# NITROGEN MINERALIZATION AND ITS IMPORTANCE IN ORGANIC WASTE RECYCLING

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## ABSTRACT

Nitrogen mineralization is the process by which organic N is converted to plant-available inorganic forms. Soils regularly amended with organic wastes will accumulate organic N until they reach a steady-state condition, a concept useful for planning N management strategies. Several factors affect mineralization rates, particularly temperature, so that release varies throughout the year in a predictable pattern. An understanding of these patterns is necessary to match crop N demands with the plant-available N in the soil.

**Key Words: manure, mineralization, land-application, nutrient budgeting**

## INTRODUCTION

Manure nitrogen (N) comes in both organic and inorganic forms. Inorganic N, mostly ammonium ($NH_4^+$) and nitrate ($NO_3^-$), is readily available to plants. Before organic N can be taken up, however, it must first be converted to inorganic forms. This process, which is completed by soil microbes as a by-product of organic matter decomposition, is called *mineralization*. The *mineralization rate* is therefore the rate at which organic N is made plant available. In manured forage systems, mineralization accounts for much or most of crop needs. An understanding of the mineralization rate concept can help improve manure management to meet crop N demands while minimizing the potential for regulatory concerns regarding groundwater pollution.

## STEADY-STATE

When manures are regularly added to soils, the organic N pool gradually increases over time until it eventually reached a plateau know as the *steady-state condition.* This concept is a central feature of a document being completed by a University of California Committee of Consultants, *Managing Dairy Manure in the Central Valley of California* (Marsha Campbell Matthews and Andrew Chang, pers. comm.). At steady-state, the amount of manure organic N added in a given year will approximately equal the amount mineralized. Under idealizedized steady-state conditions

$$N_m = N_o k \Delta t \ . \tag{1}$$

where $N_m$ (lb/ac) is the mineralized soil N *as well as* the applied manure organic N, $N_o$ (lb/ac) is the initial organic soil N, $k$ ($d^{-1}$) is the mineralization rate, and $\Delta t$ (d) is the time period of interest. Idealizedized conditions never occur, of course. Organic N is added periodically rather than continuously and soil organic N stores respond by increasing with additions and decreasing as

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mineralization proceeds. The simplest representation of non-idealizedized steady-state conditions assumes that all added organic N becomes available at the same mineralization rate (Benbi and Richter 2002)

$$N_m = N_o\left(1 - e^{-k\Delta t}\right). \tag{2}$$

Figure 1 compares N mineralization associated with the idealized conditions (Eq. 1) to the more realistic condition modeled by Eq. 2. In the figure, soil manure organic N gradually rises from an initial concentration of zero lb/ac over a ten-year period. Manure is added in lagoon water during ten-day irrigation intervals to a forage corn-winter triticale rotation. The white line, which assumes organic N is added at a continuous rate, represents the idealized steady-state condition determined from Eq. 1. The black lines grow closer together as time progresses, approaching, but never actually reaching, the white steady-state average.

Mineralization rates can also be understood in terms of a half-life, $t_{½}$ (d), the time required for one half of the organic nitrogen pool to be converted. The relationship between the two concepts is $k = 0.693/t_{½}$ or $t_{½} = 0.693/k$. Mineralization rates for half-lives of 90, 270, and 730 d are 0.00770, 0.00257, and 0.00095 $\text{d}^{-1}$ respectively. It may be easier to gain an intuitive understanding of mineralization by considering N mineralization half-lives rather than rates.

The time required to approach steady-state, $t_{\text{ss}}$ (d) is a linear function of the half-life. Mathematically, steady-state is never completely reached, but the concept can be defined in terms of a fraction, $p_{\text{ss}}$, of the ultimate steady-state soil organic N.

$$t_{ss} = -1.44\ln\left(1 - p_{ss}\right)t_{½}\,. \tag{3}$$

For example, the time to reach 95 percent ($p_{ss} = 0.95$) of the steady-state condition can be determined from $t_{ss} = 2.08\ t_{½}$. Corresponding equations for 98 and 99 percent of steady-state ($p_{ss}$ = 0.98, 0.99) are $t_{ss} = 2.71\ t_{½}$ and $t_{ss} = 3.19\ t_{½}$, respectively. Given the uncertainty associated with soil N, concentrations associated with $p_{ss} = 0.95$ are likely to be indistinguishable from the full steady-state condition. Figure 2 shows the relationship between $t_{½}$ and $t_{SS}$. Time to steady-state is a linear function of the half-life where the slope is determined by $p_{ss}$.

