Biological factors influence N mineralization from soil organic matter and crop residues in Australian cropping systems

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Abstract

Nitrogen mineralized from the soil organic matter (SOM) and crop residues makes a substantial contribution to crop N uptake. Soil N supply comes from soil organic matter and recent crop residues and the rate of supply is influenced by the soil biological capacity, i.e. microbial biomass (MB) and microbial turnover, and modulated by management and environmental factors. Soil type, crop rotation and management practices associated with tillage, stubble retention and fertilizer application can influence the diversity of microbial populations and the size of MB, and along with the environment they affect biological processes involved in N_2 fixation, mineralization and availability and losses. The rate and timing of the availability of N from stubble to the following crops is determined by the rate of decomposition and immobilization by soil microorganisms (N in MB). The amount of MB-C & N vary with soil type, crop rotation, tillage and other management practices that can influence microbial populations. In southern Australian cropping regions, the effect of loss of N from stubble removal may not be greater than its temporary tie-up during decomposition.

Key Words

Nitrogen, mineralization, immobilization, microbial biomass, microbial diversity, *amo*A, *nif*H

Introduction

In many Australian agricultural soils, carbon availability is the most limiting constraint to microbial functions hence management of biologically available C is the key to improving biological functions including those involved in N mineralization. In soils, water soluble organic C is not only an immediate source of C for microbes, but its production is microbially mediated hence it has been suggested that the flow of C through water soluble components supplies substrate for MB turnover. Soil MB is both a source and sink for nutrients and mineralization of organic substrates (e.g. soil organic matter and crop residues).The release of nutrients in soils is mainly regulated by the heterotrophic activity of decomposer microbial community and microbial turnover related processes have a significant influence on the rate and timing of N mineralization and consequently plant available mineral N levels in soils (Figure 1).

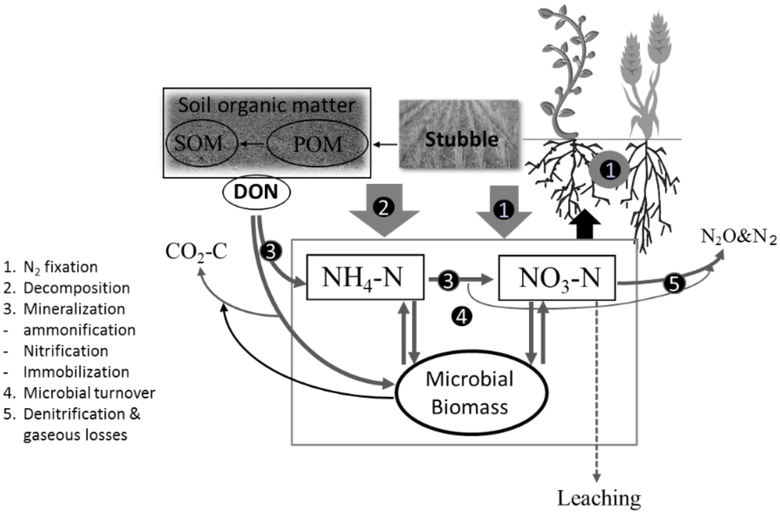


Figure 1. Biological processes involved in nitrogen cycling that influence plant available nitrogen levels in soil. SOM – soil organic matter, DON – dissolved organic nitrogen, POM – particulate organic matter.

Additionally, microflora-microfaunal (e.g. protozoa and nematodes) interactions modulate microbial turnover and thus can affect the release of N immobilized in MB. The impact of a soil biological process within a farming system depends on when they occur in relation to the crop growth (Gupta et al. 2011). Therefore, soil moisture, temperature and C availability need to be in synchrony for optimal performance of biological processes involved in N cycling to supply N during critical crop growth stages. For example, organisms involved in N mineralization are active in both the off-season and *in-crop* season. The N mineralized during the off-season may accumulate or be lost through leaching, denitrification or weed uptake, whereas the N mineralized during growing season in the rhizosphere would be utilized immediately by the crop. Similarly, N fixed by diazotrophs near decomposing crop residues must go through microbial turnover processes before it is available for plant uptake. In the low organic matter Australian agricultural soils, SOM mineralization is dependent on MB size, community structure and specific activity. N cycling biological processes in soil are a product of population diversity and activity as limited by soil and environmental constraints. Soil physico-chemical properties and management practices can influence the composition of microorganisms and their functional capability. In this paper we discuss the factors influencing MB, immobilization-mineralization and microbial turnover in southern Australian cropping soils and management strategies that can help better synchronize N availability for plant needs or improve fertilizer N use efficiency.

