

**A. Project Information:**

**Final Report:**

**OPTIMIZATION OF ORGANIC FERTILIZER SCHEDULES**

FREP Project 11-0456-SA

January 1, 2012 – July 30, 2013

Project Leaders:

David M. Crohn<sup>1</sup> and Marsha Campbell Mathews<sup>2</sup>

<sup>1</sup>Department of Environmental Sciences  
University of California, Riverside  
Riverside, CA 92501

Phone: (951) 827-3993  
Cell: (310) 903-3733  
Fax: (951) 827-3993  
Email: David.Crohn@ucr.edu

University of California Cooperative Extension  
3800 Cornucopia Way, Suite A  
Modesto, CA 95358  
Phone: (209) 525-6800  
Fax: (209) 525-6840  
Email: mcmathews@ucdavis.edu

## **B. Objectives:**

This was proposed as a three-year \$150,000 project with an extensive list of objectives. Just \$50,000 of the project was funded, so CDFA staff modified the work plan to include the following points:

1. Generate two-compartment immobilization-mineralization models of organic fertilizers and manures (Crohn).
  - a. Incubate organic fertilizers and manure samples at three temperatures.
  - b. Data analysis and curve fitting.
  - c. Code curve into NBOT.
  - d. Code for *lpsolve*.
2. Incorporation of a water management component, derived from NLEAP or a similar model, to represent leaching, denitrification, and root development.
  - a. Model components, including proposed changes developed mathematically (Crohn)
  - b. Changes to the Excel 2007 program will be coded as necessary and debugged. The program makes extensive use of macros (Crohn).
  - c. Code for *lpsolve*. (Crohn).
  - d. Development of user-friendly interfaces (Campbell-Mathews and Crohn).
3. Development of user-support system (Crohn)
4. Workshop development for Central Valley growers (Campbell-Mathews).

## **C. Abstract:**

Most crops need supplemental nitrogen (N) to reach their full potential, but excess N can leach to pollute groundwater. Organic N sources are increasingly used in California for several reasons; organic fertilizer sources are required to market crops as Certified Organic products; the cost of conventional fertilizers has risen significantly in recent years, and animal agriculture generates high amounts of N-rich manures which should be beneficially disposed.

Concerns over nitrate pollution and nitrous oxide emissions have created regulatory pressures on Central Valley and Central Coast growers to manage their fertilizers more tightly. Growers are under increasing pressure to balance their nutrient use with their nutrient needs. Many growers make use of cover crops and organic fertilizers, but little guidance is available for considering optimal fertilizer strategies throughout the year. This poses a problem for growers because organic N sources can be more difficult to manage than conventional fertilizers. While many organic fertilizers release their N gradually most crops have nutrient needs that build, peak and taper as they grow. This means that crops are over- or under-supplied as plant needs change relative to nutrient release rates. Organic fertilizers also continue to mineralize N to plant-available forms after harvests and prior to planting which can be leached during field preparation operations.

When plants are under-supplied with available N, yields suffer. When over-supplied, available N can be leached or denitrified. Accumulated nitrate-N leaches readily while N supplied with carbon-rich materials, such as manures, may also be lost from the soil through accelerated denitrification as denitrifying microorganisms use the carbon in the applied organic material to convert nitrate-N to nitrous oxide (N<sub>2</sub>O) and nitrogen (N<sub>2</sub>) gasses.

Losses can only be reduced if N availability in soils is scheduled to correspond to plant needs. Mineralization rates from organic N accumulated in soils are difficult to estimate, however. The availability of N from many fertilizers is affected by many intrinsic and extrinsic factors, such as soil temperatures and textures, which can be challenging to measure or predict. A central focus of this study was the evaluation of a new approach for predicting both N immobilization and N mineralization rates from organic N fertilizers. The approach models N dynamics based on measured C decomposition rates and C:N ratios. It was found that low C:N ratio Certified Organic fertilizers were best represented using conventional two-compartment first-order N mineralization models. Low C:N materials are unlikely to immobilize N. Where C:N ratios exceeded 11, it was best to predict N mineralization continuously based on more easily measured carbon kinetics. This N immobilization/mineralization approach was then incorporated into NBOT, a computer tool for setting annual N fertilizer schedules.

To schedule of organic N applications optimally the combined influence of previous and subsequent applications must be considered. An application in August, for example, will continue to release N for several years. Optimal plans use accepted scientific principles to select from all possible application dates and fertilizer alternatives to find the schedule that best reduces losses while assuring crops of their daily needs. This project improved a linear model for optimally scheduling land application rates once it has approached steady-state. This research made possible improvements that allow multiple fertilizer and amendment types to be included. Several compartments can be associated with each type of incorporated material to simulate the behavior of labile and recalcitrant constituents. Immobilization can now be represented. Once the user determines possible application dates, the approach uses linear programming to assign N application rates for each material. The improved model is called the NBOT for *Nitrogen Budget Optimization Tool*. Key model parameters were developed in the laboratory and incorporated into the NBOT software.

#### **D. Introduction:**

Organic fertilizers contain nitrogen (N) derived from animal or vegetable matter. Most organic N is not readily assimilated by plants. Nitrogen becomes plant-available when microbes decompose the organic fertilizer releasing CO<sub>2</sub> and N in the form of inorganic ammonium (NH<sub>4</sub><sup>+</sup>-N). This process, called mineralization, is facilitated by soil microbes at rates that vary depending on for chemical and physical conditions of the fertilizer and its environment. Microbes also need and use N to grow and compete with plants to acquire it. The process by which microbes recover and use inorganic N is called immobilization. Both mineralization and immobilization therefore affect the rates at which N becomes plant available. These processes are affected by many environmental and management factors. Among the most important are fertilizer chemistry, soil temperatures, soil moisture, and time.

Organic N mineralization rates are difficult to predict or measure directly. Mathematical models are used to understand and estimate how quickly organic N becomes plant-available over time. Mineralization is most commonly modeled as a two-compartment first-order process (Benbi and Richter, 2002; Paustian et al., 1997; Valenzuela-Solano and Crohn, 2006) but such models must be parameterized using prolonged laboratory incubations under carefully controlled conditions. Laboratory measurements take time and require repeated destructive sampling. Denitrification losses may also introduce errors leading to underestimates of mineralization as the carbon supplied with organic fertilizers also serves as substrate for denitrifiers. Temperature changes also dramatically affect release rates (Valenzuela-Solano and Crohn, 2006).

