitrite (NO_2-) into gaseous nitrogen (N_2), which then becomes part of the surrounding air; generally occurs in flooded or other low oxygen conditions

Eutrophication – aging (and "death") of surface waters at a more-rapid-than-natural pace due to elevated nutrient concentrations. Generally involves high algae populations that die and use up oxygen to then result in deaths of fish and other water creatures.
Leaching – process by which molecules (including nitrate-N) flow with water from the surface of the soil into lower depths. As a result, these molecules end up in underground aquifers or released to surface waters downstream.
Mineralization – process by which microbes break down organic products such as manure into inorganic forms, releasing plant nutrients, salts, and heavy metals; for example, organic N is broken down into ammonium (NH_4^+)
Oxidation – process by which microbes add oxygen to a reduced form of a molecule, often changing the charge and thus susceptibility to leaching; for example, ammonium (NH_4^+) is changed into nitrate (NO_3^-)
Volatilization – process by which ammonium N (NH_4^+) and other molecules pass from aqueous (in water) solution into gaseous phase, entering the air (NH_3 in this case). For ammonium, it is no longer available to plants and contributes to air pollution.

REFERENCES

1. American Society of Agricultural and Biological Engineers, *Manure Production and Characteristics*, in *ASABE Standard*. 2005, ASABE: St. Joseph, MI.
2. Harter, T., et al., *Groundwater Quality Protection: Managing Dairy Manure in the Central Valley of California*. 2007, Agriculture and Natural Resources, University of California: Oakland, CA. p. 178.
3. California Department of Food and Agriculture, *California Agricultural Resource Directory 2008-09*, A.G. Izumi, Editor. 2008, California Department of Food and Agriculture, Office of Public Affairs: Sacramento, CA. p. 93-113, Livestock and Dairy.
4. Brittan, K.L., et al., *University of California Cooperative Extension 2008 Sample Costs Produce Field Corn on Mineral Soils in the Sacramento Valley*. 2008, Department of Agricultural and Resource Economics, UC Davis: Davis, CA.
5. Miyao, G., K.M. Klonsky, and P. Livingston, *University of California Cooperative Extension 2008 Sample Costs to Produce Processing Tomatoes, Transplanted in the Sacramento Valley*. 2008, Department of Agricultural and Resource Economics, UC Davis: Davis, CA.
6. Williams, J.F., et al., *University of California Cooperative Extension 2001 Sample Costs to Produce Rice, Sacramento Valley, rice only rotation*. 2001, Department of Agricultural and Resource Economics, UC Davis: Davis, CA.
7. Campbell-Mathews, M., et al., *University of California Cooperative Extension 2001 Sample Costs to Produce Silage Corn, San Joaquin Valley*. 2001, Department of Agricultural and Resource Economics, UC Davis: Davis, CA.
8. James, T.A., et al., *Effects of dietary nitrogen manipulation on ammonia volatilization from manure from Holstein heifers.* Journal of Dairy Science, 1999. **82**(11): p. 2430-2439.
9. Adriano, D.C., A.C. Chang, and R. Sharpless, *Nitrogen loss from manure as influenced by moisture and temperature.* Journal of Environmental Quality, 1974. **3**(3): p. 258-261.
10. Van Horn, H.H., et al., *Dairy Manure Management: Strategies for Recycling Nutrients to Recover Fertilizer Value and Avoid Environmental Pollution*. 2003, Animal Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
11. Peigne, J. and P. Girardin, *Environmental impacts of farm-scale composting practices.* Water Air and Soil Pollution, 2004. **153**(1-4): p. 45-68.
12. Li, X. and R. Zhang, *Integrated anaerobic and aerobic treatment of dairy wastewater with sequencing batch reactors.* Transactions of the ASAE, 2004. **47**: p. 235-241.

