# DAIRY LAGOON WATER VERSUS ANHYDROUS AMMONIA FOR CORN SILAGE PRODUCTION AND SOIL NITROGEN MANAGEMENT

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**ABSTRACT**

*Environmentally sustainable management of dairies is critical to the economic health of California's agriculture. A major upcoming challenge is the planning, implementation, and documentation of nutrient management practices for the proposed federal regulations for concentrated animal feeding operations to control water pollution. The current project focuses on understanding the link between dairy waste management and shallow groundwater quality, and on developing improved dairy waste management methods that will ensure that impacts on groundwater quality are minimized. One study site consisted of eight irrigation checks in a field on a cooperating dairy. Four checks were farmed according to standard grower practice which utilizes pre-irrigation applied liquid manure plus water run anhydrous ammonia. The second treatment involved using only dairy lagoon water (five applications of 50 lbs $NH_4$-N) (organic N was not credited). The two treatments were assigned in a randomized complete block design with four replications. The improved lagoon water treatment was also implemented on two entire fields to monitor impacts on groundwater quality. Existing and new monitoring wells of the shallow groundwater were placed both upgradient and downgradient of the fields as well as in between the two fields. Soil sampling, corn nitrogen uptake and forage yield samples were taken at two sites within each of the three irrigation checks located in the two fields similar to the replicated site. Corn grown with the lagoon water alone and pre-irrigation with lagoon water plus anhydrous ammonia nitrogen treatments had the same yield, 42-44 tons silage/A in 1998. Soil and plant samples confirm that the soil was supplying large amounts of nutrients and that larger than desirable nitrate-N remained in the lower part of the root zone at the end of the growing season. Growing conditions were less favorable in 1999 and yields were 30-35 tons/A with both treatments having the same yields. Moderately excessive ammonium- plus nitrate-N concentrations were present in the initial soil samples with the amounts remaining at the end of the 1999 corn growing season under both treatment regimes being only slightly lower than post harvest profile concentrations in 1998. In 2000, lower rates of nitrogen were applied, yields were generally in the 30-35 tons per acre range and slightly lower soil profile nitrogen concentrations were found. The demonstration fields recorded similar corn yields for the three years with variable amounts of applied nitrogen and crop nitrogen uptake accounting for only some of the changes in soil ammonium- plus nitrate-N concentrations in the top 4 feet of soil. These data can certainly lead one to speculate how significant quantities of nitrate-nitrogen appear in the shallow groundwater.*

## INTRODUCTION

California has the highest dairy production of any state in the United States and dairy products lead all segments of California agriculture in commodity value. Environmentally sustainable management of these dairies is critical to the economic health of California's agriculture. A major upcoming challenge is the planning, implementation, and documentation of nutrient management practices for the proposed federal regulations for concentrated animal feeding operations to control water pollution (EPA, 2000). Meyer and Schwankl (2000) present a case study to improve dairy manure utilization in nutrient management schemes in the southern San Joaquin Valley. The dairy areas of Stanislaus and Merced Counties (northern San Joaquin Valley) in particular have had a long-standing history of nitrate and salt problems in their well water (Lowry, 1987). Approximately 25% of the dairy cattle in California are located in these counties (CDFA, 1996). Pratt (1979) suggested five factors as criteria for judging the relative sensitivity to leaching of nitrate from irrigated lands. A large portion of the dairy areas of Stanislaus and Merced Counties have three factors in the highly sensitive and two in the medium sensitive categories (Coppock and Meyer, 1980). Page and Boulding (1973) had indicated earlier the area was more susceptible to groundwater nitrate contamination than other areas, because soils are predominantly sandy and depth to groundwater is mostly shallow. A significant number of wells used as drinking water resources for dairy cattle approach $NO_3$-N levels of 23 mg/l (Lowry, 1987). In shallow water $NO_3$-N concentrations are commonly between 50 mg/l and 100 mg/l (Davis, 1995).

