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Nitrate Leaching Risk Assessment with Pig Manure Application of Three Red Soils in Subtropical China

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Abstract. To investigate the nitrate leaching risk of three red soils in subtropical China, this study conducted seven different manure treatments, namely, 0 (CK), 50 (F50), 100 (F100), 200 (F200), 400 (F400), 800 (F800), 1600 kg N hm^{-2} (F1600) with half of local conventional chemical fertilizers (N: 50 kg hm^{-2}, P: 25 kg hm^{-2}; K: 50 kg hm^{-2}) in a two-year pot experiment. The results showed nitrate leaching was significant affected by soil type and manure application rate. The leaching risk in the red soils decreased in the follows: granite > sandstone > red clay. The nitrate leaching risk to groundwater environment was enhanced when manure was applied at 206 kg N hm^{-2} for red clay soil, 113 kg N hm^{-2} for sandstone soil and 97 kg N hm^{-2} for granite soil.

Introduction

With the rapid development of intensive livestock farming over the past decades in China, large amount of animal dung has been becoming a serious problem of environment pollution (Li et al. 2009). An effective solution to this problem is to make full use of livestock manure as a source of nutrients which can also provide organic matter to improve soil fertility and nutrients for crop growth (Reiman et al. 2009). However, excessive use of manure fertilizer may result in the nitrate accumulation and leaching. Leaching is the main pathway of nitrogen losses and can increase the risk of groundwater contamination (Zhao et al. 2011). The environmental risks of nitrate leaching to groundwater have been concerned for many years, and have been the subject of intensive studies. However, few studies have been conducted in subtropical region where there is a rainy climate with high temperature and poor fertility. Furthermore, farmers applied excessive amounts of manure fertilizers to increase soil fertility and crop production in this region. Therefore, it is essential to determine the vertical leaching of nitrate in manure fertilized soil to evaluate the potential risk in subtropical red soils. The main objective of this study was to compare the nitrate leaching from three red soils and estimate the potential risks to make appropriate manure application rate.

Materials and Methods

The experiment was conducted at the Ecological Experimental Station of Red Soil, Chinese Academy of Soil Science in Yujiang County, Jiangxi Province (28°15.20′ N, 116°55.30′ E). This research site is characterized by a typical subtropical humid monsoon climate with an annual air temperature ranging from 17.7^{o}C to 40^{o}C and a mean annual rainfall of 1754 mm, nearly 50% of rainfall is from March to June (zhang et al. 2015).

Three dominating upland soils in subtropical China (red clay, sandstone and granite soils) were collected to fill plastic buckets (55 cm, height and 34 cm, diameter) according to the original layers in the field, respectively. The original soil of 0-20 cm and 20-50 cm layers were filled into the buckets of 0-20 cm and 20-50 cm, respectively. The initial soil properties were listed in Table 1. The pot experiment was performed in seven treatments: the application rates of pig manure were 0 (CK), 50 (F50), 100 (F100), 200 (F200), 400 (F400), 800 (F800), 1600 kg N hm^{-2} (F1600), with half of the local conventional chemical fertilization rate (N: 50 kg hm^{-2}, P: 25 kg hm^{-2}; K: 50 kg hm^{-2}). Chemical fertilizer varieties were urea, calcium magnesium phosphate and potassium chloride, respectively. A control treatment, "CK" had no allochthonous organic amendment or chemical fertilizer. The pig manure was collected from pig farms near the experimental station and had an average total phosphorus of 12.55 g kg^{-1}, total nitrogen of 28.8 g kg^{-1}, total carbon of 304.5 g kg^{-1} (dry matter basis) and water content of 69%. Each treatment with three replicates was arranged randomly.

