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Seasonal and inter-annual variation of leaching of dissolved organic carbon and nitrogen under long-term manure application in an acidic clay soil in subtropical China

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ABSTRACT

Dissolved organic matter (DOM) plays an important role in soil biological activity and transport of pollutants and nutrients in soils, but very little information is available with regard to the long-term impact of agricultural management practices on the dynamics and fate of DOM in acidic soils. The seasonal and inter-annual variation of dissolved organic carbon (DOC) and nitrogen (DON) contents and leaching were investigated in an acidic clay soil (Ferric Acrisol) by a long-term field lysimeter experiment in subtropical China. The experiment was conducted from 2002 to 2010 with 4 fertilization treatments under maize monoculture: no manure (CK), low-rate manure with 150 kg N ha^{-1} y^{-1} (LM), high-rate manure with 600 kg N ha^{-1} y^{-1} (HM), and high-rate manure with 600 kg N ha^{-1} y^{-1} and lime at 3000 kg $Ca(OH)_2$ ha^{-1} 3 y^{-1} (HML). Manure application resulted in a seasonal variation of soil DOC and DON, and significant effects were observed by manure DOC, microbial biomass and soil water content. Soil DOC, which was mainly determined by soil organic matter and soil water content, increased yearly until the seventh year when it was stabilized. Manure application on acidic clay soil did not alter DOC leaching, whereas DON leaching clearly increased after three years of high manure application of 600 kg N ha^{-1} y^{-1}. The average annual DON leaching losses under long-term manure application had a range of 3.8–5.4 kg ha^{-1}, accounting for 6–11% of total nitrogen leached. The addition of lime, combined with manure application, produced no impact on soil dynamics and leaching of DOC and DON, with the exception of increasing emission of CO_2.

1. Introduction

Soil solutions contain varying amounts of dissolved organic matter (DOM), which originates from soil humus, plant litter, microbial biomass, root exudates, urine and feces, and organic fertilizer additions to soil (Kalbitz et al., 2000). DOM is operationally defined as a continuum of organic molecules of different sizes and structures that pass through a filter of 0.45 μm pore size, and involves mainly dissolved organic carbon (DOC), nitrogen (DON), phosphorous and sulfur, of which DOC and DON are of most concern due to relatively high content and ecological importance. DOM in soils plays an important role in soil biological activity (Flessa et al., 2000), pedogenesis (Sigfusson et al., 2008) and transport of pollutants in soils. However, recent research emphasizes the turnover of DOC and DON in soils as major pathways of biogeochemical element cycling (Kalbitz et al., 2000). To date, research on DOM dynamics has concentrated on temperate forest soils (Chantigny, 2003) and, as a result, knowledge of the dynamics and fate of DOM in agricultural soils and its response to agricultural management practices, especially long-term manure application is still fragmented and often inconsistent.

Numerous biotic and abiotic factors, including soil properties, climate, crop types and agricultural management practices (e.g., tillage, liming, fertilization and crop residue management etc.), control the temporal and spatial dynamics and fate of DOM (Don and Schulze, 2008; Murphy et al., 2000). Climate influences dynamics and fate of DOM through altering the production and decomposition of DOM, which is mainly regulated by temperature and humidity. DOM fluxes in forest soils also appear to be larger in the tropics and subtropics than in temperate zones due to greater

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precipitation, substantial substrate supply and related rapid decomposition (Fujii et al., 2009; Kalbitz et al., 2000). Application of organic amendments influences soil organic matter (SOM) and DOM (Wright et al., 2008). Researchers have argued that high waste or manure application rates induced a significant increase in DOC for several weeks to years (Chantigny et al., 2002; Gregorich et al., 1998). However, if wastes are rapidly decomposed in soil, DOC may quickly return to background levels (Franchini et al., 2001). Similarly, DON in soil was close to or below the control levels after temporary enhancement in a laboratory modeling experiment (Zhao et al., 2008).

The roles of DOM leaching in soil C and N cycles of agricultural ecosystems vary depending on soil type and vegetation (Fujii et al., 2011). Soil properties such as ionic strength and pH of the water phase influence organic matter solubility, whereas ferric and aluminum oxides/hydroxides and clay minerals determine the sorption/desorption equilibrium between the dissolved phase and the solid phase of SOM (Chantigny, 2003). The DOC and DON export from the soil was found to be consistently low due to the high adsorption onto oxides and clay minerals in mineral subsoil horizons (Kalbitz et al., 2000). Application of organic amendments increased soil DOC, which may coat soil particle surfaces and reduce the ability of soils to retain nutrient cations, thereby increasing leaching potential of DOC (Ashworth and Alloway, 2004). In addition, Murphy et al. (2000) stated that SOM blocks active sites on soil minerals and reduces the sorption of DOM, and thus more DON (10% of N leached) was leached from plots receiving farmyard manure compared to inorganic N in agricultural soil in Britain. However, few studies have reported the long-term effects of manure application on the dynamics and fate of DOM in subtropical regions with high temperature and humidity, where soil generally has Al and Fe oxides/hydroxides and clay minerals in abundance.

There is much, but inconsistent, information available on the effects of liming on DOM. Liming has been shown to increase the solubility and leaching of DOC in several experiments with forest soils (Andersson et al., 2000), whereas in other experiments no such effect was detected (Smolander et al., 1995). Therefore, liming may have different effects on the dynamics and fate of DOM under different climatic conditions and in different soil types.