In Australian agricultural soils, MB-C accounts to 1.5 to 3.0% of soil organic C and MB-N 2-5% of total N. The amount of MB varies with soil type and agro-ecological region (Table 1), and is influenced by crop rotation, tillage and stubble management practices that influence microbial populations and the quantity and quality of residues. MB-C:N ratio generally varies between 6.5 and 9 and a wide MB-C:N ratio is shown to be associated with cereal crop residues and rhizosphere soils. Due to the short turnover time of MB in Australian soils, it may only act as a short-term reservoir to nutrients and a biocatalyst for organic matter transformations. Thus management practices that increase the size of the MB pool and modulate its turnover could assist with the synchronization of N mineralization to crop demand.

Table 1. Amount of microbial biomass and N supply and immobilization potentials (for the crop growth period) in agricultural soils.

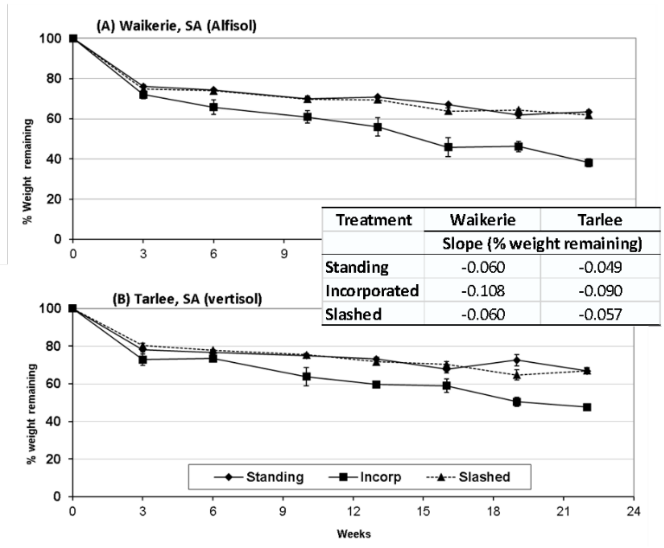
Location	**Soil type**	**MB-C**	**N immobilization potential**[&]	**N supply potential**[$]
		kg C / ha	kg N / ha	
Waikerie/Karoonda, SA	Sand and sandy loam	150 - 300	12 - 22	10 - 35
Streaky Bay, SA	Calcarosol	210 - 400	15 - 30	20 - 50
Wongan Hills, WA	Loamy sand	250 - 350	18 - 25	25 - 40
Kerrabee, NSW	Loam	420 - 525	30 - 40	35 - 50
Temora, NSW	Red earth	500 - 735	35 - 55	50 - 100
Rutherglen, Vic	Red brown earth	350 - 700	25 - 50	30 - 100
Leeton/Warialda, NSW	Clay	350 - 1000	25 - 70	25 - 75

[&] N immobilization potential is estimated assuming an average 50% increase of *in-crop* microbial biomass.

[$] N supply potential is calculated from N in MB plus N mineralization measured in a lab-incubation assay.

