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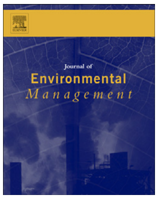

Research article

Soil gross nitrogen transformations in responses to land use conversion in a subtropical karst region

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ABSTRACT

Gross nitrogen (N) transformations can provide important information for assessing indigenous soil N supply capacity and soil nitrate leaching potential. The current study aimed to assess the variation of gross N transformations in response to conversion of maize-soybean fields to sugarcane, mulberry, and forage grass fields in a subtropical karst region of southwest China. Mature forests were included for comparison. Gross rates of N mineralization (GNM) were highest in the forests, intermediate in the maize-soybean and forage grass fields, and lowest in the sugarcane and mulberry fields, suggesting capacity of indigenous soil N supply derived from organic N mineralization was lowered after conversion to sugarcane and mulberry fields. The relative high indigenous soil N supply capacity in the maize-soybean fields was obtained at the cost of soil organic N depletion. Gross nitrification (GN) rates were highest in the forests, intermediate in the forage grass fields and lowest in the other three agricultural land use types. The nitrate retention capacity (24.1 ± 2.0% on average) was similar among the five land use types, implying that nitrate leaching potential was not changed after land use conversion. Microbial biomass N exerted significant direct effects on the rates of N mineralization, nitrification, ammonium immobilization and nitrate immobilization. Soil organic carbon, total N and exchangeable magnesium had significant indirect effects on these N transformation rates. Our findings suggest that forage grass cultivation instead of other agricultural land uses should be recommended from the perspective of increasing indigenous soil N supply while not depleting soil organic N pool.

1. Introduction

Synthetic fertilizer nitrogen (N) application has increased rapidly over the past decades in China, with the total consumption of synthetic fertilizer N increased by 191% in 2007 relative to 1981 (Guo et al., 2010). The high rates of fertilizer N inputs are usually accompanied by high rates of N losses including nitrate (NO_3^-) leaching and nitrous oxide emission in China (Zhao et al., 2012; Zhang et al., 2013b). The nitrogenous pollutants emitted from soils are mostly produced during internal/gross N transformations. For example, high rates of gross N mineralization and nitrification along with low NO_3^- consumption would lead to high risks of NO_3^- leaching. In order to develop strategies to mitigate N losses, it is hence necessary to unravel the characteristics of gross N transformations under regional-specific conditions.

Investigation of gross N transformations, especially gross N mineralization is also vital for assessing the capacity of indigenous soil N supply (defined as the N supply derived from organic N mineralization hereafter) (Osterholz et al., 2017), which is an important aspect of soil fertility (Diacono and Montemurro, 2012). Soil total N (TN) is mostly composed of organic N (>90%), especially N-containing polymers in the plow layer of agricultural fields (Geisseler et al., 2010; St Luce et al., 2011). The soil organic N needs to be mineralized to inorganic N (the primary form of crop-available N) before it can be utilized by crops (St Luce et al., 2011). It is estimated that inorganic N released during soil organic N mineralization may contribute to more than half of total N uptake

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by agricultural crops (St. Luce et al., 2014). This clearly suggests that indigenous soil N supply plays a crucial role in maintaining crop productivity. Indigenous soil N supply has often been assessed by measuring net N mineralization rate, which, however, may not fully reflect soil N supply capacity as only the change of soil inorganic N pool over a period is determined (Osterholz et al., 2017). So far, there is only one study which assesses soil N supply capacity by investigating gross N mineralization, and proposes that gross N mineralization can better represent soil N supply capacity than other measures such as net N mineralization (Osterholz et al., 2017).

Gross N transformations are controlled by multiple soil properties, such as soil organic carbon (SOC), soil TN, microbial community abundance and structure (Booth et al., 2005; Högberg et al., 2007; Yang et al., 2017). The above variables may be affected by agricultural land use type and management via their effects on detritus quantity and quality, root exudates, soil aeration, etc. (Verchot et al., 2001; Zhang et al., 2011; Staelens et al., 2012). For example, cultivation of perennial grasses and crops are regarded as efficient measures for agricultural soil sequestration of both SOC and TN (Freibauer et al., 2004). Conversion from conventional tillage to reduced tillage, especially no tillage, has been found to be efficient in enhancing SOC, TN, microbial community abundance, structure and activity (Lal and Kimble, 1997; Freibauer et al., 2004; Zuber and Villamil, 2016). Subsequently, different agricultural land use types and managements may have great impacts on gross N transformations via their influences on soil biotic and abiotic properties. For example, intensive vegetable cultivation was found to alter most N transformation rates relative to rice-wheat rotation system (Zhu et al., 2011).