The evolution of C during incubations is much easier to measure than the mineralization of N which requires destructive sampling and can be confounded by denitrification losses. This project considered whether C measurements can be used instead of N for the purpose of predicting net mineralization rates from organic fertilizers. The model has been previously applied to incubated yard trimmings (Crohn, 2013). Because the approach incorporates immobilization, the temporary tie-up of N by high C:N materials can be considered, a result that conventional first-order process models do not allow. Immobilization is partially a function of the C to organic N (C:N<sub>o</sub>) ratio of the material (Paul, 2007). Two classes of materials are included: low C:N<sub>o</sub> materials such as processed organic fertilizers, and higher C:N<sub>o</sub> materials such as manures or plant residuals.

To assist growers in the planning of fertilizer application rates, results have been incorporated into the NBOT Nitrogen Budget Optimization Tool, a planning model programmed into Microsoft Excel. The model assumes an annual quasi-steady-state condition.

## **E. Work Description:**

Task 1: Test/parameterize immobilization-mineralization models.

Our initial work was dedicated to mathematically representing the kinetics through which N becomes plant-available as simply as possible. The development of model nitrogen (N) mineralization parameters. Organic fertilizer sources release N at rates that are determined by many environmental and management. Among the most important are fertilizer chemistry, soil temperatures, soil moisture, and time. Microbes decompose organic fertilizers to release N, a process referred to as gross mineralization. As fertilizers decompose, carbon dioxide is evolved and some mineralized N is used by microbes to grow and reproduce, a process referred to as gross immobilization. Plant available N is the difference between net mineralization and net immobilization. The significance of net immobilization is known to vary according the C to organic N (C:N<sub>o</sub>) ratio of the material. We have found two approaches to be most promising, one for low C:N<sub>o</sub> materials, and one for high C:N<sub>o</sub> materials (1/2012-6/2013).

### **Task 1a. Incubation**

We considered five commercially manufactured organic fertilizers (COF) and six unprocessed residual materials (UR), four unprocessed (UR 1-4) and two anaerobically digested (UR 5,6). To reduce the potential for denitrification, the soil was mixed 1:1 with silica sand to reduce the denitrification losses. To avoid N limitation all samples were amended with KNO<sub>3</sub> at a rate of 100 mg kg<sup>-1</sup> soil. Carbon decomposition and N mineralization were studied in two separate experiments. The carbon decomposition study was conducted in 100 mL serum bottles, while N mineralization was conducted in 946 mL Mason jars. Fertilizers were applied at rates sufficient to provide a total of 400 kg ha<sup>-1</sup> total N. An unamended control was also included. Samples were packed to a density of 1300 Mg m<sup>-3</sup> and moisture was adjusted to 60 percent of field capacity. Nine samples for each material and for the control were then incubated for 60 days, three at 13° C, three at 23 ° C and three at 33° C. Vessels were left open, covered only with moistened cheese cloth, in order to keep them aerobic.

Evolved carbon dioxide (CO<sub>2</sub>) was measured from the serum bottles initially filled with 40g of the sand-soil-fertilizer mixture. The serum bottles were crimped 4 hours prior to gas sampling and 10 mL headspace samples were collected at 24 hour intervals through day 7, at 72 hour intervals through day 30, and weekly thereafter through day 60. A PP Systems EGM-4 infrared gas analyzer was then used to analyze for CO<sub>2</sub>. After sampling the bottles were purged for two minutes with 80 psi fresh air and covered with moist cloth.

Net N mineralization was measured in the Mason jars after filling them with 200 g of the sand-soil-fertilizer mixture. To make measurements, 2 g samples were removed after each of 0, 2, 5, 8, 12, 16, 21, 26, 32, 38, 45, 52, and 60 days. Nitrate and ammonium were assayed through colorimetry after an hour of shaking with 10 mL of 2 M KCl and 10 minutes of centrifuging followed by filtering (1/2012-6/2012).

### **Tasks 1b. Modeling mineralization**

The processes of mineralization and immobilization were represented separately. To obtain an acceptable fit, each contains a labile (A) and a recalcitrant compartment (1-A). At any time,  $t$  (days), decomposer microbes are assumed to break down applied organic carbon,  $C_o$  (mg/g), in the labile and recalcitrant compartments at fixed rates,  $k_1$  and  $k_2$  (days<sup>-1</sup>), respectively.

$$C = AC_o e^{-k_1 t} + (1 - A)C_o e^{-k_2 t}$$

The organic N initially present in the material ( $N_o$ ) is mineralized at the same rate as the initial organic C ( $C_o$ ), in proportion to the initial C to organic N ( $C_o:N_o$ ) ratio of the material,  $Z_o$ . A fraction of the mineralized N,  $\varepsilon$ , is recovered by the microbial community to build its tissue and the rest is released to the soil as  $NH_4^+$ -N. This is the substrate conversion efficiency (Gilmour, 1998; Paul, 2007). Recovered N is restored to the soil organic N pool. Because some N is recovered but C is continually lost, the C:N ratio of the fertilizer eventually falls to a final C:N ratio,  $Z_f$ . The N kinetics of the labile and recalcitrant carbon compartments can each be represented separately as:

$$N = N_o \left[ \frac{Z_o}{Z_f} e^{-kt} + \left( 1 - \frac{Z_o}{Z_f} \right) e^{kt/(\varepsilon-1)} \right]$$

when  $Z_o$ ,  $Z_f$ ,  $Q_{10}$  and  $\varepsilon$  are fitted to that compartment (Crohn, 2013). An Arrhenius relationship is used to fashion a multiplier,  $h$ , that modifies  $k$  so that heat effects are incorporated:

$$h = Q_{10} \left( 1 + \frac{T_r}{10} \right) \left( 1 - \frac{T_r}{T} \right)$$

where  $t$  is time,  $T$  (K) is the soil temperature,  $T_r$  (K) is a reference temperature (typically  $T_r = 298.15$  K, or 25°C), and  $Q_{10}$  is the relative proportion by which  $k_r$  increases after a 10 K temperature increase from the reference temperature ( $Q_{10} = k_{T_r+10}/k_{T_r}$ ).