Decomposition

In Australian agricultural soils, above-ground crop residues and below-ground root associated inputs are the two major sources of C for soil biota. With the effective management of weeds using herbicides in modern farming systems and intensive cropping practices, C inputs from crops have become the sole source of C for soil organisms. It is estimated that >60% of MB and biological activity in soil is concentrated near crop residues in the rainfed cropping soils in southern Australia and thus stubble retention generally increases the amount of MB in soil compared to stubble burning, especially during the first 3-5 months of decomposition. The proportion of C and nutrients used for respiration and growth depends upon the quality of organic molecules. Therefore, microbiology of stubble decomposition can have a significant impact on many of the N cycling processes. Crop rotation can significantly influence the quality of organic residues available for microbial decomposition i.e. a wide C:N ratio for cereal stubble (ave. 85:1) compared to that for legume residues (ave. 35:1). Decomposition of crop residues is influenced by the composition and activity of soil microflora, e.g. Acidobacteria *vs*. Proteobacteria and copiotrophs *vs*. oligotrophs (Gupta et al. 2015). Soil fauna help in the fragmentation and incorporation of stubble into soil thereby improving the contact between stubble and microbes, in particular in no-till systems. Decomposition rates are generally faster in sandy soils (ave. 30-60% in 12 wks) compared to that in loam and clay soils (ave. 30-45%) because sandy soils provide less protection. Stubble incorporation accelerates the rate of decomposition in all soil types through the improved contact between crop residues and microbes and increased soil bacterial diversity (Figure 2).



Treatment	Waikerie	Tarlee
	Slope (% weight remaining)	
Standing	-0.060	-0.049
Incorporated	-0.108	-0.090
Slashed	-0.060	-0.057

Figure 2. Decomposition of wheat stubble in litter bag experiments conducted in field experimental plots in SA during 2007 and 2008. Incubation started immediately after harvesting of wheat crop in the previous season. In general there was a sharp decline in the N concentration of stubble during the first 3 wks of incubation after which the changes were small.

N released during the decomposition and SOM cycling can be rapidly assimilated into MB which is subsequently released through microbial turnover and microbe-fauna interactions. In general, 15-40% of C used is retained within microorganisms. During microbial turnover 50-65% of MB is retained, the remaining respired (for C) or released (N) into nutrient pool, and these proportions vary depending upon the quality of organic matter source and soil conditions. Due to the wide C:N ratio of cereal residues, the rate of decomposition can significantly influence the dynamics of microbial immobilization of mineral N. It is suggested that crop residues with a C:N ratio >22:1 generally result in immobilization of mineral N in MB. The rate and timing of availability of N from stubble to the following crops is determined by the rate of decomposition and immobilization.

Mineralization and Immobilization

Since MB is a store-house for nutrients, changes in the amount of MB due to management and seasonal variation can exert a significant impact on microbial immobilization and net N mineralization. Therefore, the estimation of N supply potential at the beginning of a crop season should include the amount of N in MB and the N mineralized from SOM and crop residues. Although the composition of microbial community and abundances of specific microbial groups have been shown to influence the rates of different N cycling biological processes, edaphic factors are suggested to be the rate-limiting factors associated with gross N transformation processes. For example, tillage practices accelerate the decomposition and microbial turnover resulting in quick accumulation of mineral N, especially in soils with lower MB levels. Significant differences in the *in-crop* net N mineralization were observed between different stubble management strategies in a sandy soil at Karoonda in South Australia (Figure 3).

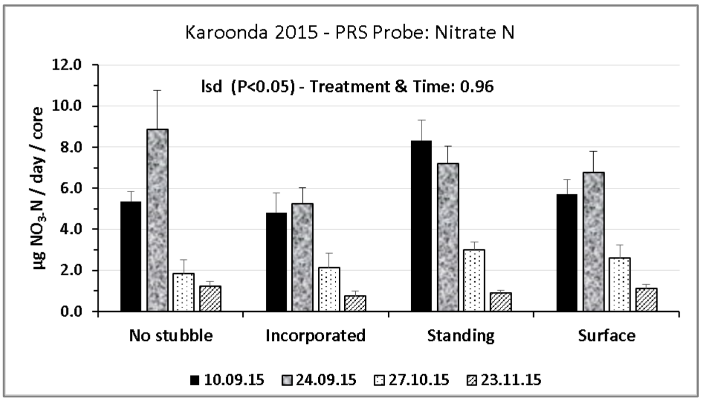


Figure 3. Net N mineralization (ave ±std error) measured *in-situ* within a wheat crop as influenced by stubble retention practices on a Kandosol in South Australia. PRS^{TM} probes (www.westernag.ca) were incubated (ave. 14 days) in the surface 10 depth soil inside open PVC cores in field experimental plots. Stubble quantity and its contact with soil are attributed to the treatment and temporal variation.

