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Paddy rice ecohydrology pattern and influence on nitrogen dynamics in middle-to-high latitude area

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SUMMARY

Paddy rice in middle-to-high latitude areas has a longer growing period with lower temperature. Therefore, it was hypothesized to have a different soil ecohydrology pattern and nitrogen (N) efficiency. Based on daily monitoring of soil moisture and N concentrations in soil water at four depth layers, the characteristics and their ecohydrological interactions, soil environmental indexes and N dynamics were analyzed. The temporal–vertical observations of soil moisture and soil water acquisition rates demonstrated the existence of an impermeable soil layer at 30 cm, which had lower soil organic carbon content. The soil moisture greater in the upper layer had higher soil organic carbon content, which provided the critical conditions for the rice tillage. Lower than the 60 cm depth, the soil moisture increased and had a peak acquisition rate of approximately 0.0075 $cm^3\ s^{-1}$. The concentration of NO_3^--N in the water at the soil subsurface was approximately 2.4 times than that of NH_4^+-N. The NO_3^--N had a larger concentration at the deeper layer as a result of downing leaching, but the NH_4^+-N had a greater concentration in the tops soil layer than the other depths. The soils under the influence of freeze–thawing had the largest TN concentration in surface water at the end of April, which was about three times than that of the peak during the growing period. This study aligned the interactions between the N dynamics with soil microclimatic factors such as temperature, water pH and moisture across the 90 cm profile. The temporal–vertical pattern of soil moisture and the N in soil water provided evidence for the hypothesis that the soil ecohydrology dynamics in this area. These findings were of particular significance to understanding the impacts of paddy rice ecohydrology with N dynamics in middle-to-high latitude areas, which can help to optimize the N availability and water efficiency.

1. Introduction

Paddy rice cultivation in the middle-to-high latitude regions of China occurs in the most northern latitude paddy rice area the world. This cultivation is based on the long interactions of water and nutrients under cold conditions (Chen et al., 2013). Nitrogen (N) is a major yield-limiting nutrient factor of crop production in the agro-ecosystem (Möller et al., 2006). Nitrogen loss is also the main environmental issue for long term agricultural activities, which is critical for environmental quality (Arauzo et al., 2011). The impacts of irrigation, fertilizer, and crop rotation on N leaching have generally been explored from the perspective of agricultural management (Fuller et al., 2010; Gheysari et al., 2009). Previous studies found that the soil ecohydrology feature is the most important variable for the N transportation (McIsaac and Libra, 2003; Shrestha et al., 2007). It has been hypothesized that the paddy rice cultivation had different ecohydrology dynamics under the cold conditions and had special impacts on the N movement. In this study, the temporal–vertical dynamics of soil water and their impacts on N were observed and analyzed.

The rice cultivated in the middle-to-high latitude ranges requires special practices that impact the paddy land ecohydrology and the N cycle in the rice fields (Singh et al., 2006). The soil moisture and N availability in soil are controlled by patterned tillage practices and fertilization application principles, which also impact the relationship between the soil microclimate and N (Zvomuya et al., 2006; Joseph and Henry, 2008). The ecohydrology and interactions with N in middle-to-high latitude paddy rice are still not thoroughly understood and have not been well documented by

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field research (Hao et al., 2013). The ecohydrology in rice fields is characterized by ponding under saturation conditions during the growth period, but is sometimes unsaturated under intermittent submerged conditions (Boling et al., 2008). Under this condition, the amount of N and soil water in each layer of the soil profile below the arable layer is an important part of soil N storage. Vertical flows are more effective than horizontal flow systems because of their high oxygen transfer rates and longer ponding times (Cooper, 2005).

The N dynamics in paddy rice depend on the varieties of edaphic, tillage, climatic, and agronomic factors. The soil properties, such as texture and organic matter content, are the priority factors that affect the water-holding capacity of soils (Hopmans, 2003; Sleutel et al., 2008). The greater leaching due to higher soil moisture and the presence of preferential flow pathways may decrease N availability (Shipitalo et al., 2000). The N transformation is highly sensitive to soil ecohydrology variations, which is a controlling variable that affects the redox potential of soil (Yu and Ehrenfeld, 2009). Furthermore, the paddy land ecohydrology can include water storage and availability levels, which are the necessary for rice growth. The temperature sensitivity of net nitrification and N mineralization also vary with soil hydrological status (Craine and Gelderman, 2011) and long-term studies show that N losses by leaching typically increase with higher soil moisture conditions (Bryant et al., 2011).