The time to effective steady-state, $t_{ss}$, could also be written as a function of the mineralization rate, but what factors determine $k$ or its related $t_{½}$? Mineralization is principally a function of temperature, moisture, soil texture, and manure characteristics (Leirós et al. 1999). Elevated temperatures dramatically accelerate decay. A rule of thumb is that decay rates double for every 18ºF. Microbes live in a film of moisture on soil particles. Too little moisture deprives them of their habitat, while too much can block needed oxygen from infiltrating into the soil as can very finely textured soils which tend to drain slowly. In California, most summer forages receiving manure are grown on irrigated soils with good drainage, which helps to control for the influence of water and texture on decomposition rates. Cooler temperatures tend to maintain moisture levels adequate for mineralization during winter months. Temperature is therefore the most important environmental factor in determining mineralization rates.

Manures that contain bedding materials or that are otherwise rich in carbon can temporarily immobilize nitrogen from the soil, delaying its release to plant-available forms. As microbes decompose carbon, they use the liberated energy to grow and reproduce. Nitrogen is also needed for microbial growth and to supply this need they will convert inorganic N into microbial biomass. Eventually manure carbon concentrations fall decreasing the microbial biomass and liberating immobilized N. Because immobilization is a temporary phenomenon, it has a short-term (a few weeks or moths) rather than a long-term impact on soil fertility. Examples used in this paper are associated with the use of dairy lagoon water which contains anaerobically stabilized organic matter less likely to immobilize N.

## SEASONAL VARIATIONS

Idealized steady-state as conceptualized thus far is useful for predicting the total amount of N mineralized in any given year. Organic N concentrations that vary *during* the year, but that are at approximately the same level from year-to-year on a *particular* date, may also be considered to be at steady-state. In this case, the amount of organic N added still equals the amount mineralized to plant-available forms. While the steady-state concept can help mold an overall N management strategy, it does not necessarily reflect how crops will make use of added N. Crops tend to take up N slowly during their initial establishment, quickly as they develop, and then more slowly as they mature. Manure mineralization, by contrast, is a continuous process that varies mainly with temperature. In the summer, N mineralizes relatively quickly, while in the winter, mineralization slows considerably. The influence of temperature on mineralization can be incorporated into management models by way of the Arrhenius equation. The procedure is based upon the concept of temperature-adjusted time, $t^o$ (d). The idea is that time can be adjusted to account for the influence of temperature. Effectively, summer days are stretched to allow more mineralization, while winter days are contracted. This simplifies management by keeping $k$ terms constant for differing climates and seasons. The temperature-adjusted time stream can be determined as

$$t^\circ = \sum_{\Delta t \le t} Q_{10}^{\left(1+\frac{T_r}{10}\right)\left(1-\frac{T_r}{T_t}\right)} \Delta t \qquad (4)$$

where $T_r$ (K) is a reference absolute temperature, often 25ºC, $T_t$ (K) is the soil absolute temperature at time $t$, $\Delta t$ (days) is the time step, and $Q_{10}$ is the relative change in the decay rates expected after a 10ºC (18ºF) increase in temperature from the reference temperature. Note that temperature is measured in Kelvins (K) which is the temperature in Centigrade (˚C) increased by 273.15 so that 20ºC = 298.15 K. As a rule of thumb, $Q_{10} \approx 2$ (Crohn and Valenzuela-Solano 2003). Although Eq. 4 appears complex, it can be computed easily with a computer and tabulated.

Figure 3 compares crop N demand for a forage corn-winter triticale rotation grown in Stanislaus County, California. Manure organic matter is added as a constituent of dairy lagoon water, which contains 50 percent, organic N and 50 percent ammonium N. Application rates are derived by matching the total N in added lagoon water to the anticipated needs of the crop over a 10-day irrigation interval. An additional 30 percent is added to account for application inefficiencies and possible losses through ammonia volatilization or denitrification. In practice, ammonia volatilization should be controlled by thoroughly diluting the dairy lagoon water into irrigation water. Dilution also helps minimize crusting. The considered soils are well-drained loamy sands, which helps to reduce the incidence of denitrification (Thomas Harter, pers. comm.). Because crop uptake is anticipated to be similar each year, lagoon water additions follow the same pattern from year-to-year. Lagoon water inorganic nitrogen is therefore identical each year, but the mineralization of lagoon water organic N increases as the soil organic N pool builds to a steady-state condition.