Preliminary estimates of the nitrogen budget on selected dairies in Stanislaus and Merced County show that nitrogen surplus on individual dairies varies from 55 lbs N/A to 380 lbs N/A (RWQCB, 1998). Assuming a net leaching rate of approximately 2 A ft/A with only a 60% irrigation efficiency (Campbell and Schwankl, 1989), this translates into estimated average leachate concentrations of 10 mg/l $NO_3$ -N on the dairy with the lowest nitrogen surplus to 75 mg/l $NO_3$-N on the dairy with the largest nitrogen surplus. While these values reflect the variability of nitrate values observed in shallow groundwater under the dairies in the area, they do not reflect differences in measured groundwater nitrate concentrations between dairies. In fact, nitrate concentrations in groundwater below dairies with low nitrogen surplus vary within a similar range and are as high as those below dairies with a large nitrogen surplus.

Our current project, (Campbell-Mathews, M., R. D. Meyer and T. Harter, 1999 and Harter, T., R. D. Meyer and M. Campbell-Mathews, 1999) focuses on understanding the link between dairy waste management and shallow groundwater quality, and on developing improved dairy waste management methods that will ensure that impacts on groundwater quality are minimized. Shallow groundwater quality has been monitored on five cooperating dairies in the San Joaquin Valley. Waste management practices on these five dairies are considered to be representative of many dairies, particularly in the northern San Joaquin Valley. Groundwater underneath the dairies is very shallow (6 to 10 ft.), soils are predominantly sandy and irrigation systems promote large drainage volumes. Consistent with previous reports, nitrate levels in the most shallow groundwater are found to be elevated. Seasonal trends in nitrate concentration are indicated in observation wells near lagoon water managed fields. Besides seasonal changes, however, no discernable trend was observed in the average nitrate concentration over the first three year observation period. The data suggests that significant amounts of nitrate leaching takes place in fields receiving excess manure water applications. Less is known about potential nutrient leaching from corrals and ponds, although both have been shown to contribute some nitrate to groundwater. More recently there has been a dramatic decline in shallow groundwater nitrate concentrations as the result of intensive lagoon water nutrient management on the demonstration fields (Harter, T., M. C. Mathews and R. D. Meyer, 2001). Work is considered to be ongoing and results are preliminary.

The second major component of our project deals with the improvement in dairy lagoon water nutrient management. Most dairies handle a large percentage of their manure as pond water derived from flush systems in the freestall barns. Many of the dairy facilities have been in operation since the 1960s and 1970s and have increased in herd size without increasing the capacity of the dairy lagoons. Consequently, to keep the pond from overflowing in the winter, many dairy operators find it necessary to apply the lagoon water to the winter forage crop in quantities that far exceed the ability of the crop to utilize the nitrogen. The effect of excess application of pond water is evident in increased concentrations of nitrate in the groundwater under these fields (Harter et al., 1999). Lagoons were for the most part designed with large valves to empty quickly into existing irrigation pipelines (36-42" diameter) and as such it becomes difficult to deliver the small flow rates necessary to apply nutrients to meet crop need. In some cases pipelines were laid out so that adequate mixing of lagoon water and irrigation water cannot be accomplished. This often resulted in nutrient deficient crops and subsequent discrediting of nutrients contained in lagoon water. Thus both the control of volume and nutrient concentration of the lagoon water as well as what was applied on the field became very difficult if not impossible to manage. Corn silage is grown in the summer on most dairies. Because it could be applied more uniformly in the field, water run anhydrous ammonia fertilizer was found easiest to meet the nitrogen requirements of the summer crop. Although some lagoon water is applied to the corn, the common practice in the area is to apply manure water without crediting it as a source of nutrients, particularly nitrogen. As the ability to measure volumes of irrigation and lagoon water as well as the concentrations of ammonia and organic nitrogen are improved, the next major challenge to reduce the amount of nitrogen moving below the crop root zone was to assist growers in the decisions regarding the rates and timings of lagoon water application. Growers do not want to risk under-fertilization of their crop. All of these practices--winter applications of lagoon water, not compensating for manure applications, and inability to apply adequate nutrients to the crop uniformly--contribute to the excessively high nitrate concentrations measured in the shallow groundwater of the area.