It remains unclear to date how long-term manure application influences the dynamics of DOC and DON in subtropical regions of high humidity and temperature, where the turnover and mineralization of SOM is rapid. Simultaneously, management practices in agricultural systems, e.g., manure application and liming, will change the sorption capacity of soil and the resulting composition of DOM (Murphy et al., 2000). Thus, leaching of DOC and DON needs further investigation due to strong adsorption derived from high clay content and the presence of Al and Fe oxides/hydroxides in these regions. Therefore, we report here work from a lysimeter experiment to determine the effects of manure application and liming on (1) dynamics of DOC and DON in soil and (2) long-term leaching of DOC and DON through seepage in an acidic clay soil planted with corn in a subtropical region.

2. Materials and methods

2.1. Site and lysimeters

The lysimeter experiment was set up in National Agro-Ecosystem Observation and Research Station in Yingtan (28°15′20″N, 116°55′30″E, 38 m a.s.l.), which is located in Yujiang County, Jiangxi Province in Southeast China (Fig. 1). This region is characterized by a subtropical humid monsoon climate with a mean annual temperature of 17.6 °C and a mean annual precipitation of 1795 mm. Precipitation concentrates in Spring and early Summer, with 58.3% of total annual rainfall occurs in March–June. The acidic clay soils are typically distributed in hilly region of Southeast China. The experimental soil is an acid loamy clay derived from Quaternary red clay (Ferric Acrisols in the FAO classification system and Udic Ferralsols in Chinese Soil Taxonomy), which has 43–52% of clay, and 11.7–25.3% of ferric oxide and 26.3–34.1% of aluminum oxide in soil colloids, on a dry basis in a soil profile of depth 0–140 cm.

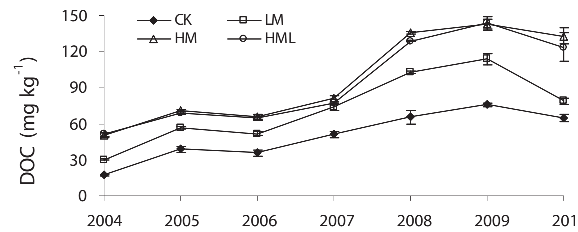

Fig. 1. Inter-annual variation of dissolved organic carbon (DOC) in surface soil under continuous manure application during 2004–2010. Vertical bars refer the standard error of three replicates. CK, no manure; LM, low-rate manure with 150 kg N ha^{-1} y^{-1}; HM, high-rate manure with 600 kg N ha^{-1} y^{-1}; HML, high-rate manure with 600 kg N ha^{-1} y^{-1} and lime ($Ca(OH)_2$ applied at 3000 kg ha^{-1} 3 y^{-1}).

Twelve concrete lysimeters, 2 m wide ×2 m long ×1.5 m deep, were constructed in the field and repacked with acidic clay soil in layers corresponding to the observed field profile in 1996. After a 3-year experiment studying the nutrient leaching under peanut-oilseed rotation (Sun et al., 2008), the surface layer (0–20 cm) of soil was removed in 2000. Then the surface soil collected from waste land with a vegetation of sparse pine trees was repacked into the plots of the container to achieve a bulk density of 1.11 g cm^{-3} in the surface layer (0–20 cm). The lysimeters were under fallow for two years prior to conducting the experiment of manure application in April 2002.

The main soil properties of the surface layer (0–20 cm) at the beginning of the experiment were: pH 4.79; SOM 0.6%, total N 0.29 g kg^{-1}, available P and available K of 20 and 48.45 mg kg^{-1}, respectively.

2.2. Treatments

A monoculture of corn (*Zea mays* L.), cultivar no. 1 of Denghai, was planted annually in the lysimeters at a density of 50,000 plants ha^{-1} in April and harvested in July during 2002–2010, while the remainder of the time they were fallow. There were no tillage and management measures with the exception of weeding by hand. Additionally, the same corn cultivar was planted in a guarding row around the experimental area. Four pig manure rates were compared in a contrast design with three replications: (1) no manure (CK); (2) low-rate manure with 150 kg N ha^{-1} y^{-1} (LM, equal to 3827 kg ha^{-1} y^{-1} of dry pig manure); (3) high-rate manure with 600 kg N ha^{-1} y^{-1} (HM, equal to 15,306 kg ha^{-1} y^{-1} of dry pig manure) and (4) high-rate manure with 600 kg N ha^{-1} y^{-1} and lime at 3000 kg $Ca(OH)_2$ ha^{-1} 3 y^{-1} (HML, lime was incorporated into 0–15 cm depth of soil once every three years before manure application). The pig manure was collected from pig farms near the experimental station and had average total N of 39.2 g kg^{-1}, total C of 30.6%, dissolved total N (TDN) of 7.9 g kg^{-1}, DON of 4.0 g kg^{-1} and DOC of 55 mg kg^{-1} on a dry matter basis, water content of 80% and pH 7.7. The manure was incorporated into the surface soil layer (0–15 cm) one day before sowing.

2.3. Sampling and chemical analysis

The soil samples from surface layer (0–15 cm) were collected weekly during the growth stages or more frequently following