## DISCUSSION

An understanding of temperature effects on mineralization can help to predict mineralization during the year. Cool weather will slow mineralization during the winter, adding significance to inorganic N sources at that time of the year. Management practices may consider this by increasing application rates during the winter and then reducing them during the summer to meet overall farm nutrient management goals. On an annual basis, warmer climates will converge to a steady-state condition more quickly than cooler climates because organic N half-lives are considerably shorter under warmer conditions.

The examples presented here assume no manure organic N is present. If that is the current condition of the field, initial crops are likely to be deficient in N and higher application rates may be appropriate. If higher applications are made, convergence to steady-state will occur more rapidly and application rates should be reduced to the steady-state condition sooner than Figure 2 indicates. If applications at the steady-state rate are made to a field that has received high loading rates in the past, soil organic N concentrations from manure will likely exceed steady-state levels. Soil organic nitrogen will mineralize, however, until a steady-state concentration is reached. The excess N is likely to leach into the groundwater (Follett et al. 1991).

Much nitrate loss occurs as the crop mature and uptake is reduced. This is evident in Figure 3 which shows N mineralization in excess of crop needs from August through September and from March through April. Consideration of the mineralization process will permit reduction or elimination of applications during mature phases of development. Much excess inorganic N is also generated between the harvests and subsequent plantings. Reduction of late season application rates will help to reduce these losses as well.

Despite the simplified form of Eqs. 1 and 2, not all organic N mineralizes at the same rate. It is therefore common practice to consider two organic N compartments, a labile one which mineralizes readily, perhaps within a few days or weeks of applications, and a recalcitrant compartment which requires more time (Benbi and Richter 2002, Gilmour et al 2003). The labile compartment is sometimes considered to be immediately available, just like manure ammonia. The assumption of instantaneous availability is likely to be more valid in the summer than in the winter. Tests are needed to assess the labile component of applied manures.

Note that the irrigation scheme illustrated in Figure 3 is not representative of most manure irrigation systems in Stanislaus County. In the figure, summer and winter applications are scheduled similarly (according to crop uptake rates) in order to highlight climate affects on mineralization. Winter crops Stanislaus County tend to be watered naturally rather than with irrigation and manures are therefore typically applied to winter crops in one operation. Further work is under way to assist in optimizing winter applications.

University of California Cooperative Extension is in the process of developing a comprehensive spreadsheet application for managing dairy lagoon manure. The project is being coordinated by Marsha Campbell Matthews, UCCE Stanislaus County agronomy advisor. A comprehensive spreadsheet application has been developed that considers many of the pertinent aspects of lagoon water management, including nutrient determination and optimal application rate management.

## CONCLUSIONS

Crops can only assimilate inorganic forms of N, such as nitrate and ammonium. Much or most of manure N is applied in the organic form, however. Organic N remains in the soil until it mineralizes. Mineralization is a continuous process, but a number of factors influence the rate at which it occurs. Temperature is the most important factor affecting mineralization rates, but temperature affects can be easily estimated with a temperature-adjusted time approach. The steady-state concept is useful for considering overall soil N budgets. In its idealized steady-state condition, organic N is added continuously while mineralizing at an equivalent rate so that soil organic N concentrations remain constant. In actuality, organic N is added in discrete manure spreading events and mineralization rates vary, mainly in response to temperature changes. This causes soil organic N and associated mineralization to vary during the year, but all things remaining equal, these systems also converge to a steady-state, albeit seasonally varying, condition. Under steady-state conditions the amount of manure organic N added in a given year equals the amount mineralized to plant-available forms. The mineralization rate affects how N release is distributed throughout the year, however. Steady-state conditions can be reached by applying manure according to crop removal rates with appropriate adjustments for volatilization and denitrification losses. UCCE is developing a spreadsheet approach to modeling the mineralization process in California so that N release most closely matches crop nutrient demands.

