Cooperative Extension Service
College of Tropical Agriculture and Human Resources
University of Hawai'i at Mānoa

Soil and Crop Management
July 2006
SCM-15

Nitrogen Mineralization Potential in Important Agricultural Soils of Hawai'i

Jonathan Deenik
Department of Tropical Plant and Soil Sciences

Most of the nitrogen (N) in the environment is in forms that are unavailable for plant uptake. Nitrogen in the plant root zone is either nitrogen gas (N_2), as a component of the air occupying the soil pore space, or organic N present in various forms, including plant and microbial proteins and amino acids, in the soil organic matter. In a process known as *N mineralization*, the *organic* N contained in soil organic matter is converted into plant-useable *inorganic* forms (ammonium, NH_4^+, and nitrate, NO_3^-) as a result of the activities of soil microorganisms.

In managing plant nutrients over continuing crop cycles, farmers face the challenge of estimating the amount of the soil's organic N resource ("N pool") that is made available for plant uptake (mineralized) over time. This publication discusses the soil N mineralization process, its primary controlling factors, and their plant nutrient management implications. It also shows how differences in N mineralization rates among Hawai'i's important agricultural soils can affect farm productivity and the need for nutrient inputs. For farmers, N mineralization is an important process to be aware of, particularly for the farmer who wishes to farm organically, without inorganic N fertilizers.

Background

In undisturbed natural environments, plants obtain N for their growth from two microbial processes. The first is biological N fixation, the conversion of atmospheric N_2 to inorganic N by various soil microorganisms, some symbiotic with plants. The second, the subject of this publication, is N mineralization, which is the conversion of organic N contained in soil organic matter into inorganic, plant-available N as it is decomposed by soil bacteria and fungi. Enzymatic processes occurring during organic matter decomposition release ammonium into the soil solution.

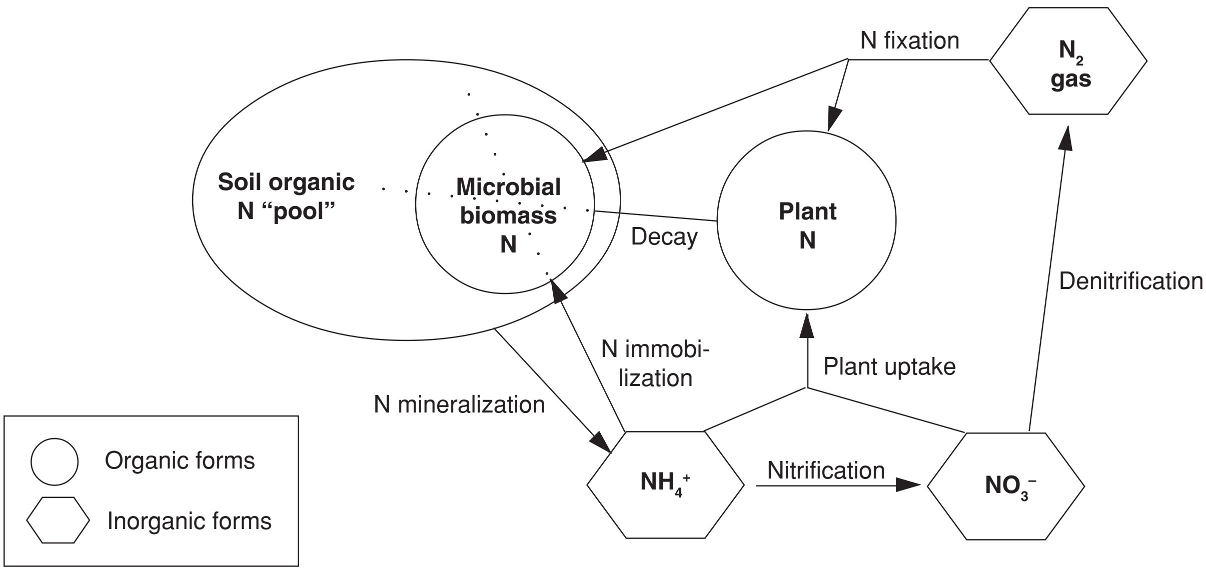
Once in the soil solution, ammonium can follow several pathways, illustrated in Figure 1. It can be

- oxidized by nitrifying bacteria and converted to nitrate or nitrite (NO_2^-), which under flooded conditions can be returned to the atmosphere as N_2 gas through *denitrification* processes,
- held as an exchangeable cation (positively charged ion) on negatively charged surfaces such as those occurring on some soil clay particles,
- lost by conversion to gaseous ammonia (NH_3) under alkaline soil conditions, or
- assimilated by soil microorganisms and plants to supply their N requirements; this is called *immobilization*, because the ammonium is incorporated into tissues and is thus rendered temporarily unavailable until those tissues decompose.