## OBJECTIVES

1. Evaluate dairy lagoon water alone as compared to the conventional pre-irrigation with lagoon water (ignoring nutrient content) plus anhydrous ammonia for the production of forage (corn in summer and cereals in winter) crops.
2. Develop several methods for in-field rapid determination of ammonium, the primary immediately available nitrogen component of dairy lagoon water as well as recording the organic nitrogen, and demonstrate its use in substituting lagoon water nitrogen sources for anhydrous ammonia fertilizer.
3. Develop practical procedures for estimating flow of irrigation and lagoon water throughout the course of an irrigation, and demonstrate how these can be used in conjunction with ammonium and other nutrient determinations to calculate the amount of crop nutrients being applied to a field.
4. Manage a demonstration area with the effective use of dairy wastewater for the production of forage crops large enough to show improvements in groundwater quality as a result of using these sustainable practices.

**METHODS**

One study site consisted of eight irrigation checks (each measuring approximately 150 feet wide by 1200 feet long) in a field on a cooperating dairy. Four of the eight irrigation checks were farmed according to standard grower practice which utilizes water run anhydrous ammonia fertilizer (five applications of 50 lbs N/A) without counting the pre-irrigation applied liquid manure as a source of nitrogen for the crop (conventional treatment). The remaining four irrigation checks were farmed using only dairy lagoon water as the primary nitrogen source (five applications of 50 lbs $NH_4$-N/A) (organic N was not credited because of the unknown release rate). The two treatments were assigned in a randomized complete block design with four replications. Nitrogen applications from pond water on the winter crop were monitored using the same techniques as for the corn crop. For each irrigation in which nitrogen was applied; flow, concentration of nutrients, and irrigation times were closely monitored and recorded. Mixed irrigation/lagoon water samples were collected and analyzed for ammonium and electrical conductivity (EC) in the field and in the laboratory for ammonium and total nitrogen content, as well as EC and other constituents as appropriate. One to four water samples per check were taken at the valve of both lagoon and anhydrous irrigation water treatments to determine the rate of nitrogen application. Samples were also taken to monitor lagoon water nitrogen application rate and the crop nitrogen uptake throughout the winter forage growing season. Irrigation advance and recession times were recorded on selected checks and irrigations to give an indication of the uniformity of applied water and nutrients.

Soil samples were taken soon after the winter forage crop was harvested, before most irrigations throughout the corn growing season and after the corn was harvested (9 times in both 1998 and 1999 and 6 times in 2000). Soil samples were taken from a subplot within each of six irrigation checks and at two subplots within each check (12 subplots). At each subplot and each sample date, 12 cores were taken from the 0”-6” depth and the 6” - 12” depth, while 6 cores were taken from the 12”-24”, 24”-36”, and 36”-48” depths. For each depth, cores from each subplot were composited at the time of sampling, thoroughly mixed, and a subsample analyzed for ammonia-nitrogen and nitrate-nitrogen. Soil moisture measurements were taken to express final analyses on a soil dry weight basis. Ammonia-N and nitrate-N were determined after equilibrium extraction of soil with two molar potassium chloride and subsequent determination by diffusion-conductivity (Carlson, 1978; Keeney and Nelson, 1982).