Together, N contributions are:

$$N = AN_o \left[ \frac{Z_{o1}}{Z_{f1}} e^{-k_1 t} + \left( 1 - \frac{Z_{o1}}{Z_{f1}} \right) e^{\left( \frac{k_1 h}{\varepsilon_1 - 1} \right) t} \right] + (1 - A)N_o \left[ \frac{Z_{o2}}{Z_{f2}} e^{-k_2 t} + \left( 1 - \frac{Z_{o2}}{Z_{f2}} \right) e^{\left( \frac{k_2 h}{\varepsilon_2 - 1} \right) t} \right]$$

where subscripts 1 and 2 represent the labile and recalcitrant compartments, respectively.

The initial C:N<sub>o</sub> ratios of the labile and recalcitrant compartments are related through conservation of mass as:

$$Z_{o2} = \frac{Z_{o1}Z_o(1 - A)}{Z_{o1} - Z_oA}$$

Values for  $N_o$  and  $Z_o$  were measured directly. Other parameters were estimated from incubation data. Then Eq. (1) was fitted to C respiration data. This provided values for  $A$ ,  $k_{C1}$ , and  $k_{C2}$ . These values were then used to fit Eq. (4) to incubation soil measurements. The sequence is important because C measurements are more reliable than N measures. Carbon is conserved in the headspace as  $CO_2$ , while inorganic N can be lost through denitrification and volatilization. It is therefore important that C decomposition parameters be determined first and N mineralization parameters second. For this study, the Microsoft Excel 2007 non-linear Solver was used to locate parameters by minimizing the sum of square errors between model predictions and observed data. To avoid overfitting, parameter values were lumped between different treatments whenever reasonable. Determining the degree to which parameter values can be reasonably consolidated has been a major objective for this research.

For low C: $N_o$  materials net immobilization is much less important than net mineralization and Eq. (11) was not found to be necessary. In this case a simple two compartment net N mineralization model was found to serve best:

$$N = BN_o [Be^{-k_{N1}ht} + (1 - B)e^{-k_{N2}ht}]$$

where  $k_{N1}$  and  $k_{N2}$  are net mineralization rates for the labile and recalcitrant compartments, respectively ( $days^{-1}$ ) and  $B$  partitions the nitrogen compartments. The form for Eq. (6) is simpler, but potentially more difficult to fit. Parameterization of Eq. (6) requires a N mineralization study. Such studies require destructive sampling and are subject to drift due to denitrification losses. We found that denitrification losses were common early on in incubation studies. In quality control measures (data not shown) we observed significant nitrous oxide ( $N_2O$ ) during the first few days of incubations. Because most denitrified N is in the form of  $N_2$ , which we cannot detect, we used fitting techniques to determine a fixed day 1 denitrification loss constant for each studied material. This loss is deducted prior to fitting Eqs. (5) and (6) (5/2012-3/2013).

#### Task 1c. Coding NBOT

Equation (5) was substituted for the existing mineralization model. Because NBOT operates at steady-state, it is necessary to calculate the Day 1 condition prior to optimization. This is fairly complex since initial conditions are a function of all subsequent conditions at steady-state. Equation (5) introduces immobilization which resulted in negative soil storage values (and some confusing results) until the estimate of Day 1 storage was re-derived for the new model (7/2012-6/2013).

#### Task 1d. Code for *lp\_solve*.

NBOT requires mixed-integer linear programming in order to determine optimal application schedules. A powerful solution package is needed to solve this complex problem. Software packages sell for thousands of dollars and would not be practical for NBOT because they cannot be freely shared to users. Fortunately, there is a shareware package, *lp\_solve*, that is adequate to the job and it was our intention to use this solver. Unfortunately, at the time our proposal was considered computers moved from 32- to 64-bit architectures which interfered with *lp\_solve* as it was called from our Microsoft Excel application. Considerable time was therefore expended in getting *lp\_solve* to work in the 64-bit environment. These efforts delayed the project considerably but were ultimately completely successful. The new mineralization algorithm also required exhaustive reprogramming of the matrix of information that is exported to *lp\_solve* as a linear model. This programming was completed and tested (6/2012-6/2013).

#### Task 2. Water management

(1a) Water management approaches represent a simplified version of the NLEAP model. A more complex version of the water handling component based on NLEAP was also considered as part of this project and may be adopted in the near future. The model assumes plug flow during precipitation and irrigation events. Nitrate is lost as a function of the user identified leaching fraction. Denitrification follows precipitation and irrigation events as a function of soil texture and temperature conditions. Task 1 research suggests that Certified Organic fertilizers denitrify less than unprocessed residuals but this observation has not yet been incorporated into NBOT. Growers can therefore enter the design leaching fractions used to manage their irrigation events. (b) Components for handling leachate and additional fertilizers have been added and the NBOT model is functional. (c) *lp\_solve* coding was not needed for this objective as the matter could be handled within Excel. (d) A user-friendly interface allows for convenient entry of user preferences. Users may enter their preferences on either of two calendars (1/2013-6/2013).

#### Tasks 3. User assistance.

A manual has been incorporated into NBOT in the form of a pdf file. A narrated slide show was also developed and evaluated, but the manual was found to be a more efficient means of conveying how to use the application (1/2012-8/2012).

#### Task 4. Plan for outreach.

This was written as a three-year project, but was funded for just one year, a period too brief to extend results since the represents a research phase. A plan for outreach was developed, however (5/2013-6/2013).

- The mineralization research and NBOT will be presented at the FREP conference to be held in October 2013. A paper has been submitted that describes the project.



- The NBOT will be presented and demonstrated at a hands-on workshop for crop consultants working with manure and other organic nitrogen sources at a workshop in late November 2013 in Modesto.
- A link to the NBOT and associated documentation will be provided on Nutrient and Irrigation Management SAREP Solution Center Website.
- The organic nitrogen mineralization equations and models developed with this project will be used to illustrate and teach nitrogen management concepts for annual cropping systems in the curriculum for the CDFA funded UC Nitrogen Management Planning Curriculum to be presented beginning in January 2014 in meetings held in
  - Modesto
  - Fresno
  - Tulare
  - Salinas
  - Williams.

## F. Results:

Materials were collected and analyzed (Table 1). For COF  $Q_{10}=1.61$  while two were used for UR. For aerobically digested materials  $Q_{10}=2.67$  while for anaerobically digested materials  $Q_{10}=3.92$ . COF could be fitted to  $CO_2$  evolution data, but these fits did not result in consistent predictions of net N mineralization. This is due to the very low C:N ratios of these materials. Fits using Eq. (6) to directly represent mineralization were effective (Fig. 1).