Table 1. Physical and chemical properties of the surface soils (0-20 cm)

Soil type	pH (2.5:1)	Organic C (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Available N (mg kg^{-1})	Available P(mg kg^{-1})	Silt (0.002-0.02 mm) (%)	Clay (<0.002mm) (%)
Red clay	4.64	5.16	0.50	0.40	59.50	28.34	20.68	45.92
Sandstone	4.51	2.82	0.30	0.11	48.50	5.82	7.88	15.44
Granite	5.44	3.92	0.41	0.28	58.48	20.40	11.61	6.79

Prior to sowing, the surface soil samples (0-20 cm) were mixed with fertilizers as a basic fertilizer in each growing season, and there was no any fertilization during the growing period and radish growth. Peanut-radish (***Arachis hypogaea** L.-**Raphanus sativus** L.*) rotations were conducted during this experiment, and peanuts were sown in the early of April and harvested in the middle of August. Radish, as a catch crop, was then sown in the beginning of September and harvested in the beginning of December. It was leisure period from January to March of the following year. The experiments were conducted under the condition of natural rainfall (zhang et al. 2015).

The nitrate concentrations were analysed using a Smartchem 200 Discrete Auto Analyzer (AMS-Westco, Italy). The means (n= 3) and standard deviations (S.D.) of the nitrate concentrations are presented. The significant differences among the soil types and fertilization treatments were assessed using a one-way ANOVA followed by the LSD test at a 5% probability level.

Results and Discussion

The highest amount of manure treatment (F1600) was exampled to research the dynamics of nitrate concentration in leachate of the three red soils (Fig. 1). Over the whole growth period of peanut and radish, nitrate leaching mainly concentrated in May and the concentrations were lower than 20 mg l^{-1} (Quality Standard for Underground Water, GB/T14848-93) in the other periods. The leaching of nitrate mainly occurred in May, which was partly caused by the higher manure mineralization rate in higher temperature and moisture and the nitrification of NH_4^+-N (Gil et al. 2011; Mohanty et al. 2011). On the other hand, the nutrient demand for plant growth was relatively low during this period, resulting in higher leaching for nitrate.

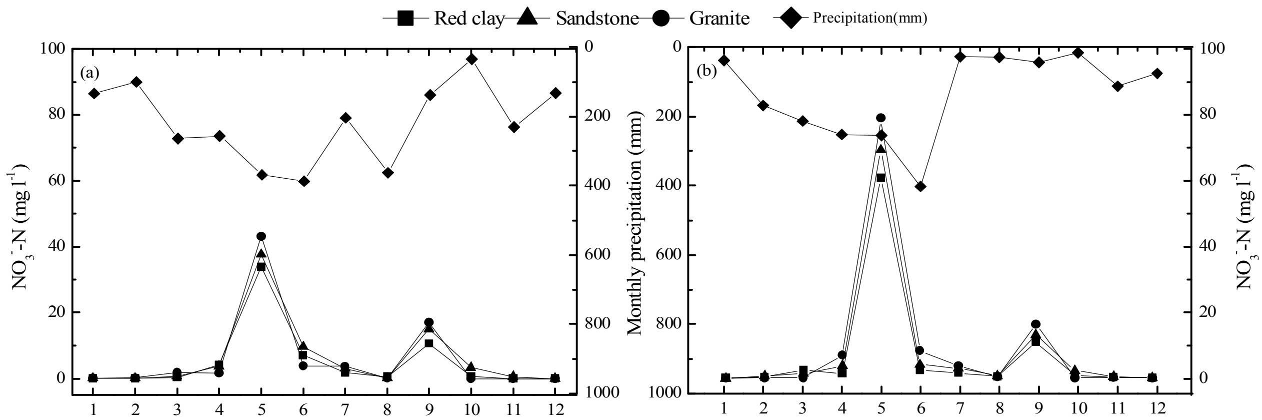

Fig. 1 Dynamics of nitrate concentration in leachate of red soil with three soil types (a: One year after fertilization; b: Two years after fertilization)

In May, the effect of soil type had obvious effect on nitrate leaching. There was no significant difference among the three soils with control treatment (CK) after one year and two-year fertilization (Fig. 2). Significant difference occurred between granite, sandstone soils and red clay soil with low level of pig manure (F50-F200), but there was no significant difference between granite soil and sandstone soil. Under the high manure treatments (F400-F1600), there was significant difference among the three soils (***P***<0.05). In general, nitrate leaching risk followed the order: granite soil > sandstone soil > red clay soil, indicating that the nutrient leaching were closely related to the soil type and also demonstrating that the red clay soil had a stronger nutrient preserving capability compared to the other two soils. Soil texture, structure and physicochemical properties were all different in the three red soils (Table 1), which can significantly affect the mineralization of organic N. Sørensen (2001) and Hernøández (2002) found organic N mineralization in manure was influenced by soil type, organic N mineralization being greater in the sandy soil than in the clay soil. Not only that, with higher clay contents in red clay soils, slower water movement and a lack of oxygen in pores may reduce nitrogen nitrification, thus decreasing nitrate-N leaching (Griffin et al. 2002; Giardina et al. 2001). Moreover, the combination of soil clay and organic matter can form organic and inorganic complex to produce adsorption ability and retain more nitrate for longer and with less leaching (Gaines et al. 1994; Simmelsgaard 1998).