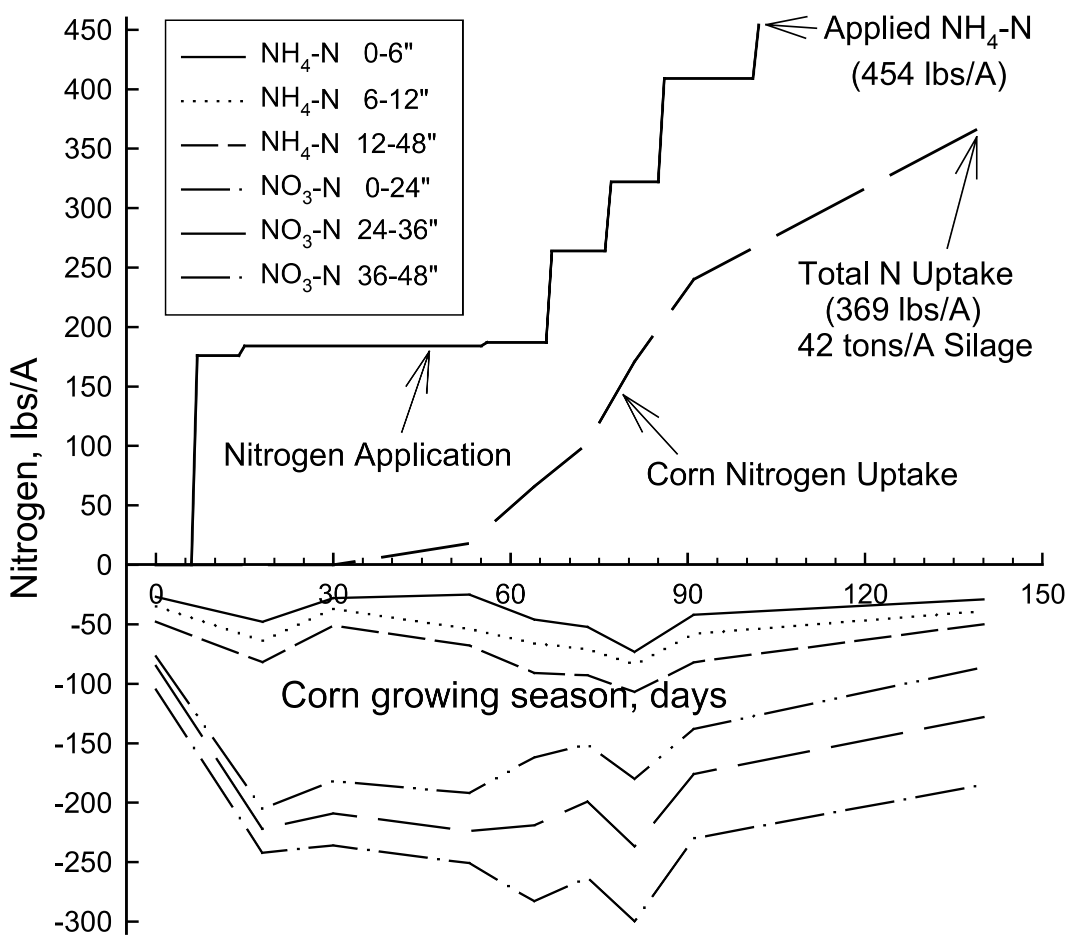
At each of the locations where soil samples were collected, 25 feet of one corn row was cut, weighed, subsampled and weighed, dried and weighed to determine moisture content, ground and submitted to the laboratory for nutrient analysis. These samples were collected on each soil sample date after the corn reached a height of 12-15”. Corn leaf samples which serve as indicators of the nitrogen status of the crop were taken 3-4 times during each growing season. Final harvest samples were collected as field chopped silage blown on the ground at the site of the soil sampling location and sampled for nutrient analysis (Gavlak et al., 1994). Corn yields were determined by weighing every silage truck coming from each check, measuring the harvested area, and correcting for moisture.

The improved lagoon water treatment was also implemented on two entire fields (approx. 50 acres total) to monitor impacts on groundwater quality. These demonstration fields were managed by the same grower and located near the replicated treatment field. Existing and new monitoring wells of the shallow groundwater were placed both upgradient and downgradient of the fields as well as in between the two fields. Soil sampling, corn plant uptake and final forage harvest samples were taken at two sites within each of the three irrigation checks located in the two fields.