Figures 2 and 3 illustrate the result when net N mineralization is estimated for UR based on C decomposition rates. All of the curves for all UR materials share common values of  $Z_f = 4$  and  $\varepsilon = 0.05$ . An  $\varepsilon$  of 0.05 is low compared to reported literature values of 0.4 to 0.6 (Paul, 2007). A value of 0.6 served well for decomposing green waste (Crohn, 2013). It is not clear why decomposers of animal wastes would be so inefficient with N. It may be that efficiency is reduced when N is abundant relative to C in substrates. The poorest fit was associated with UR product E which also had the lowest C:N<sub>o</sub>. UR E may have more in common with the COFs than with other UR materials. This material also was associated with more sustained N<sub>2</sub>O emissions than other fertilizers based on N<sub>2</sub>O measurements (data not shown) these losses may have contributed to the fit of the model since we only correct for Day 1 denitrification losses.

To estimate mineralization rates from  $CO_2$  evolution data, it is also necessary to parameterize  $Z_{o1}$  the initial C:N ratio of the labile C fraction. Excluding UR product E which had a very low C:N ratio, a strong relationship was found ( $r^2 = 0.962$ ) between the decay rate of the labile carbon fraction,  $k_1$ , and  $Z_{o1}$  (data not shown). The curves in Fig. 3 were generated using this relationship illustrated rather than with direct estimates of  $Z_{o1}$  values. It may be possible to estimate  $Z_{o1}$  values from  $k_1$  though other possibilities may also emerge and additional research is needed.

This research demonstrated that immobilization need not be represented with COF. Work on the project revealed that considerable modifications are needed to incorporate immobilization into NBOT fertilizer plans. A version of the NBOT that includes immobilization has also been produced with convenient data-entry and a user manual to describe its use. Users may enter their plans into a calendar-like interface (Fig. 4) or into a line-item menu.

### **G. Discussion and Conclusions:**

Net mineralization from low C:N<sub>o</sub> fertilizers (<6) was best represented by directly fitting parameters to observed mineralized N. At higher C:N<sub>o</sub> levels, inclusion of C provides good results. Fittings depend on which parameters are lumped. The COF were less sensitive to changes in temperature and their Q<sub>10</sub> could also be lumped. Since COF are processed and marketed by fertilizer companies their properties should be more consistent from batch to batch than UR. Incubations for describing the mineralization of COFs are quite practical as these fertilizers have consistent properties from batch to batch. The release rates measured here for organic fertilizers are lower than expected. It is possible that some denitrification losses were encountered, though no N<sub>2</sub>O losses were detected. The characteristics of UR materials such as composts, cover crops, and manures are much more variable, however, making incubations that include destructive sampling for N less realistic.

Ideally, higher C:N ratio materials should be able to be represented using C measurements or estimates only. The model developed here includes the fundamental relationships associated with N mineralization kinetics that are described in the literature. There are three main reasons to use C to model N mineralization. First, C measurements are more reliable since they are not affected by denitrification. Second, C measurements are easier since they do not require destructive sampling and subsequent extractions. Third, incorporation of C into N net mineralization models permits the influence of microbial immobilization to be included. A two-compartment model is needed to represent C decomposition. Anaerobically and aerobically digested UR appeared to have different Q<sub>10</sub> values but within these categories Q<sub>10</sub> parameters could be lumped. Anaerobic UR materials were most strongly affected by temperatures. It may be that the initial C:N ratios of the labile C compartment can be estimated from its decay rate, but more work is needed to verify this. Warm (33°C) incubations may provide more rapid parameter estimates but research is needed to evaluate other approaches.

While the NBOT functions well a stand-alone program, it can be used in conjunction with a real-time recordkeeping program and also an in-season soil nitrogen prediction tool currently under development. Here are descriptions of how these programs can function together to make a complete suite of management tools.

- a) NBOT returns the best annual application strategy for a proposed system based on user defined parameters such as annual and per application minimum and maximum rates for each type of fertilizer or manure material, feasible application dates and expected crop N removal. The optimization program returns the N budget with the least

amount of nitrate in the soil during leaching or denitrification events while ensuring that crop requirements are met.

- b) An application tracking program (Aptrak Records) is under development to keep track of the amount of nutrients and water applied as they occur. This is an essential management tool for protecting groundwater quality because many farm managers do not have accurate records of how much nitrogen and water they are applying and cannot make informed management decisions without this information. It is designed to accommodate both novice computer-phobic and advanced users. The Excel spreadsheet platform is familiar to most users. Data can be typed directly onto the spreadsheet, or more advanced users can utilize helper menus which automate many data entry tasks so that application results are displayed immediately after only a few keystrokes.
- c) A checkbook-type balance sheet (Aptrak N Ledger) which tracks the net amount of crop available nitrogen in the soil after crop uptake and losses (leaching and denitrification) are subtracted. The program predicts when nitrogen deficiencies will occur and how much manure or fertilizer material needs to be applied in order to correct it. The purpose of these nitrogen management tools is not necessarily to replicate exactly the complex plant and soil system but to serve as an interactive educational tool to help farm managers understand, visualize and consider if different N rates, timings and materials will provide enough N to the crop and also how they might impact nitrate leaching. While the models do suggest application rates and timings, the models are intended to be used to strategically direct and focus, not replace, in-season monitoring by indicating where deficiencies or excesses of N in the soil might occur. Manual adjustments to the predicted soil nitrogen content can and should be made as the season progresses based on monitoring results.
- d) After a year of farm activity, NBOT can be used once again to formulate applications for the next year.

Table 1. Characteristics of study fertilizer materials

Treatment	Total C (%)	Total N (%)	NH <sub>4</sub> <sup>+</sup> -N (ppm)	NO <sub>3</sub> <sup>-</sup> -N (ppm)	N <sub>o</sub> (ppm)	C: Organic N
BM	28.5	5.5	430	24.0	5.5	5.2
FM	49.3	12.7	780	13.4	12.6	3.9
GP	46.4	11.8	1799	34.4	11.6	4.0
FC	16.4	4.0	5430	12.4	3.5	4.8
LGS	42.9	7.8	358	10.6	7.8	5.5
A	18.6	1.6	277	95.2	1.6	11.9
B	13.2	1.1	157	15.0	1.0	12.6
C	43.9	1.5	381	3.9	1.4	30.6
D	24.5	2.0	429	25.1	2.0	12.5
E	21.4	4.3	2980	16.4	4.0	5.3
F	18.6	1.4	825	4.3	1.3	14.4