As Figure 1 shows, mineralization and immobilization can be occurring simultaneously, because microorganisms not only break down organic N but they can also temporarily assimilate ammonium into their cellular processes. The dynamic nature of these competing processes causes either an increase in soil inorganic N or, conversely, a decrease when inorganic N is immobilized into organic forms. The decrease in soil inorganic N is termed "immobilization" because inorganic N is assimilated back into the microbial population, temporarily reducing the plant-available N pool.

Published by the College of Tropical Agriculture and Human Resources (CTAHR) and issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Andrew G. Hashimoto, Director/Dean, Cooperative Extension Service/CTAHR, University of Hawai'i at Mānoa, Honolulu, Hawai'i 96822. An equal opportunity/affirmative action institution providing programs and services to the people of Hawai'i without regard to race, sex, age, religion, color, national origin, ancestry, disability, marital status, arrest and court record, sexual orientation, or status as a covered veteran. CTAHR publications can be found on the Web site <http://www.ctahr.hawaii.edu/freepubs>.

Figure 1. Diagram illustrating some processes in the nitrogen cycle in soils.



(Adapted from Murphy et al., 2003, Advances in Agronomy 85:69–118).

Factors affecting N mineralization

Decomposition of soil organic matter and the subsequent release of inorganic N from the organic N pool occur through the activity of soil microflora, principally bacteria and fungi. Environmental and soil mineralogy factors affect the microflora players and their actions, which in turn determine the rate of N mineralization in the soil and thus the amount mineralized over time. Climate interacts with soil properties, including the soil's microflora, to affect the size and chemical nature of the soil's organic N pool.

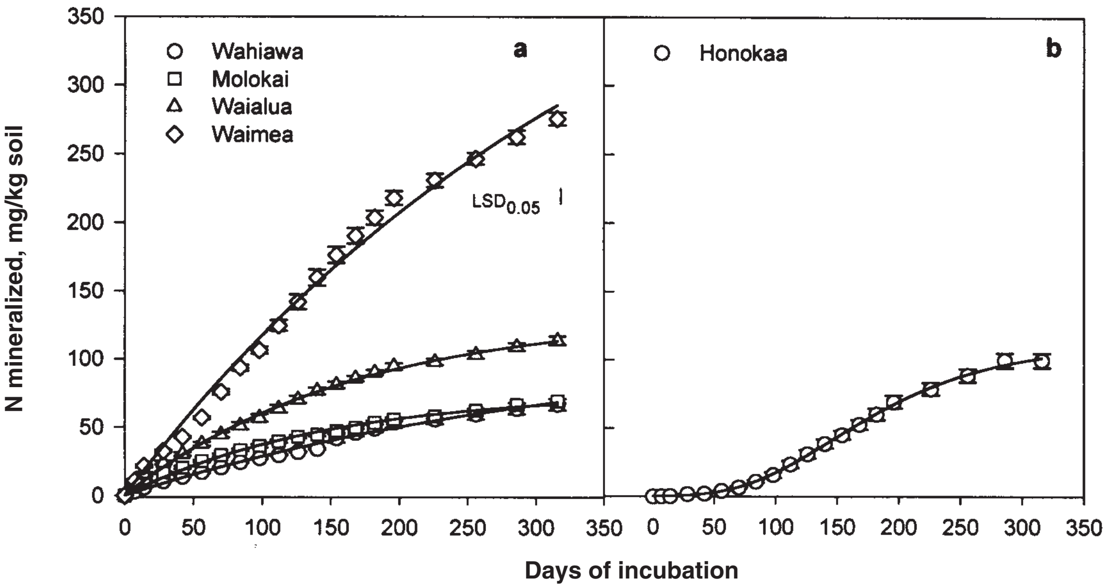
Soil temperature and moisture content have a strong effect on N mineralization reactions. Microbial activity is limited at soil temperature near freezing and increases with rising soil temperature. Maximum N mineralization occurs when the soil temperature reaches 30–35°C (86–95°F). In dry soils, N mineralization is low because soil microorganism activity is limited by water availability. In saturated soils, lack of oxygen limits N mineralization because only soil microorganisms that can survive under anaerobic conditions are active.

The amount and type of clay in a soil affects N mineralization reactions. Mineralization tends to be greater in coarse-textured soils low in clay and less as the soil clay content increases. Finely textured soils high in clay are abundant in micropores in which organic matter can find physical protection from microbial decomposition.