**RESULTS AND DISCUSSION**

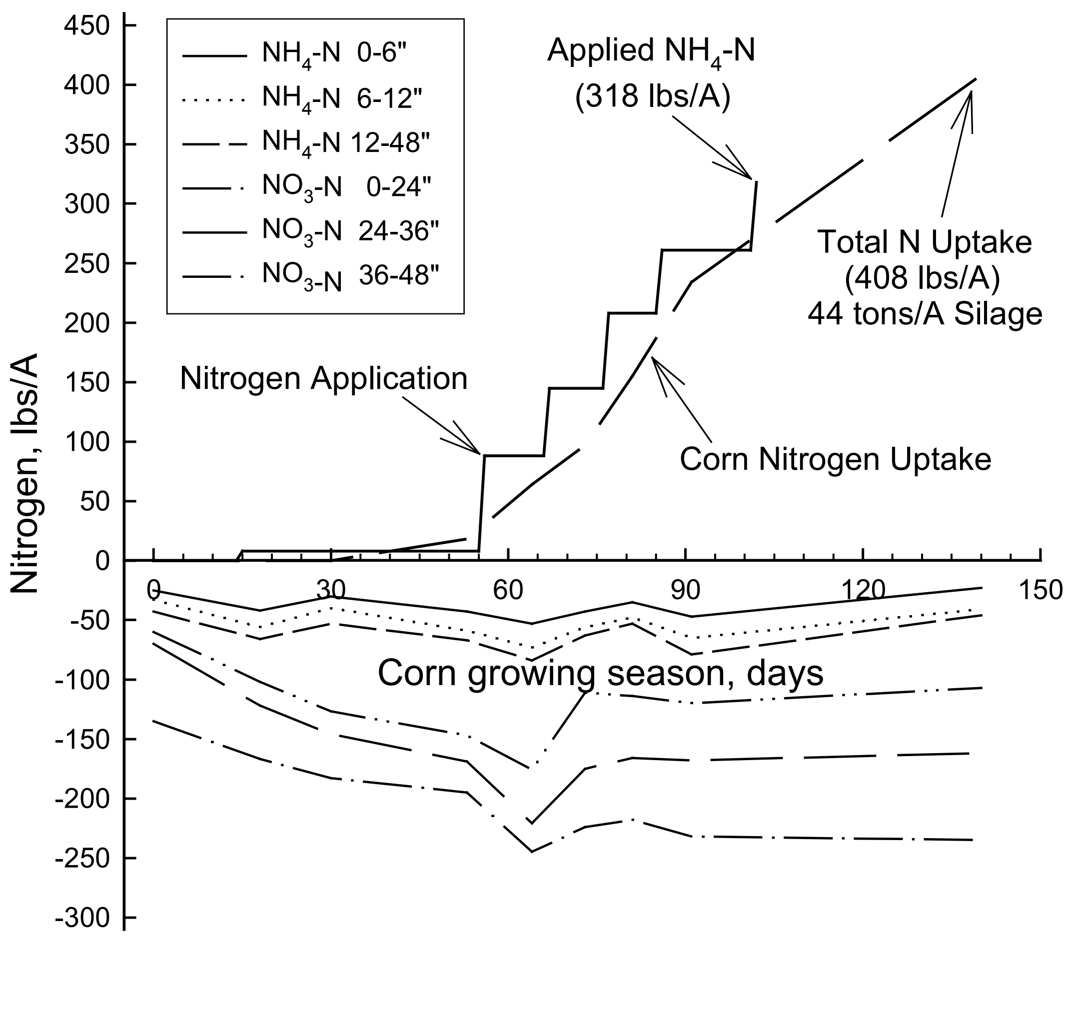
Corn grown with the lagoon water alone and pre-irrigation with lagoon water plus anhydrous ammonia nitrogen treatments on the replicated field had the same yield, between 42-44 tons silage/A (70% moisture) in 1998 (Figure 1 and 2), well above the county average of 27.2

Figure 1. Corn yield and uptake of nitrogen, applied ammonia nitrogen from pre-irrigation lagoon water and anhydrous ammonia fertilizer, and soil ammonium and nitrate nitrogen in the surface four foot of soil throughout the 1998 growing season. (Day 0 was April 29)