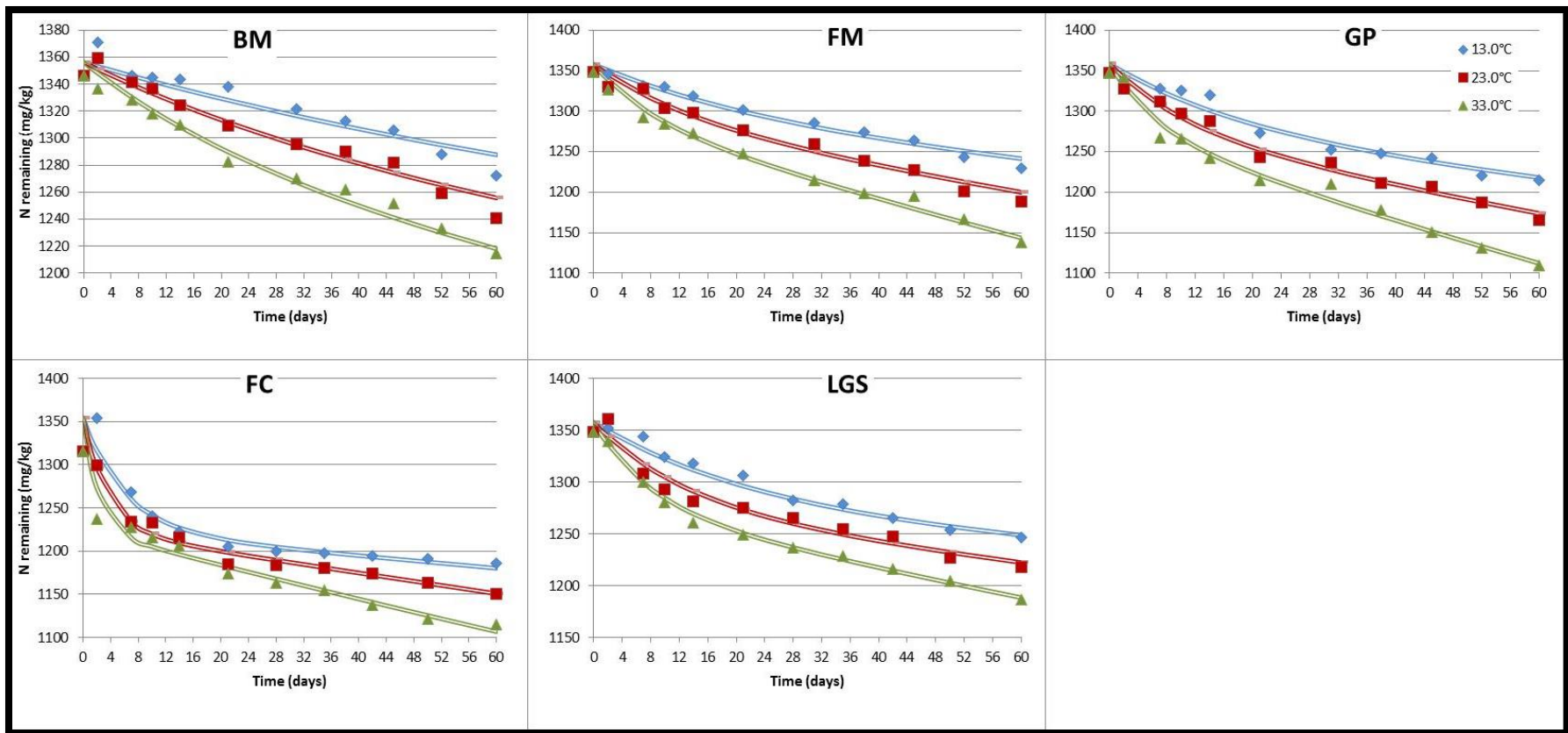


Figure 1. Fitting the N mineralization of COF at three temperatures using Eq. (6).