Compared to soil texture, the effects of soil mineralogy on N mineralization are less clear. Soils dominated by clay minerals that shrink and swell with fluctuations in soil moisture, such as montmorillonite, tend to have higher N mineralization rates than those containing clays that do not shrink and swell, such as kaolinite. Volcanic ash soils rich in organic matter tend to have high N mineralization rates.

The interaction of the N mineralization and immobilization processes is closely tied to the carbon (C) cycle, because decomposing microorganisms derive their energy from carbon compounds they find in soil organic matter. Carbon and N compounds in soil organic matter can be placed in two pools: a labile (active), and a stabilized (passive) pool. The labile pool is composed of microbial biomass, particulate organic matter (fine plant residues), and compounds that are readily decomposed by soil microorganisms. The stabilized pool of organic matter is composed primarily of complex stable organic compounds that are resistant to microbial decomposition. Over the long term, because it provides the underlying food source for soil microorganisms, this pool of organic matter is an important source of slowly mineralizable N.

Figure 2. Cumulative N mineralized from five Hawaiian soils with differing mineralogical properties in a 312-day incubation experiment. Each point is a mean of three replicates, and bars associated with the points represent the standard error of the mean.



Nitrogen mineralization potential of five Hawaiian soils

A recent laboratory incubation experiment measured the N mineralization potential of five soils with varying physical, chemical, and mineralogical properties. The soil names, classifications, mineralogy, and selected physical and chemical properties are given in Table 1. These soils were chosen to represent the range in mineralogy of the most important agricultural soil types in Hawai'i.

The Waimea series is a fertile sandy loam soil developed on volcanic ash deposits in areas with moderate rainfall. It is found in Waimea on Hawai'i, and similar soils are found in the Kula area on Maui. The Honokaa* soil is representative of the highly weathered volcanic ash soils of the Hāmākua coast of Hawai'i. It is an infertile silty clay soil low in nutrients, especially calcium (Ca) and phosphorus (P). The Waialua series is a fertile soil found in the lowlands of O'ahu. The Molokai soil is a red soil, dominated by kaolinite, found in dry, low-elevation areas of west and central Maui, Moloka'i, and central O'ahu. The Wahiawa soil covers extensive areas of the Wahiawa-Schofield plateau on O'ahu. It is more acidic and less fertile than the Molokai series. We used a leaching experiment to characterize the rate at which inorganic N was released from the soils.

Soil type had a strong influence on N mineralization (Fig. 2a, b). The fertile Waimea soil mineralized the largest amount of N, equivalent to approximately 310 lb/acre during the incubation period. The Waialua soil mineralized the equivalent of 130 lb/acre of N, and the Molokai and Wahiawa soils mineralized approximately 75 lb/acre. These four soils exhibited similar patterns for N mineralization (Fig. 2a), with gradually increasing N mineralization throughout the incubation period. The Honokaa soil (Fig. 2b) exhibited a lag in N mineralization during the first quarter of the incubation period but mineralized a total of 120 lb/acre by the end of the incubation.

The high organic carbon and total N contents of the Honokaa soil would suggest a high mineralization potential. Previous studies have found, however, that soils rich in allophane tend to have low N mineralization rates. Several explanations have been proposed to explain this, including physical protection of organic substances in soil micropores, complexation of organic compounds

*Place names in the text include the Hawaiian pronunciation aids ('okina and kahakō), but these were not included in the names of soil series when the Soil Taxonomy for Hawai'i was developed.

Table 1. Classification and selected physical and chemical properties of the soils used in the incubation study.

Soil series	Soil classification	Textural class	Mineralogy	Clay %	pH	N %	OC %	P lb/acre
Waimea	Haplustand	Very fine sandy loam	Allophane	4.0	6.9	0.55	5.8	790
Honokaa	Hydrudand	Silty clay loam	Allophane	NA	5.8	0.50	10	39
Molokai	Torrox	Silty clay loam	Kaolinite	39.8	6.6	0.094	1.4	130
Wahiawa	Haplustox	Clay	Kaolinite	76.1	6.0	0.13	1.5	38
Waialua	Haplustoll	Silty clay	Smectite/halloysite	54.7	6.8	0.079	1.3	420

with iron and aluminum oxide surfaces, and reduced microbial activity from P deficiency. The curve depicting N mineralization in the Honokaa soil suggests that microbial activity was suppressed during the first quarter of the incubation period.

Our results agree with previous findings. The Honokaa soil is rich in clay, which offers considerable physical protection to organic matter; its P level is also low, which can limit microbial activity. In addition, we found that the hot-water extractable C fraction (a measure of microbial biomass) was much lower (342 mg C per kg soil) than that of the Waimea soil (806 mg/kg), another indication of lower microbial activity at the outset of the incubation.