Research in Victoria and SA has shown that tillage and rotation can affect the linkages between the activity of microbes processing organic N and those related to fertilizer and mineral N transformations influencing the rate of release and accumulation of mineral N in soil (Phillips et al. 2015; Gupta et al. 2014). Immobilization of fertilizer N in MB, becoming unavailable to plants, is generally short-term and has been found to be available to crops later in the crop season. Gross N mineralization is generally found to be higher in the presence of a growing plant i.e. *in-crop* compared to that in summer mainly due to the rhizosphere influence, however increased immobilization from higher MB may result in lower net N mineralization. But increased micro-faunal predation in the rhizosphere releases the immobilized N for plant uptake, especially in the stubble retained systems.

Nitrification

Abundance and type of nitrifying microbes (bacteria-AOB and archaea-AOA) vary with soil type and depth, and management practices e.g. stubble retention, tillage and agrochemical addition influences their activity.

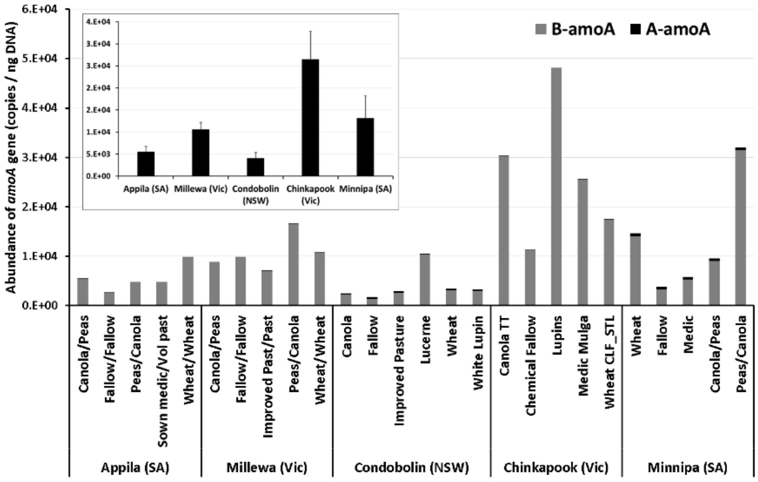


Figure 4. Abundances of AOB (B-amoA) and AOA (A-amoA) in surface 10 cm soils as influenced by crop rotation (Gupta V.V.S.R. and Wilhelm N., unpublished).

AOB are more abundant in the surface soils whereas AOA are higher at depth. Additionally, relative proportions of AOA and AOB populations can vary seasonally, i.e. in-crop vs. out-off crop season. AOA abundances have shown significant responses to changing soil water status (water-filled pore space), however rate of nitrification seems to be better correlated to AOB populations.

Banding fertilizers can influence the activity of nitrifiers, the amount of MB and nitrate N accumulation (Angus et al. 2014). Thus, fertilizer N-use efficiency could be manipulated through fertilizer placement or the use of nitrification inhibitors. Future work on the contribution of AOA and AOB to nitrification in agricultural soils and finding practices that modify nitrification to improve fertilizer use efficiency is needed.

Diazotrophic Nitrogen fixation

There is a diverse group of diazotrophic (*nif*H) bacteria present in Australian cereal crop fields with a potential for management strategies that can promote N_2 fixation in different soils and regions. Recent research has shown that diazotrophic N fixation can make agronomically significant contribution to the available N pool in stubble retained cereal based systems and perennial grass systems (Gupta et al. 2014).

Conclusions

Nitrogen mineralized from the SOM and crop residues makes a substantial contribution to crop N uptake. Management strategies including stubble retention, tillage and rotation and crop and variety selection can help manipulate composition and abundances of microbial communities involved in N mineralization, the size and turnover of MB and influence fertilizer N use efficiency. N supply potential estimates need to reflect soil's ability and seasonal conditions in order to make better N management decisions in cropping soils.

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