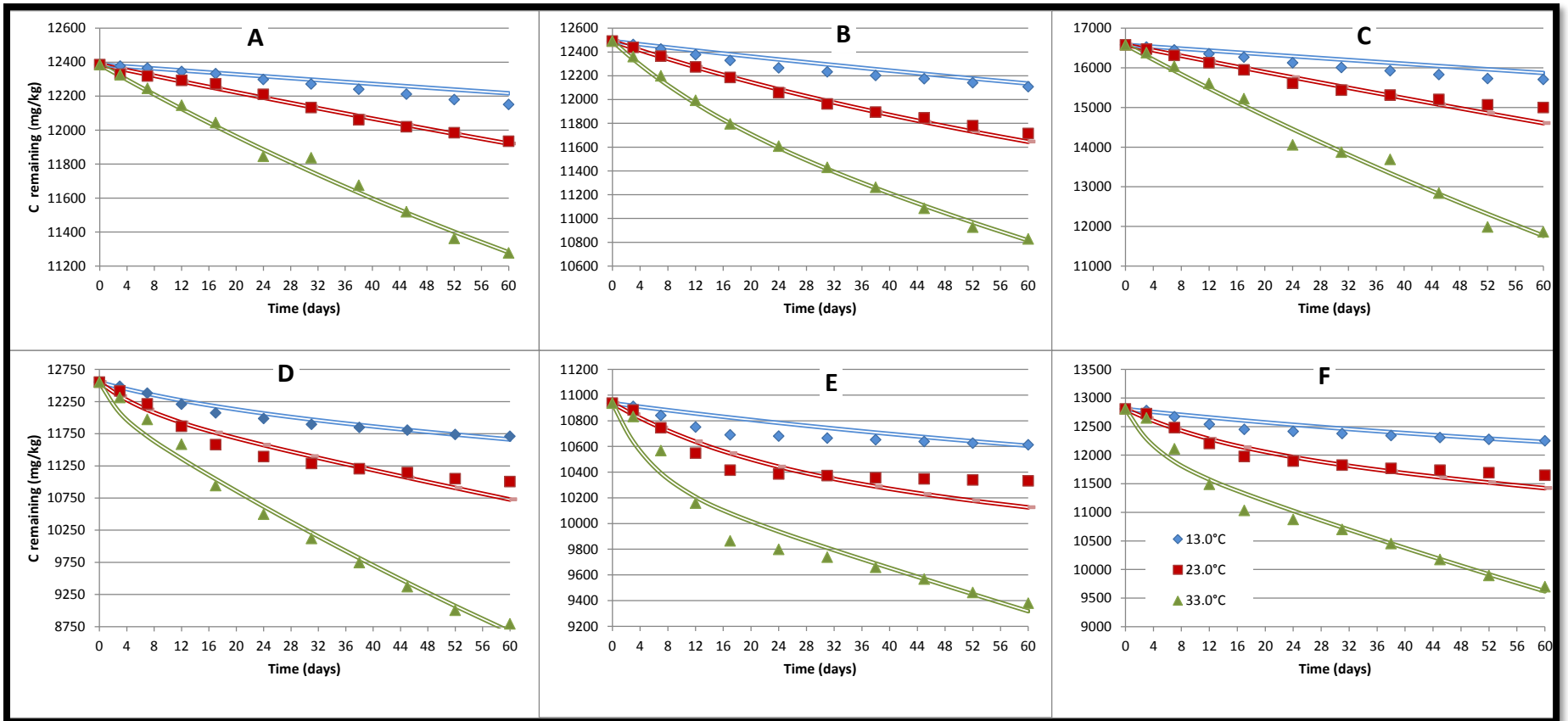


Figure 2. Fitting the C decomposition of UR at three temperatures using Eq. (1).

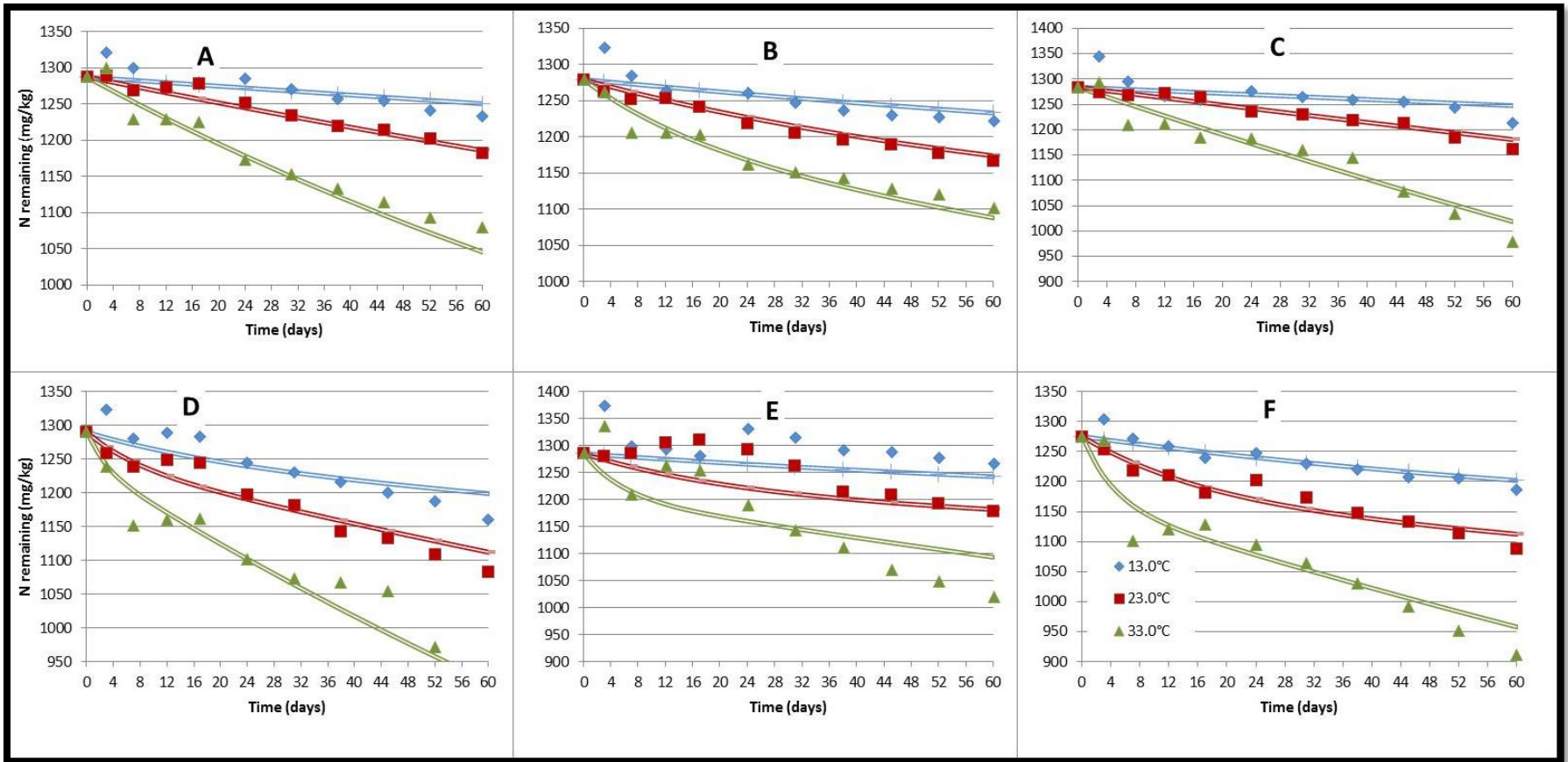


Figure 3. Fitting the net N mineralization of five UR at three temperatures based on C decomposition rates using Eq. (4).

