Development of a Mass Balance Model – Case Study University Agricultural Lab (UAL) at CSUF

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Introduction

At present, non-point source pollution is considered to be the biggest threat to the sustainable development of agriculture and to both surface and underground drinking water sources. agricultural activity is considered to be one of the main causes for the surface water pollution. Pollution caused by the fertilizer use has become a serious issue. With the increasing demand of food, the use of fertilizer is increasing for higher crop yield to cope with this demand.
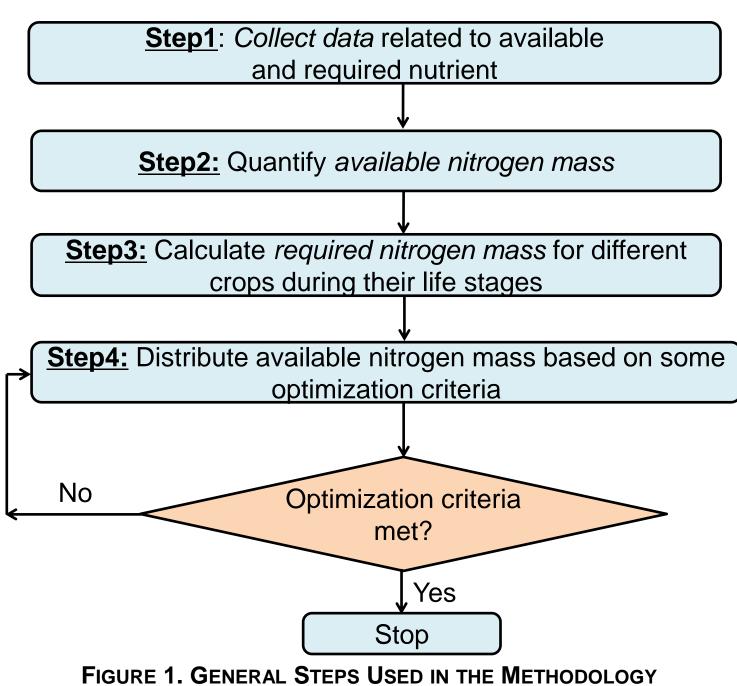
Central Valley of California is renowned for its agricultural production. A significant amount of land in the Central Valley is cultivated not only for the different types of crops but also for the animal grazing. For both purposes water and nutrient are the key components. The question that seeks answer is; can the nutrient or the effluent produced from the animal grazing or dairy farm be used as a fertilizer for other crops? Just discharging this effluent containing high concentration of nutrient to the stream or lake can impair the quality of in-stream or lake water causing severe environmental impacts. Preserving water for sustainable future is not a slogan any more it is a burning question for all the water users including the agricultural community. The agricultural communities are embracing various water resources management practices to preserve the water for sustainable future.

On-farm drainage management can be a such practice in which the effluent full of nitrate, ammonia, and other nutrients from rangeland or dairy farm can be used as fertilizer for other crops. This practice not only provides irrigation water but also supplies nitrogen and other nutrients to the crops, necessary for their high yields. This measure reduces the environmental wastes to the air and surface water and groundwater as well. Hornbuckle et al (2005) showed the benefits of controlled drainage from the past and into the future including better crop production, less disposal problems, minimal salt mobilization below the root zone, improved irrigation water use efficiency, and minimization of drainage costs. Shouse et al (2009) explained how the disposal of agricultural effluent can be expensive and harmful to the environment. How a water management practice can be developed to reduce the effluent resulting less pollution are explained.

This study calculates total nitrogen available in the effluent from a dairy farm and also nitrogen requirements for various types of crops in different life stages. A mass balance model is set up to quantify and distribute the available mass. The mass balance model is capable of quantifying the mass at different points of time and space. The model is applied to the University Agricultural Laboratory (UAL) of California State University, Fresno.