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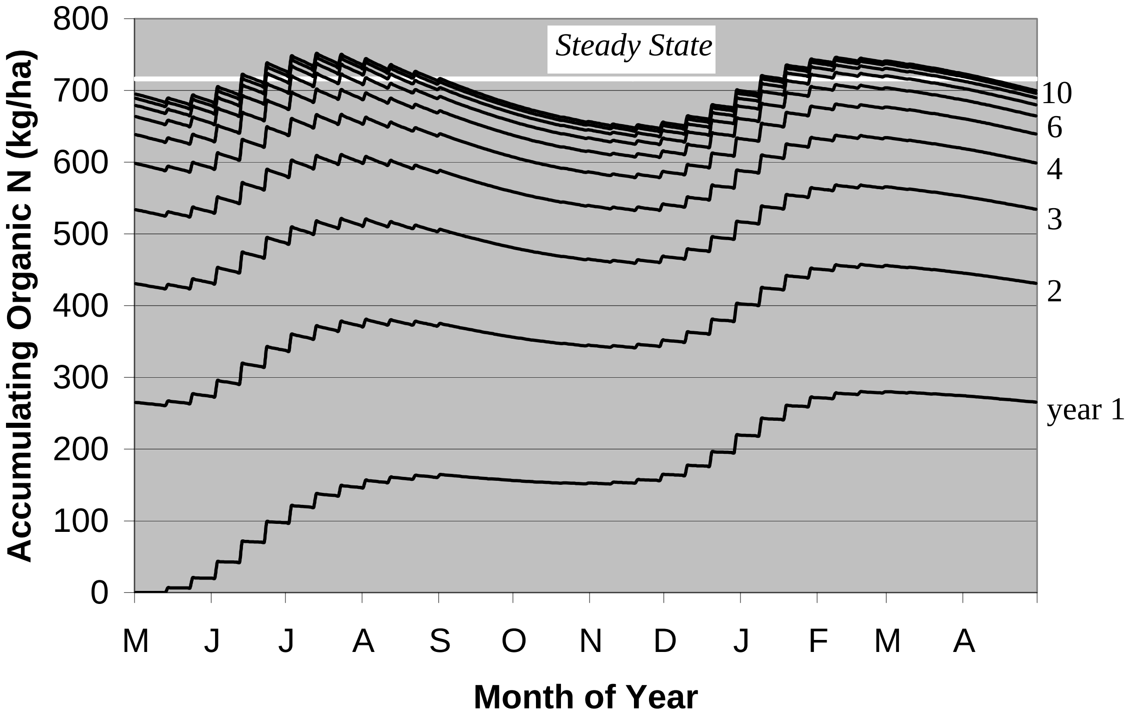

**Fig 1.** Model predictions for a soil accumulating soil organic N after 10 years of manure applications at agronomic rates to a forage corn-triticale rotation in Stanislaus County, CA. White line represents the ideal steady-state condition. Manure half-life is $t_{½}$= 283 d at 77ºF (25ºC). Decomposition is adjusted for temperature with Eq. 4.