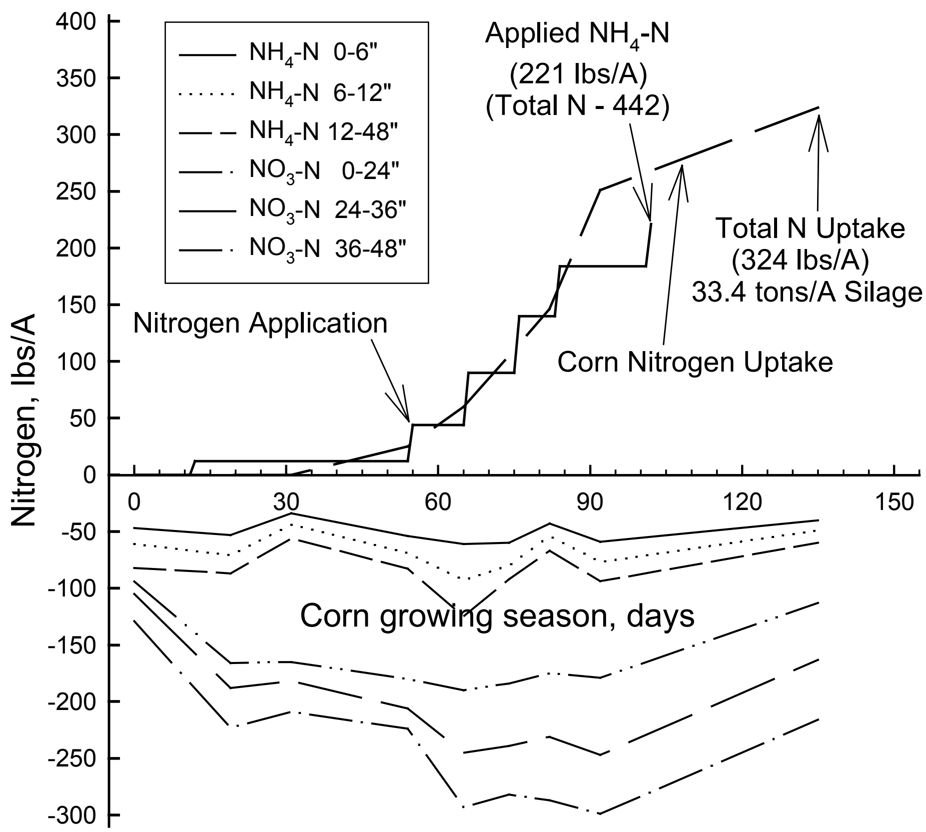

tons/A, and an exceptional yield for corn produced on sandy soils. This field has had a history of large applications of lagoon water. Soil and plant samples confirm that the soil was supplying large amounts of nutrients and that larger than desirable nitrate-N remained in the lower part of the root zone at the end of the growing season. Growing conditions were much less favorable in 1999 and corn silage yields were in the 30-35 tons per acre range with both treatments having the same yields. Moderately excessive ammonium- plus nitrate-N concentrations were present in the initial soil samples taken after the winter forage crop. The amounts remaining at the end of the 1999 growing season were nearly the same as the amounts present at the beginning under both treatment regimes and only slightly lower than post-harvest profile concentrations in 1998. In 2000, lower rates of nitrogen were applied, corn growing conditions were less favorable, yields were generally in the 30-35 tons/A range and slightly lower soil profile nitrogen concentrations were found.