Methodology

Methodology involves four steps. Data related to available nutrient from effluent and the nutrient requirement for different crops is collected in step 1. From nutrient data available nitrogen mass is calculated in step 2. Step 3 calculates the required nitrogen amount. In this step the required nitrogen mass is calculated for each crop during its different life stages first. Then the monthly average nitrogen mass is calculated for four different categories of crops. Please note that crops are broadly classified into four categories. Finally the available nitrogen mass is distributed to different crop fields based on some criteria defined in the optimization scheme in step 4

Criteria to distribute available nitrogen mass includes distance from source, crop field area, crop yield, and revenue. Figure 1 shows the flowchart of the methodology. An objective function will be set up and the value of the objective function will be quantified for each combination. Based on the criteria there might be many combinations. The objective value for each combination will be checked and compared each other. The combination that results most favorable will be chosen.

Step1: *Collect data* related to available and required nutrient

Step2: Quantify *available nitrogen mass*

Step3: Calculate *required nitrogen mass* for different crops during their life stages

Step4: Distribute available nitrogen mass based on some optimization criteria

Optimization criteria met?

No

Yes

Stop

FIGURE 1. GENERAL STEPS USED IN THE METHODOLOGY

Case Study

University Agricultural Laboratory (UAL) is located at California State University Fresno (Fresno). Specifically, the UAL is located in the City of Fresno on north-south direction between Barstow and Sierra Ave and on the east-west direction between Cedar and Willow Ave. The total farming land is about 760 acres. The Figure 2 shows the campus farm (i.e., UAL) and the selected crop fields. The dairy farm is located near the northwest corner of the intersection of Barstow and Chestnut Ave. The dairy farm was established in 1954. It maintains two different breeds of dairy cattle, the Holstein and the Jersey. There are approximately 300 cows. About 150 of these cows are used in the milk string, and each cow in the milk string is milked twice a day.
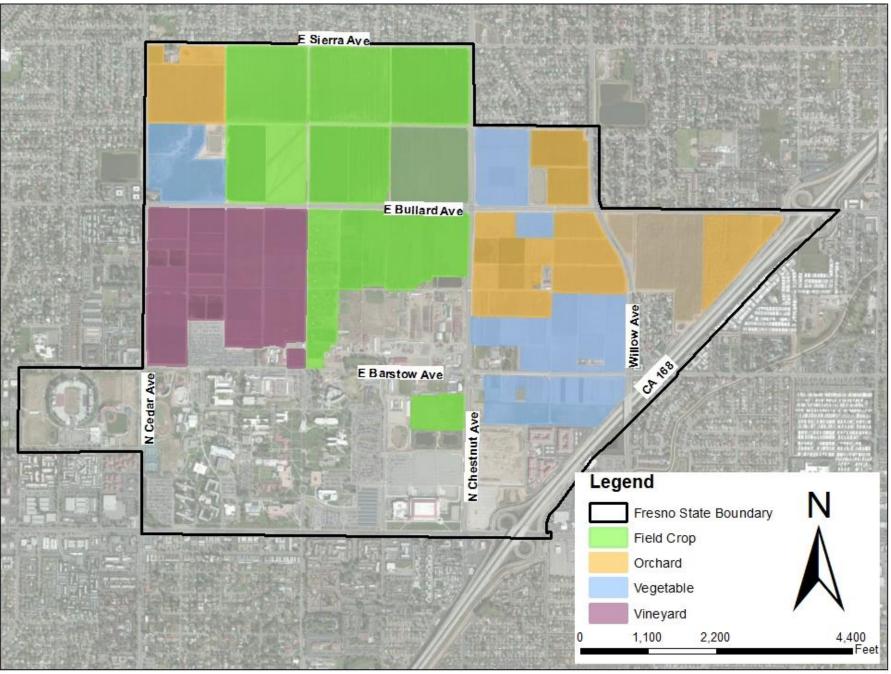

Legend
- Fresno State Boundary
- Field Crop
- Orchard
- Vegetable
- Vineyard

FIGURE 2. UNIVERSITY AGRICULTURAL LAB AT CSUF

The crops at the UAL are broadly classified into four categories. The land area for each crop and the centroidal distances of the crop land from the effluent pond are shown in Table 1.