Understanding the interactions of soil ecohydrology and nitrogen (N) is important to improve the efficiency of water use and N in the farmland, which is more critical in the middle-to-high latitude agricultural systems (Fuentes et al., 2003). Paddy land ecohydrology dynamics depend on a combination of micro-variables, including soil texture, precipitation, evaporation, and crop transpiration (Hupet and Vanclooster, 2005). During N transport in soil water, dissolved organic N is recognized as the main form in soil surface water (SW) and leaching in soil subsurface water (SSW) (Fellman et al., 2008). In addition to serving as transport media for N transport, soil water also influences the denitrification process and the availability of N to plants (Hagedorn et al., 2001).

The paddy rice in this middle-to-high latitude area was reclaimed from wetlands during agricultural exploitation, and how to minimize the environmental impact with larger yields is the priority concern (Hao et al., 2012). In this study, the quantity of soil water and N dynamics (TN, NO_3^--N, and NH_4^+-N) in SW and SSW at different depths was monitored daily. The impacts of soil temperature, pH, and soil ecohydrology on soil water N dynamics were also identified. In brief, the objectives of the study were to: (1) discriminate the paddy rice field ecohydrology characteristics at four soil depths in middle-to-high latitude area, (2) identify the interactions between the soil ecohydrology and the transportation of TN, NO_3^--N, and NH_4^+-N at four soil layers, and (3) quantify the impacts of ponding and soil microclimate on four forms of N concentrations in the 0–90 cm soil profile.

2. Materials and methods

2.1. Research site description

Field investigations provide the most direct and effective means for evaluating soil water dynamics and N transportation (Bagarello et al., 2010; Jalali, 2005). Field observations were conducted on a farm in a middle-high latitude area, which has latitude more than 45°. The experiment station in Paddy #1 of the Bawujiu Farm adjoins the Ussuri River in northeast of China, (Fig. 1). The field was irrigated by well water, where the well location is approximately 10 m north of the field. The irrigation and drainage canals embayed the field on two sides with a total length of 50 m. The topography of the field is defined by a 0–1% slope in east-west and north-south direction. The regional climate is cold temperate continental monsoon with a mean annual precipitation (1983–2010) of 588 mm and a mean annual air temperature (1983–2010) of 2.94 °C. The monthly average air temperature is below 0 °C for approximately 6 months during the year (Ouyang et al., 2013).

2.2. Soil characterization and farming practice

The paddy rice growing area in this region has a special vertical profile and there is an impermeable *albic* layer at around 30 cm depth, which is the necessary condition for rice growth (Hao et al., 2013). The soil texture and chemical characteristics, such as soil bulk density, pH, organic matter, TN, and organic carbon of the 90 cm profile is summarized (Table 1). The planting and harvesting dates, detailed irrigation events, and tillage and fertilization practices are presented in Table 2. Irrigation amounts from ponding to harvesting in the rice growing season ranged from 20 to 60 mm. The field received N, P, and K from chemical fertilizer of urea (N 46%), diammonium phosphate (N 18%, P_2O_5 46%), and potassium sulfate (K_2O 33%).

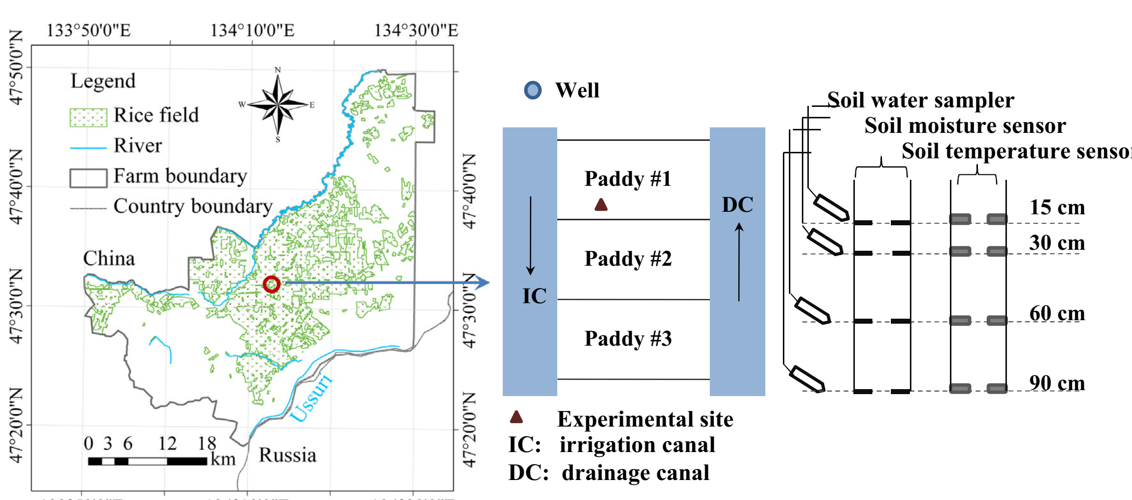

Fig. 1. Location of the experimental field and associated sensors and samplers.