Figure 2. Corn yield and uptake of nitrogen, applied ammonia nitrogen from lagoon water, and soil ammonium and nitrate nitrogen in the surface four foot of soil throughout the 1998 growing season. (Day 0 was April 29)




The average corn yield, uptake of nitrogen, applied ammonium-nitrogen from lagoon water, and soil ammonium- and nitrate-nitrogen in the surface four foot of soil throughout the 1998 growing season in the demonstration fields is given in Figure 3. The data for the 2000 growing season is given in Figure 4. Yields were similar for the three years 33.4, 32.0 and 29.7 tons/A for 1998, 1999 and 2000 respectively. Applied ammonium-N was similar for 1998 and 1999, 221 and 241 lbs N/A respectively but somewhat lower in 2000 (189 lbs N/A) with total nitrogen being 442 (est.), 548 and 343 lbs N/A for the 1998, 1999 and 2000 seasons. Crop uptake of nitrogen was 267 lbs N/A for 1998, 282 lbs N/A in 1999 and 267 (est.) lbs N/A in the 2000 season. Soil ammonium- and nitrate-nitrogen in the surface four foot of soil increased throughout the 1998 growing season by nearly 100 lbs N/A, approximately 70 lbs N/A in 1999 and nearly 100 lbs N/A in 2000. Several disturbing features can be drawn from Figure 4. Since the soil samples are

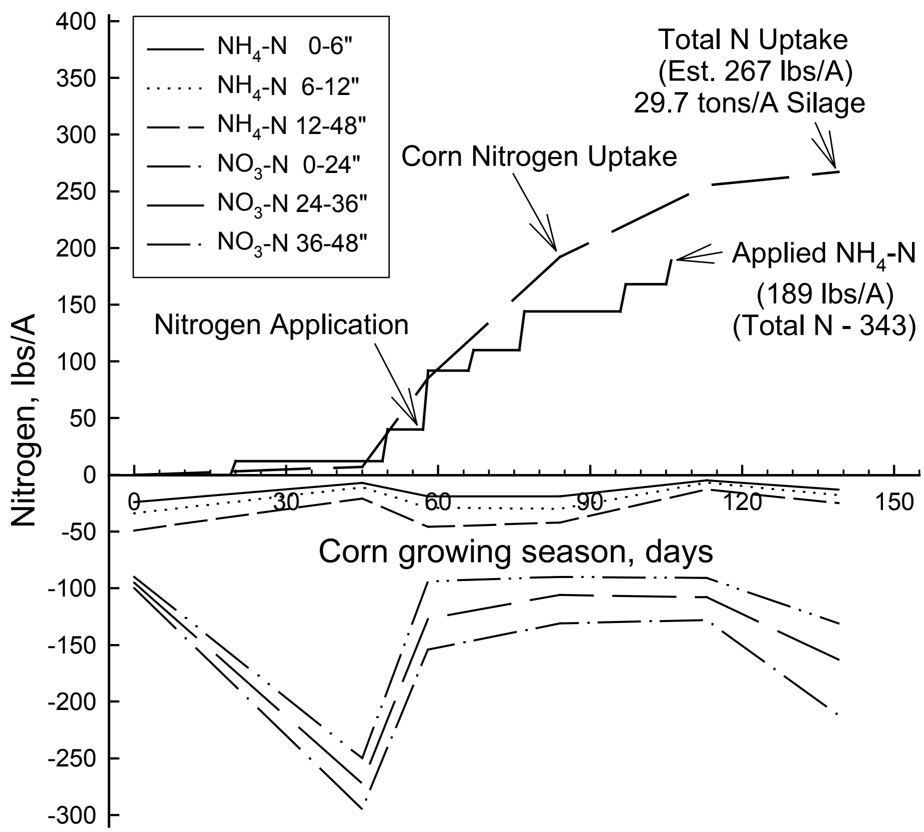
Figure 3. Corn yield and uptake of nitrogen, applied ammonia nitrogen from lagoon water, and soil ammonium and nitrate nitrogen in the surface four foot of soil throughout the 1998 growing season in the demonstration fields. (Day 0 was April 28)




usually taken from 1-3 days prior to the next irrigation, it certainly raises the question of whether a considerable portion of the nitrate-N (approx. 225 lbs N/A) in the top 2 feet on day 45 was leached below 4 foot depth by the sampling on day 60 when only about 100 lbs $NO_3$-N/A remained in the top 4 feet. It can be seen however that nearly 100 lbs N/A was taken up by the developing corn crop but an equal amount of nitrogen was applied over the same time period.