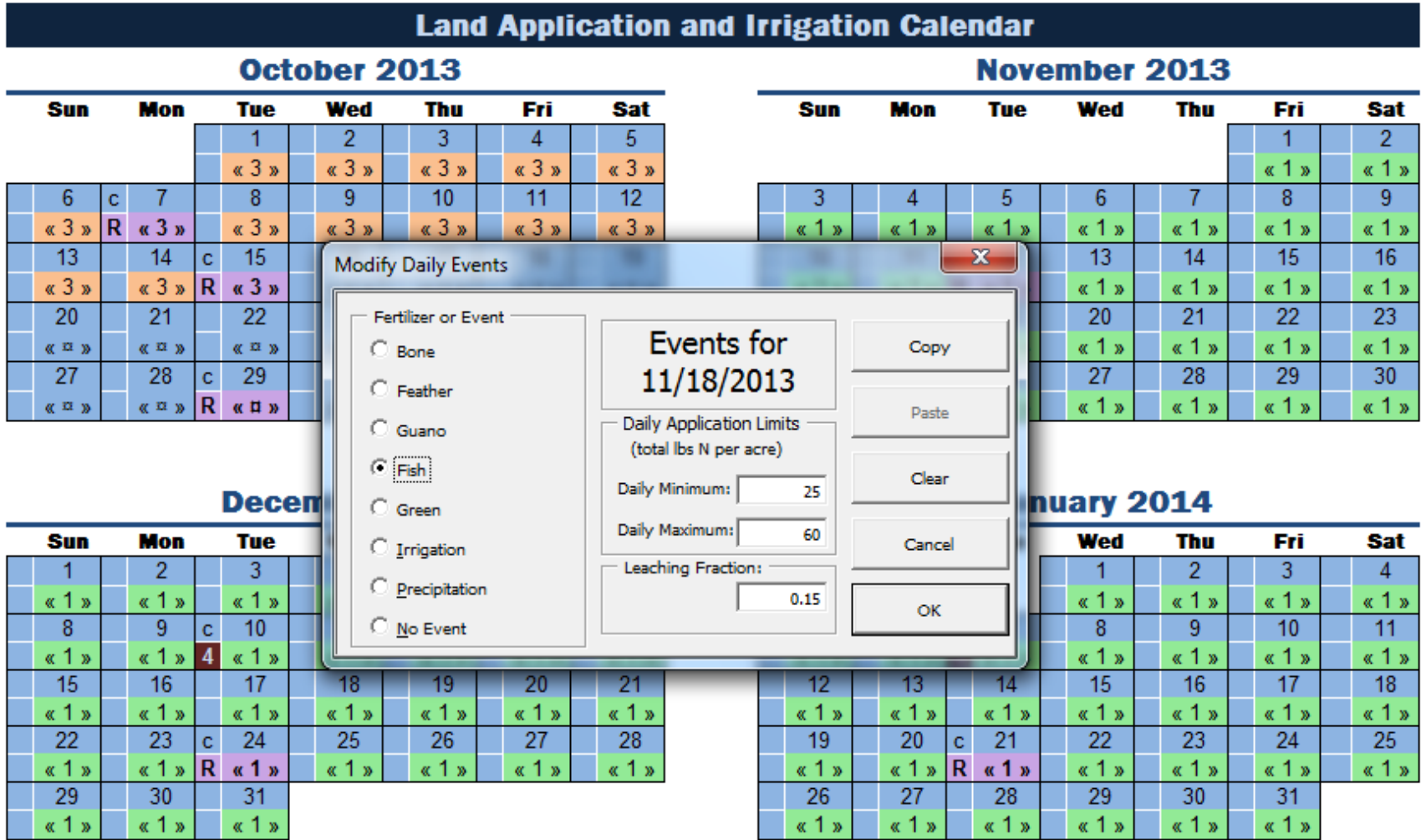


Fig 4. Graphic from the NBOT data entry system.



#### **H. Project Impacts:**

This project has developed a model that may, with further work, provide an way for predicting mineralization rates from organic fertilizers with C:N ratios exceeding approximately 11:1. Predictions are based on carbon decay rates, temperatures, and initial C:N ratios. The ability to accurately predict mineralization will assist growers in planning their nutrient budgets. We have improved the NBOT so that it can make use of an improved mineralization component that includes the ability to represent immobilization. The approach will be particularly useful to users trying to coordinate management of high C:N materials, such as composts or unprocessed residues, with conventional or organic fertilizers. Currently NBOT is expected to serve principally as an educational tool. As regulations increase the need for tighter N budgeting, NBOT can be used to formulate annual nutrient plants.

#### **I. Outreach Activities Summary:**

This was not part of this contract, however a plan for future outreach has been presented in the work description.

## **J. Factsheet/Database Template:**

1. Project Title: Optimization of Organic Fertilizer Schedules
2. Grant Agreement Number (Assigned by CDFA): 11-0456-SA
3. Project Leaders: David M. Crohn, Department of Environmental Sciences, University of California, Riverside, and Marsha Campbell Mathews, University of California Cooperative Extension, Stanislaus County.
4. 2012/2013
5. Location: University of California, Riverside
6. County: Riverside
7. Highlights
  - **A new method for understanding nitrogen release from organic fertilizers was tested.**
  - **Immobilization can now be included annual application plans**
  - **A computer application was developed for finding optimal fertilizer schedules**

### 8. Introduction:

Most crops need supplemental nitrogen (N) to reach their full potential, but excess N can leach to pollute groundwater. Organic N sources are increasingly used in California for several reasons; organic fertilizer sources are required to market crops as Certified Organic products; the cost of conventional fertilizers has risen significantly in recent years, and animal agriculture generates high amounts of N-rich manures which should be beneficially disposed.

Concerns over nitrate pollution and nitrous oxide emissions have created regulatory pressures on Central Valley and Central Coast growers to manage their fertilizers more tightly. Growers are under increasing pressure to balance their nutrient use with their nutrient needs. Many growers make use of cover crops and organic fertilizers, but little guidance is available for considering optimal fertilizer strategies throughout the year.

Organic N sources can be more difficult to manage than conventional fertilizers. Many organic fertilizers release their N gradually though most crops have nutrient needs that build, peak and taper as they grow. This means that crops are over- or under-supplied depending on plant needs and nutrient availability. Organic fertilizers also continue to release N after harvests and prior to planting. This N is often leached during field preparation operations for subsequent crops. Denitrifying microorganisms may also use the carbon in organic fertilizers to denitrify N, an additional loss that, depending on soil conditions, can be substantial. Losses can be reduced if fertilizer applications are designed such that throughout the year N availability in soils corresponds as closely as possible to crop N demands. Mineralization rates from organic N accumulated in soils are difficult to estimate, however. The availability of N from many fertilizers is affected by many intrinsic and extrinsic factors, such as soil temperatures and textures, which can be challenging to predict. A central focus of this study was the evaluation of a new approach for predicting both N immobilization and N mineralization rates from organic N fertilizers. The approach models N dynamics based on measured C decomposition rates and C:N ratios.

To schedule of organic N applications optimally the combined influence of previous and subsequent applications must be considered. An application in August, for

example, will continue to release N for several years. Optimal plans use accepted scientific principles to select from all possible application dates and fertilizer alternatives to find the schedule that best reduces losses while assuring crops of their daily needs. This project improved a linear model for optimally scheduling land application rates once it has approached steady-state. This research made possible improvements that allow multiple fertilizer and amendment types to be included. Several compartments can be associated with each type of incorporated material to simulate the behavior of labile and recalcitrant constituents. Immobilization can now be represented. Once the user determines possible application dates, the approach uses linear programming to assign N application rates for each material. The improved model is called the NBOT for *Nitrogen Budget Optimization Tool*. Key model parameters were developed in the laboratory and incorporated into the NBOT software.