TABLE 1. LAND AREA AND DISTANCE OF CROP FIELD FROM EFFLUENT POND

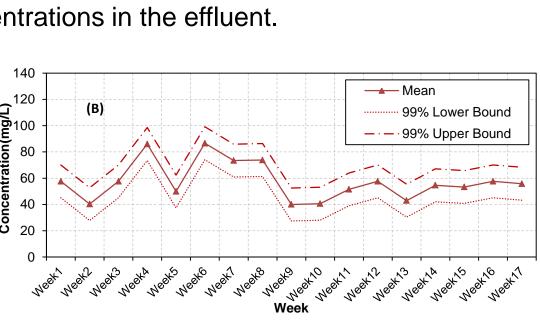| Crop type	Field	Distance (ft)	Area (acre)	Crop type	Field	Distance (ft)	Area (acre)
Field-Crop	1	6,171	72.9	Vineyard	1	5,706	14.8
	2	5,097	35.6		2	5,386	25.8
	3	4,170	76.1		3	4,693	20.3
	4	2,996	58.2		4	3,791	28.5
	5	2,200	61.6		5	3,270	31.9
Total			**304.3**	**Total**			**121.3**
Orchard	1	7,907	32.1	Vegetable	1	6,248	29.8
	2	6,423	23.1		2	3,955	26.0
	3	3,909	66.4		3	3,177	47.1
	4	2,257	31.1		4	2,480	23.6
	5	1,227	27.1		5	1,402	11.2
Total			**179.8**	**Total**			**137.8**

To estimate the total available nitrogen in the dairy effluent, the concentrations of NH_4, NO_3, and total Kjehldahl nitrogen (TKN) have been tested from May 2015 to October 2015. The following figures show NH_4, NO_3, and TKN concentrations in the effluent.

FIGURE 3. CONCENTRATIONS OF (A) NH4, (B) NO3, AND (C) TKN IN DAIRY EFFLUENT
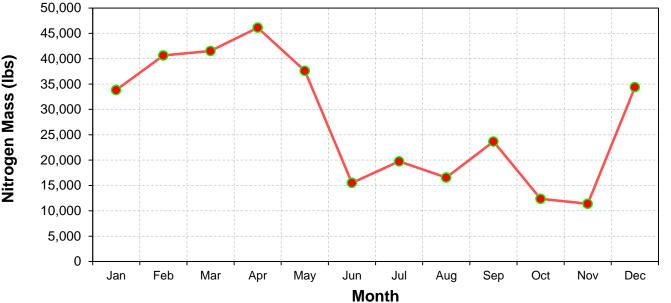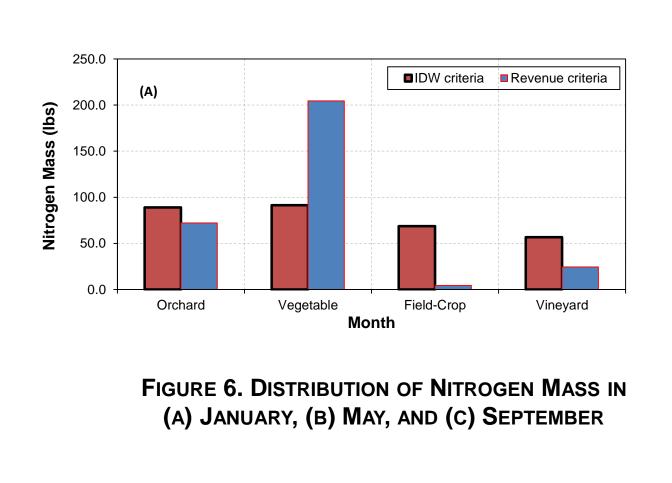
Case Study (*continued*)

Heubeck et al (2014) reported that the average effluent from a dairy farm is 50 l/cow/day. Considering this effluent and the nitrogen amount in NH4, NO3, and TKN, the monthly available nitrogen mass has been calculated. Figure 4 shows the nitrogen mass available in a year.