Based on our knowledge of soil classification, we can use the results from the incubation experiment to predict the N mineralization potential of other important agricultural soils in Hawai‘i (Table 2). For example, we predict that the Kula and Pane series on Maui, which belong to the same group of soils as the Waimea series, would have a high N mineralization potential under undisturbed conditions. The Ewa (O‘ahu, Maui), Paia (Maui), and Makaweli (Kaua‘i) soils belong to the same group as the Waialua series and would have intermediate N mineralization potentials. The soils of the Hāmākua coast (Hawai‘i), such as the Hilo, Akaka, and Kaiwiki series, would nave N mineralization dynamics similar to the Honokaa series. Weathered Oxisols, including the Mahana and Lihue (Kaua‘i) and Lahaina (O‘ahu, Moloka‘i, Maui) series, would exhibit relatively low N mineralization potentials, similar to the Wahiawa and Molokai series.

Soil management and N mineralization potential

Soil management practices have a strong effect on the N mineralization potential of a soil. Intensive farming practices that rely heavily on tillage and synthetic fertilizers tend to decrease the soil's mineralizable N pool—N mineralization decreases because conventional farming practices tend to deplete soil organic matter. The data in Table 3 show how long-term cultivation changes the N mineralization potential of the Waimea and Waialua series soils. For both soils, long-term cultivation decreased N mineralization by a factor of 30. In the case of the Waimea soil, the decreased N mineralization is accompanied by dramatic decreases in soil organic carbon and total N. The decline in N mineralization indicates low microbial activity and a degradation of the biological properties of the soil. Restoring the N mineralization potential of a degraded soil requires sustained organic matter inputs in large amounts. The data at the bottom of Table 3 show that compost additions raised the N mineralization potential of a degraded soil within 2 months after their addition, but several years of sustained compost additions are needed to restore an N mineralization potential adequate for good crop production.

Summary

- Nitrogen mineralization potential varies with soil type. Moderately weathered volcanic ash soils such as the Waimea series have very high N mineralization potentials; highly weathered ash soils such as the Honokaa series have a lower mineralization potential and had little mineralization during the first 2 months

Table 2. Soil classification can be used to extrapolate N mineralization potential to important agricultural soil series using the Great Group level of the Soil Taxonomy.

N Mineralization potential	Great Group	Soil series
High	Haplustand	Io, Kula, Kaipoipoi, Kamaoa, Kikoni, Oli, Palapalai, Pane, Naalehu, Waimea
Intermediate	Haplustoll	Ewa, Haleiwa, Iao, Kawaihapai, Koloa, Makaweli, Mokuleia, Paia, Pulehu, Waialua, Waipahu
	Hydrudand	Akaka, Hilo, Honokaa, Kaiwiki, Kukaiau, Ookala
Low	Haplustox, Eutrustox, Eutrotorrox	Lahaina, Lihue, Mahana, Molokai, Niu, Wahiawa

Table 3. The effect of long-term cultivation and compost additions on the N mineralization potential of two soils.

Soil	Management	N mineralization potential* (mg NH_4^+-N/kg soil)	Organic carbon (%)	Total nitrogen
Waimea	Virgin	154 (17.0)	5.8	0.55
	Cultivated	4.89 (0.4)	3.2	0.29
Waialua	Virgin	39.6 (5.77)	1.3	0.08
	Cultivated	–3.60 (3.76)	-	-
	Cultivated + 10 T/acre compost	9.43 (1.2)	-	-
	Cultivated + 40 T/acre compost	17.8 (2.7)	-	-

*Determined by the 7-day anaerobic incubation method. Numbers in parentheses represent the standard error of the mean.

of our experiment; moderately weathered soils with near-neutral pH, such as the Waialua series, have N mineralization potentials that are intermediate between the Waimea and Honokaa soils; highly weathered soils, such as the Wahiawa series, have the lowest N mineralization potential.
- Nitrogen mineralization is a measure of soil quality: soils with high N mineralization potential tend to be inherently fertile, while soils with low N mineralization potential tend to be less fertile and require greater agricultural inputs.
- Extensive cultivation with minimal organic matter input depletes soil organic matter, causing a significant decline in the potential for N mineralization processes to provide plant-available N.
- Organic inputs increase the potential for N mineralization to contribute to plant nutrition.

Acknowledgments

The incubation studies were supported by the Natural Resource Conservation Service through CESU Cooperative Agreement No. 68-3A75-4-72 Mod. 3. Drs. G. Uehara and N.V. Hue provided helpful comments during preparation of this publication.