13. Martin, J.H., Jr., *A comparison of dairy cattle manure management with and without anaerobic digestion and biogas utilization*, in *AgSTAR Program, US EPA*, K. Roos, Editor. 2004, Eastern Research Group, Inc.: Boston, MA. p. 59.
14. Pratt, P.F., *Estimated leaching and denitrification losses of nitrogen in a four-year trial with manures*, in *Nitrate in Effluents from Irrigated Lands*, P.F. Pratt, et al., Editors. 1979, University of California: Riverside, CA. p. 813.
15. Paul, J.W. and B.J. Zebarth, *Denitrification and nitrate leaching during the fall and winter following dairy cattle slurry application.* Canadian Journal of Soil Science, 1997. **77**(2): p. 231-240.
16. Whalen, S.C. and J.T. DeBerardinis, *Nitrogen mass balance in fields irrigated with liquid swine waste.* Nutrient Cycling in Agroecosystems, 2007. **78**(1): p. 37-50.
17. Bussink, D.W. and O. Oenema, *Ammonia volatilization from dairy farming systems in temperate areas: a review.* Nutrient Cycling in Agroecosystems, 1998. **51**: p. 19-33.
18. Muck, R.E., R.W. Guest, and B.K. Richards, *Effects of manure storage design on nitrogen conservation.* Agricultural Wastes, 1984. **10**: p. 205-220.
19. Mahimairaja, S., et al., *Losses and transformation of nitrogen during composting of poultry manure with different amendments: An incubation experiment.* Bioresource Technology, 1994. **47**(3): p. 265-273.
20. Beauchamp, E.G., G.E. Kidd, and G. Thurtell, *Ammonia volatilization from liquid dairy cattle manure in the field.* Canadian Journal of Soil Science, 1982. **62**: p. 11-19.
21. Bouwman, A.F., L.J.M. Boumans, and N.H. Batjes, *Estimation of global NH_3 volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grasslands.* Global Biogeochemical Cycles, 2002. **16**(2): p. 10.1029/2000GB001389.
22. Barkle, G.F., et al., *Fate of the ^{15}N-labelled faeces fraction of dairy farm effluent (DFE) irrigated onto soils under different water regimes.* Nutrient Cycling in Agroecosystems, 2001. **59**(1): p. 85-93.
23. Pain, B.F. and R.B. Thompson, *Ammonia volatilization from livestock slurries applied to land*, in *Nitrogen in organic wastes applied to soils*, J.A. Hansen and K. Henriksen, Editors. 1989, Academic Press: London. p. 202-211.
24. Davis, J.G., et al., *Nitrogen uptake and leaching in a no-till forage rotation irrigated with liquid dairy manure*, in *Animal waste and the land-water interface*, K. Steele, Editor. 1995, CRC Lewis Publishers: Boca Raton, FL. p. 405-410.
25. Lowrance, R., et al., *Denitrification from soils of a year-round forage production system fertilized with liquid dairy manure.* Journal of Environmental Quality, 1998. **27**(6): p. 1504-1511.
26. Paul, J.W. and B.J. Zebarth, *Denitrification during the growing season following dairy cattle slurry and fertilizer application for silage corn.* Canadian Journal of Soil Science, 1997. **77**(2): p. 241-248.
27. Jonker, J.S., R.A. Kohn, and J. High, *Dairy herd management practices that impact nitrogen utilization efficiency.* Journal of Dairy Science, 2002. **85**(5): p. 1218-1226.
28. Davidson, S., et al., *Effects of amounts and degradability of dietary protein on lactation, nitrogen utilization, and excretion in early lactation Holstein cows.* Journal of Dairy Science, 2003. **86**(5): p. 1681-1689.
29. Dunlap, T.F., et al., *The impact of bovine somatotropin, three times daily milking or extended photoperiod on nitrogen flows from dairy farms.* Journal of Dairy Science, 2000. **83**: p. 968-976.
30. Hanson, B. and L.J. Schwankl, *Surface Irrigation*. Water Management Series. Vol. publication number 94-01. 1995, Davis, CA: University of California Irrigation Program, University of California, Davis.

31. Schmitt, M.A. and K.A. Kelling, *Applying Manure to Alfalfa: Pros, Cons, and Recommendations for Three Application Strategies*, in *North Central Regional Research Report 346*. 2003, College of Agricultural and Life Sciences, University of Wisconsin-Madison: Madison, WI.

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[1] Approximately 50% of excreted N is in urine and 50% in feces. In the urine, 70% of the N is in urea [1, p.30].

[2] The excretion rate of 1.0 lbs/head/day assumes milk production of 88 lb/day. To calculate N excretion associated with different milk production rates, see ASABE Standards equations [1].

[3] In 2007, California's Central Valley had 1.59 million dairy cows (75% of state total), with an average of 1084 cows/dairy facility [3]

[4] 2008 UCCE costs studies indicated N cost of $0.55/lb N as aqua ammonia[4] and $0.745/lb N for UN-32[5]; in 2001 UCCE cost studies, costs for aqua ammonia (on rice) and anhydrous ammonia (on corn silage) were $0.30 and $0.28 per lb N, respectively[6, 7]. Using the same cost ratio, we assume 2008 anhydrous ammonia cost of $0.513/lb N.

[5] These calculations assume that fertilizer is the main purchase of N on the farm; this value increases with increasing proportions of purchased N in feed and feed supplements.

[6] Assumptions for Figure 1: (1) Average of 305 days lactating and 60 days dry, (2) Some feed purchases necessary to balance ration, assume 36% of total feed N as concentrate, consistent with James et al. [8], (3) Cows are 1400 lb Holsteins, (4) No replacement stock included in calculations, and (5) N excretion values based on ANR Publication 9004 [2].

[7] See bulletin on irrigation system design and performance

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