The other disturbing feature is the nearly 70 lbs $NO_3$-N/A increase in the top 4 feet of soil at the end of the growing season. It is doubtful the winter grown cereal crop will be able to utilize very much of the existing soil nitrogen because winter rains and cool temperatures will prohibit much growth prior to a spring irrigation which will move the nitrates in the 3rd and 4th foot beyond the root zone. These data can certainly lead one to speculate how significant quantities of nitrate-nitrogen appear in the shallow groundwater.

Figure 4. Corn yield and uptake of nitrogen, applied ammonia nitrogen from lagoon water, and soil ammonium and nitrate nitrogen in the surface four foot of soil throughout the 2000 growing season in the demonstration fields. (Day 0 was April 26)




**REFERENCES**


California Department of Food and Agriculture. 1996. California Dairy Industry Statistics.

Campbell, M. and L. Schwankl, et al. 1989. Corn water management study conducted in cooperation with Turlock Irrigation District.

Campbell-Mathews, M., R. D. Meyer and T. Harter. 1999. Using dairy lagoon water to replace commercial fertilizers. Proceedings, 1999 California Plant and Soil Conference, California Chapter of American Society of Agronomy and California Fertilizer Association, Visalia, California. pp 133-139.

Carlson, R. M. 1978. Automated separation and conductimetric determination of ammonia and dissolved carbon dioxide. Anal. Chem. 50:1528-1531.

Coppock, R. and R. D. Meyer. 1980. Nitrate losses from irrigated cropland. Div. of Agri. Sci. University of California. Leaflet 21136. pp 23.

Davis, H. H. 1995. Monitoring and evaluation of water quality under Central Valley dairy sites. Proceedings, 1995 California Plant and Soil Conference, California Chapter of American Society of Agronomy and California Fertilizer Association, Visalia, California. pp 158-164.

EPA, 2000, National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitations Guidelines and Standards for Concentrated Animal Feeding Operations, Proposed Revisions, Dec. 15, 2000; http://www.epa.gov/owm/afos/proposedrule.htm

Gavlak, R. G., D. A. Horneck and R. O. Miller. 1994. Plant, soil, and water reference methods for the Western Region. University of Alaska Cooperative Extension Service Western Regional Extension Publication 125.

Harter, T., R. D. Meyer and M. Campbell-Mathews. 1999. Shallow groundwater quality under dairies in Merced and Stanislaus County. Proceedings, 1999 California Plant and Soil Conference, California Chapter of American Society of Agronomy and California Fertilizer Association, Visalia, California. pp 122-127.

Harter, T., M. C. Mathews and R. D. Meyer. 2001. Dairy nutrient management effects on groundwater quality: A case study. Proceedings, 2001 California Plant and Soil Conference, California Chapter of American Society of Agronomy and California Fertilizer Association, Fresno, California. (In press).

Keeney, D. R. and D. W. Nelson, Nitrogen-inorganic forms, *In*: A. L. Page (ed.), Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties, Monograph Number 9 (Second Edition), p 643-698, ASA, Madison, WI, 1982.

Lowry, P. 1987. Hilmar Ground Water Study, CVRWQCB Files. pp 56.

Meyer, D. and L. J. Schwankl. 2000. Liquid dairy manure utilization in a cropping system: A case study, *In*: Land Application of Agricultural, Industrial and Municipal By-Products, SSSA Book Series No. 6, 409-422, Madison, WI.

Page, R. W. and G. O. Boulding. 1973. Geology and quality of water in the Modesto-Merced Area, San Joaquin Valley, California, U. S. Geological Survey Water Resources Investigations 6-73, pp 85.

Pratt, P. F. 1979. Nitrate in effluents from irrigated lands. Final Report to the National Science Foundation. pp 637-683.

RWQCB. 1998. Central Valley Dairy Waste Study, Merced and Stanislaus Counties, California. Final Report, in preparation.