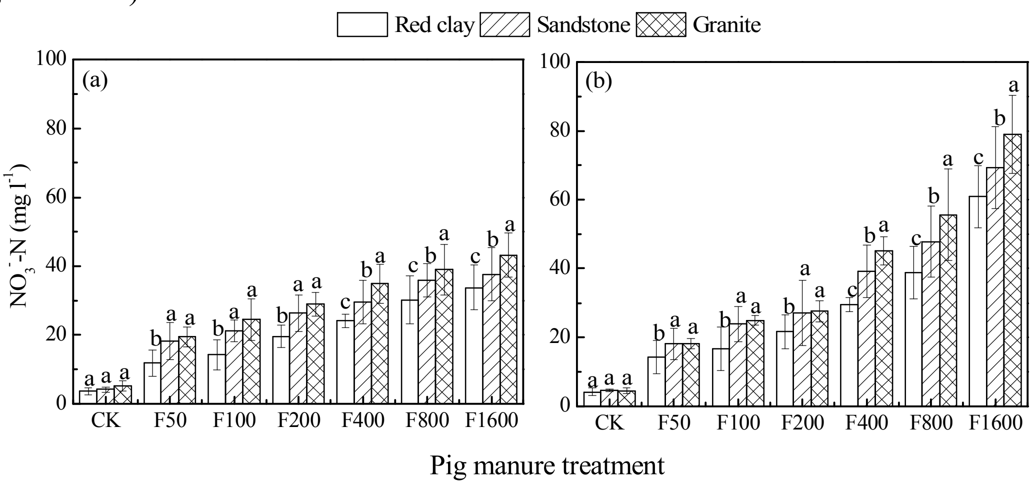

Fig. 2 Difference in nitrate concentration in leachate of red soil with three soil types in May (a: One year after fertilization; b: Two years after fertilization)

Significant differences (***P*** < 0.05) between soil types are indicated by different lowercase letters

Considering the nitrate leaching risk to groundwater environment, more attention need to be paid, especially in May. The relationship between nitrate concentration in leachate and manure application rates can be described by exponential model in this period (Fig. 3). The result found that nitrate concentration was over the 20 mg l^{-1} when manure was applied at 206 kg N hm^{-2} for red clay soil, 113 kg N hm^{-2} for sandstone soil and 97 kg N hm^{-2} for granite soil.

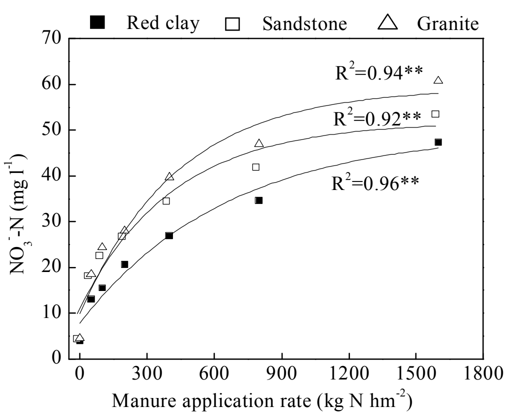

Fig. 3 Simulated nitrate concentration in leachate with increasing manure in three red soils

Conclusions

In conclusion, the nitrate leaching was significantly affected by soil type and manure application rates. The leaching risk in the three red soils decreased in the follows: granite > sandstone > red clay. The nitrate leaching risk was enhanced to groundwater environment when manure was applied at 206 kg N hm^{-2} for red clay soil, 113 kg N hm^{-2} for sandstone soil and 97 kg N hm^{-2} for granite soil.

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