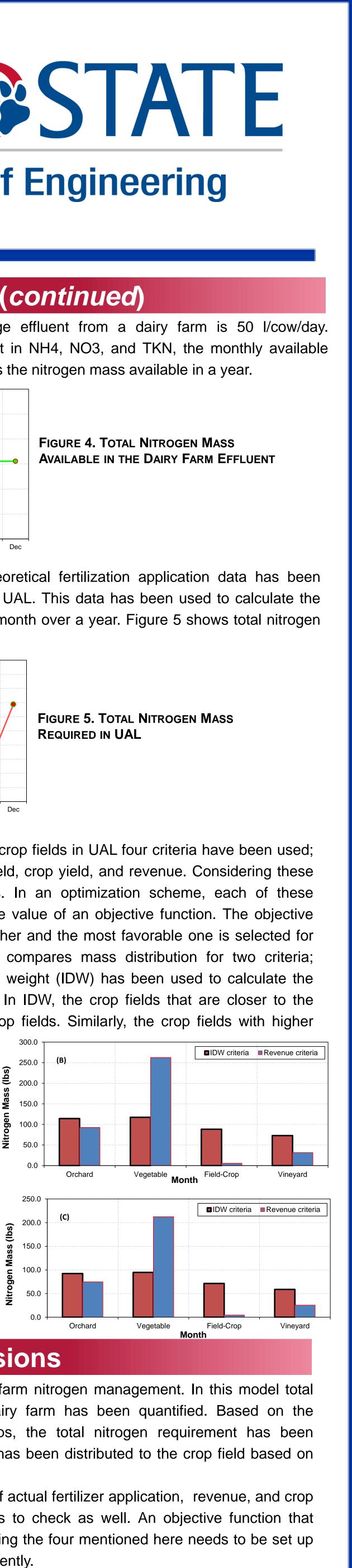**FIGURE 4. TOTAL NITROGEN MASS AVAILABLE IN THE DAIRY FARM EFFLUENT**

Fertilizer application varies crop to crop. The theoretical fertilization application data has been collected for all the crops that are cultivated in the UAL. This data has been used to calculate the total nitrogen requirement for all the crops in each month over a year. Figure 5 shows total nitrogen requirement per month.

FIGURE 5. TOTAL NITROGEN MASS REQUIRED IN UAL

To distribute the available nitrogen mass to different crop fields in UAL four criteria have been used; distance from effluent pond, land area of the crop field, crop yield, and revenue. Considering these four criteria there can be numerous combinations. In an optimization scheme, each of these combinations needs to be evaluated to calculate the value of an objective function. The objective values of these combinations are compared each other and the most favorable one is selected for the available nitrogen mass distribution. Figure 6 compares mass distribution for two criteria; revenue and distance. The idea of inverse distance weight (IDW) has been used to calculate the weight i.e., percentage fraction for each crop field. In IDW, the crop fields that are closer to the effluent pond get more weights than the remote crop fields. Similarly, the crop fields with higher revenue get more weights in revenue criteria.

FIGURE 6. DISTRIBUTION OF NITROGEN MASS IN (A) JANUARY, (B) MAY, AND (C) SEPTEMBER

Conclusions

A mass balance model has been developed for on-farm nitrogen management. In this model total nitrogen mass available in the effluent from a dairy farm has been quantified. Based on the theoretical nitrogen requirements for different crops, the total nitrogen requirement has been calculated for the UAL next. The available nitrogen has been distributed to the crop field based on some optimization criteria.

Model requires some refinements including the use of actual fertilizer application, revenue, and crop yield data. Optimization requires other combinations to check as well. An objective function that includes all the criteria together including and excluding the four mentioned here needs to be set up so that the optimal distribution can be calculated efficiently.