Karst ecosystems are widely distributed in southwest China, and in other regions of the world as well (Wen et al., 2016; Li et al., 2017a). In the past, intensive agricultural activities and other human disturbances resulted in serious land degradation in the karst region of southwest China. Maize-soybean rotation system (maize-soybean field hereafter) was traditionally widespread in the karst region. Nevertheless, maize-soybean cultivation involves two times of tillage each year, and is notorious as one major driver of agricultural land degradation. Sugarcane and mulberry cultivations were proposed in the 1980s as conservation agriculture systems in the karst region of Guangxi Zhuang Autonomous Region. Forage grass cultivation-livestock raising model was recently proposed to replace the maize-soybean rotation system in order to improve soil fertility and prevent land degradation in the karst region. Nevertheless, how effective the three proposed conservation agricultural systems (i.e., sugarcane, mulberry and forage grass cultivation) were in soil fertility improvement and NO_3^- leaching reduction has never been assessed in the karst region.

In the present study, we measured gross N transformations in the maize-soybean, sugarcane, mulberry and forage grass fields, with mature forests included for comparison. The major objectives were to address: how does conversion of maize-soybean fields to the three proposed conservation agriculture systems impact soil gross N transformations; what are the major factors driving the dynamics of soil gross N transformations during the land use conversion; which conservation agriculture system is most effective for improving indigenous soil N supply; and how does the conversion of maize-soybean fields to the three proposed conservation agriculture systems affect soil NO_3^- leaching risk?

2. Materials and methods

2.1. Experimental design

The study was carried out in Huanjiang County (24°42′N – 25°02′N, 107°57′E – 108°21′E), southwest China. The region is within the subtropical climate zone. The mean annual air temperature varies from 17.8 to 21.1 °C, and mean annual precipitation ranges from 1346 to 1498 mm (Li et al., 2017b). The periods from April to August and from September to March of the next year are wet and dry seasons, respectively. The region is interwoven with karst and non-karst areas and characterized by flat valleys surrounded by hills. The soil is calcareous lithosols over the karst areas (Wen et al., 2016; Li et al., 2017a).

This study adopted a randomized complete block design with five blocks (about 9 km^2 each) distributed over a karst region. The distance between any two blocks ranged from 4 to 20 km. In each block, the four agricultural land use types, i.e., maize-soybean, sugarcane, mulberry and forage grass fields, were distributed randomly. The latter three land use types were transformed from maize-soybean fields, and had been managed continuously for about 15 years (Table 1). A represented field was selected for each land use type in each block. In each field, one sampling area (i.e., plot, > 400 m^2 each) was selected for soil sample collecting. Additionally, five nearby mature forests (>50 years old) were selected for comparison. All the plots were distributed over the valley or bottom slopes. The forage grass fields were planted with hybrid Napier grass, a hybrid between pearl millet (*Pennisetum americanum* (L.) Leeke) and Napier grass (*Pennisetum purpureum* Schumach) (Pincam et al., 2017).

Field sampling was carried out in October 2016. At each plot, ten mineral soil cores (0–10 cm) were sampled randomly with soil corers after removal of possible litter layer. The ten soil cores were well mixed as a composite sample by plot. Bulk density was measured with metal rings. SOC was measured by wet oxidation with dichromate redox colorimetric method (Carter and Gregorich,

Table 1
Management information for the five land use types.

Land use type	Life form	Tillage	Harvest	Fertilization	Replanting frequency
Maize-soybean	Annual	Tillage to a depth of 30 cm in March and July each year.	The aboveground biomass is harvested in July and December each year	Compound fertilizer ($N:P_2O_5:K_2O = 15:15:15$) is applied in March at a rate of about 1100 kg ha^{-1}, i.e., 1100 kg ha^{-1} yr^{-1}.	Every year
Sugarcane	Perennial	Tillage to a depth of 30 cm every 3 years.	The aboveground biomass were harvested in December or January each year	Compound fertilizer ($N:P_2O_5:K_2O = 15:15:15$) is applied in April at a rate of about 3000 kg ha^{-1}, i.e., 3000 kg ha^{-1} yr^{-1}.	Every 3 years
Mulberry	Perennial	Tillage to a depth of 30 cm every 10 years.	The mature leaves are harvested every 20 days, and all the branches are pruned in July and December, respectively.	Compound fertilizer ($N:P_2O_5:K_2O = 15:15:15$) is applied in March and July at a rate of about 1100 kg ha^{-1} each time, i.e., 2200 kg ha^{-1} yr^{-1}.	Every 10 years
Forage grass	Perennial	Tillage occurs only before planting.	The aboveground biomass is harvested for 3–5 times during the growing period	Compound fertilizer ($N:P_2O_5:K_2O = 15:15:15$) is applied in March and July at a rate of about 1400 kg ha^{-1} each time, i.e., 2800 kg ha^{-1} yr^{-1}.	Every 20 years
Forest	Perennial	Not applicable	Not applicable	Not applicable	Not applicable