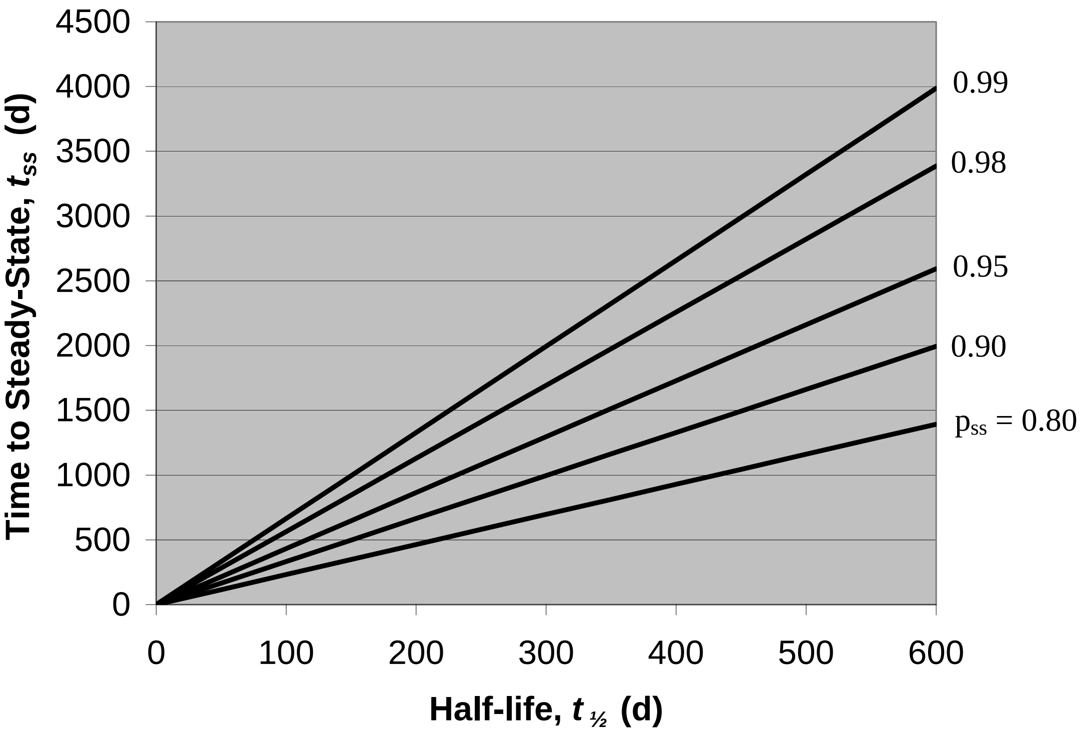

**Fig 2.** Time required to reach approximately steady-state conditions according to Eq. Because ideal steady-state is never actually reached, nutrient budgets may be developed by considering conditions where 95 percent of steady-state is complete.

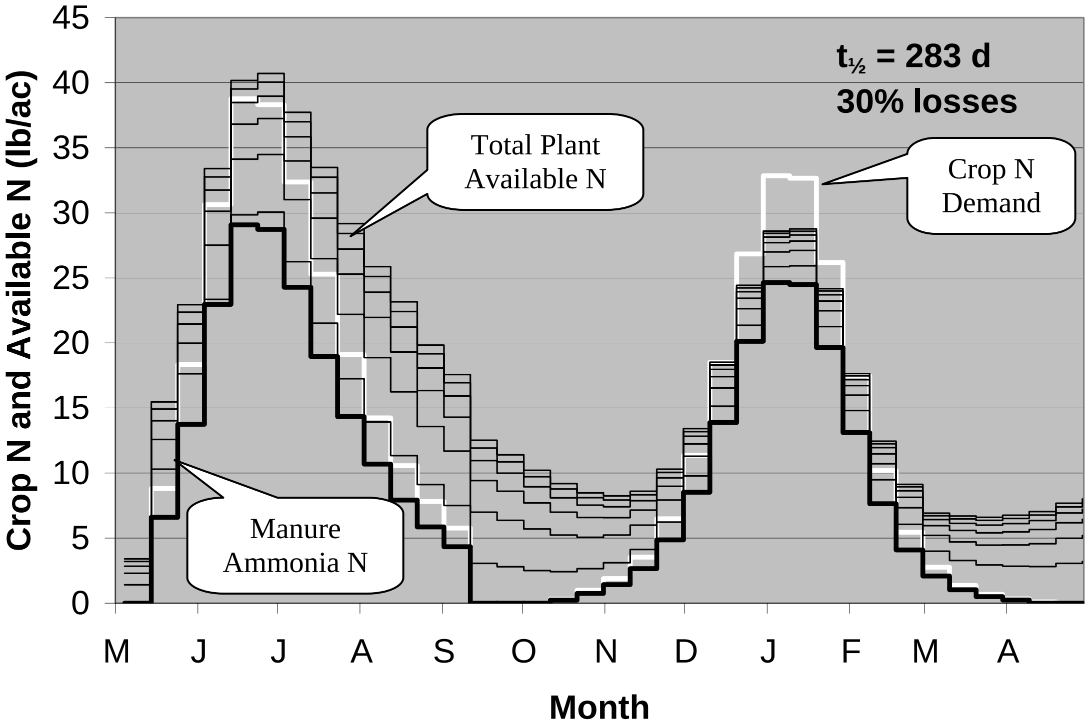

**Fig 3.** Model predictions for total plant available N over a six-year period. Each horizontal segment represents a ten-day planning period corresponding to a typical irrigation interval. Values represent the *total for that period*. Manure is applied at a rate 30 percent over project crop demand for that irrigation period. White line represents crop N demand. Dark black line is the inorganic N associated with manure applications assuming that total manure N is half ammonia N and half organic N. Fine black lines include both applied ammonia N and additional N mineralized for that period.