#### 9. Methods/Management: (Summarize project activities, methods, and materials)

This study first evaluated a new approach for predicting both N immobilization and N mineralization rates from organic N fertilizers based on measured C decomposition rates and C:N ratios. We considered five commercially manufactured organic fertilizers and six unprocessed dairy manures, both unprocessed and anaerobically digested. Samples of each material were mixed with soil and sand and, along with a control, were separately incubated for 60 days with separate treatments at 13° C, 23 ° C and 33° C. Three replications were included for each treatment. Evolved carbon dioxide (CO<sub>2</sub>) and available N were monitored over time. Results were fit to a first-order mineralization/immobilization model which included both gross mineralization and immobilization. Results were then incorporated into a computer application called the NBOT (Nitrogen Budget Optimization Tool).

Because organic N must be mineralized to ammonium before it can be assimilated by plants, organic nitrogen (N) fertilizers can be more difficult to manage than conventional alternatives. An application in August, for example, will continue to release N for several years, to be joined by releases from July, June, November and others. To schedule of organic N applications optimally, the combined influence of previous and subsequent applications must be considered. NBOT optimally schedules organic fertilizer rates once a system has approached steady state. The model uses a daily time-step and up to five different fertilizers can be considered simultaneously. Organic N becomes available gradually over time, although the rate at which this occurs depends on fertilizer properties, soil conditions, and climate. Immobilization can now be represented. Optimal plans select from designated dates and fertilizer alternatives to find the schedule that best reduces losses while assuring crops of their daily needs.

#### 10. Findings:

Carbon decomposition was represented without problem for all materials, though anaerobically digested residues were more sensitive to temperature effects than aerobically-prepared wastes. Nitrogen mineralization results were more complex. Denitrification was observed in the first few days following incorporation of manures but not from Certified Organic fertilizers. Low C:N ratio organic fertilizers were best represented using conventional two-compartment first-order N mineralization models as

they did not immobilize appreciable N. Where C:N ratios exceeded 11, it was best to predict N mineralization continuously based on more easily measured carbon kinetics. Carbon decay is measured relatively easily, and it is also more easily predicted from measurable properties than N mineralization. With further development the approach may develop into a technique for laboratories to estimate immobilization and mineralization from land applied residuals such as composts, green wastes, cover crops and manures.

In NBOT, N mineralization and immobilization are represented using a first-order carbon decay model and temperature-adjusted time. To use the model a grower identifies crops, planting dates, harvest dates, harvest N, fertilizer qualities, and possible application dates. Local climate data are used to modify crop development patterns and soil organic N mineralization rates. The model calculates daily crops needs and optimal application rates needed to meet crop demand while minimizing losses. Losses are controlled by reducing the amount of inorganic N present in the soil at times where leaching or denitrification is likely. NBOT has been programmed using Microsoft Excel 2010.

### Nitrogen Application Schedule

Date	Material	Method	N (lb/ac)
Nov. 4, 2013	Guano	Spread no-till	28 lb
Jan. 2, 2014	Feather	Spread no-till	26 lb
Jan. 27, 2014	Guano	Spread no-till	28 lb
Feb. 24, 2014	Guano	Spread no-till	41 lb
Mar. 24, 2014	Guano	Spread no-till	37 lb
Jun. 3, 2014	Fish	Spray irrigation	25 lb
Jun. 17, 2014	Fish	Spray irrigation	27 lb
Jun. 24, 2014	Fish	Spray irrigation	74 lb
Jul. 1, 2014	Fish	Spray irrigation	60 lb
Jul. 29, 2014	Fish	Spray irrigation	25 lb
Aug. 5, 2014	Fish	Spray irrigation	25 lb
Aug. 12, 2014	Fish	Spray irrigation	178 lb

### Nitrogen Schedule Result Summary

N Application Summary (lb/ac)		N Fate Summary (lb/ac)	
Meal total:	0	Total crop N removal:	477
Feather total:	26	Leaching losses:	14
Guano total:	133	Denitrification losses:	22
Fish total:	413	Volatilization losses:	58
Fish 2 total:	0		
All applied N:	572	Regulatory N supply ratio:	1.20



Figure 1. NBOT example organic fertilizer plan for a corn/winter small grain rotation.

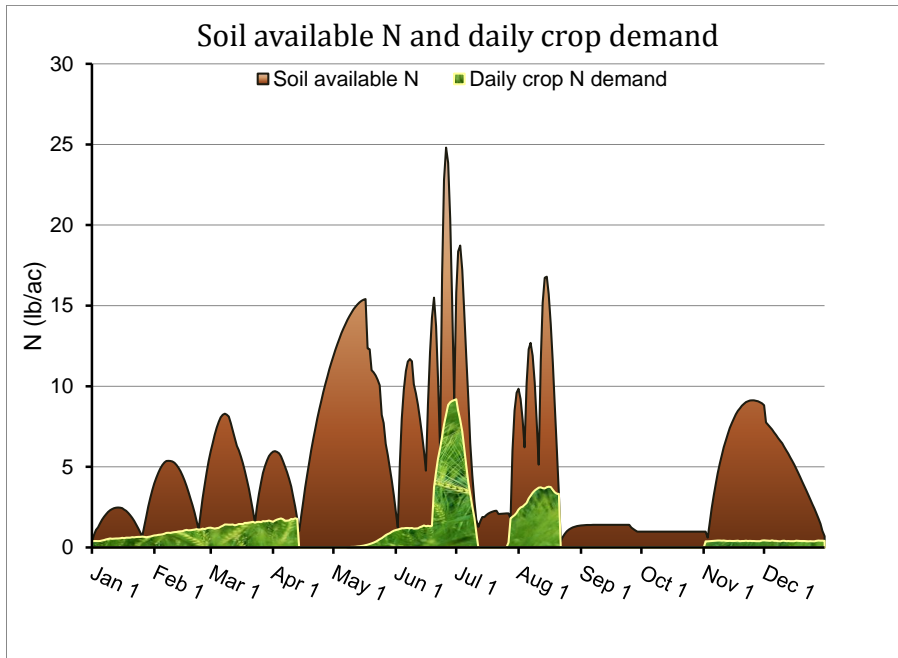


Figure 2. NBOT solution soil available N and daily crop demand for a corn/winter small grain rotation.