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Long-term effects of controlled release urea application on crop yields and soil fertility under rice-oilseed rape rotation system

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ABSTRACT

Nitrogen (N) fertilizer has played an important role in increasing rice and oilseed rape yields, but more than half of the N fertilizer applied into the field has been lost and results in not only an environmental hazard but also a substantial economic loss. Thus, the controlled release N fertilizer was expected to reduce the labor cost from fertilizer dressing, to the convenience of fertilizers application and to increase N use efficiency. A 7-year field fertilization experiment applied controlled-release urea (CRU) 100% (180 kg ha^{-1}), 70% (126 kg ha^{-1}) and 50% (90 kg ha^{-1}) of the recommended N fertilizer to explore its effects on crops yield and soil fertility under the rice (*Oryza sativa L.*)-oilseed rape (*Brassica napus* L.) rotation system in Hubei province of China. Meanwhile the equivalent rates of N as common urea were supplied as split applications in different growth stages as the control. The N release characteristic of CRU in field condition was closely matched to the demand for N during the whole growth periods of crops. Consequently, the CRU treatments achieved significantly higher rice and oilseed rape yield by 6.1–8.2% and 6.3–15.5%, the mean nitrogen use efficiency (NUE) of CRU treatments was increased by 15.4–38.4%, and the average annual net profit was also increased by 16.0–20.8%, compared with urea treatment at the same N rate. For each type of N fertilizer, the yield increased as the input N rate increased. However, reducing CRU rate by 30% produced the same yield of rice and oilseed rape as with the 100% rate of urea. And, the rice yield of CRU50% treatment was even showed no significant with Urea100% treatment. The contents of nitrate N (NO_3^--N) and ammonium N (NH_4^+-N) were higher in 0–40 cm soil of CRU treatments than urea treatments over 7-year fertilization in 2013, but the opposite trend was found in 60–100 cm soil, which indicating that CRU decreased the NO_3^--N and NH_4^+-N leaching to deep in the soil. The contents of total N and organic matter were increased by applying CRU for 7 years compared with urea fertilizer. Although the contents of available P and K were increased over the 7 years of fertilization and cultivation, no prominent difference was observed between CRU70% and Urea100%. The results suggest that a 30% decrease in the recommended application rate of N is possible with CRU while maintaining the same yield, preserving the soil fertility and also labor/time-saving.

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1. Introduction

Paddy-upland crop rotations are the most important cropping system in South and East Asia countries such as China, India and Nepal (Timsina and Connor, 2001). An example is the rice-oilseed rape rotation system that is the main cropping system in the Yangtze River valley of China. Rice is the main staple food for more than 60% of the population in China (Bi et al., 2009), and the crop yield was increased mainly through the application of chemical fertilizers which had gradually become the main measures to improve the soil fertility (Nam et al., 2013). Nitrogen is the most required nutrient for plant among the most important growth-limiting factors (Yin et al., 2014), and N has a significant effect on yield-increase during long-term cultivation compared with no N treatment (Shen et al., 2004; Lyu et al., 2011). Considerable researches have showed that N fertilization effects on N cycling, soil C storage and mineralization rates (Sardans et al., 2008), and also influence significantly temporal and spatial distribution of inorganic soil N (Shi et al., 2012). However, the utilization efficiency of N fertilizer is very low

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with an average of 27.5% in China (Zhang et al., 2007). Meanwhile, excessive chemical N fertilizer in fields may negatively affect the quality of environment and soil through leaching, runoff, and the volatilization of N (Galloway et al., 2008).

Many studies had found that the application of controlled release N fertilizer significantly increased the NUE and yields of crops (Yang et al., 2011; Haderlein et al., 2001). Besides, some reports asserted that certain CRU enhanced N uptake and rice grain yield through prolonged N release from these fertilizers (Fu et al., 2001; Kiran et al., 2010). Using CRU on rice, N rate and application frequency were reduced in a 2-year field experiment (Yang et al., 2012). Moreover, the rice yield and oilseed rape yield with applied CRU increased by 6.9% each, even when CRU rate was reduced by 20% relative to common urea (Zhang et al., 2010).

A long-term fertilization experiment is an important platform to identify important scientific problems and to carry out scientific research (Manna et al., 2005; Chinnadurai et al., 2014). Systematic research with long-term experiments on soil fertility was conducted by many countries. For example, Regmi et al. (2002) reported that the long-term fertilized with recommended NPK fertilizer application or farmyard manure not only maintained or increased N, P and organic carbon contents in soil, but also decreased available K content compared with the initial soil. Some similar studies found that N application increased residues, including roots, returned to the soil, and increased the organic matter content in most crops land of China (Liao et al., 2013).

Much effort has been made to explore the long-term influences of fertilizers on soil quality and nitrogen use efficiency, but all the researches focused on the effects of common urea, organic fertilizer or combined mineral manure with farmyard manure on crop yield (Shang et al., 2014a). So far, there is a dearth of reports on the long-term effect of CRU on crop yield and soil chemical properties. Thus, continuous fertilization of CRU compared with common urea at three N levels (90, 126, and 180 kg ha^{-1}) was conducted from 2006 to 2013. We hypothesized that long-term application of CRU (1) increased the yield of crops and increased N use efficiency, (2) a 30% decrease in the recommended application rate of N is possible with CRU while maintaining a high yield, achieving much farm profit and reducing labor cost of fertilization, (3) and improved soil fertility under rice-oilseed rape rotation system.

2. Materials and methods

2.1. Study site and materials

The study was conducted over a period of 7 years from 2006 to 2013 at the experimental farm located in Zhijiang, Hubei province, China (E 111°45′26″, N 30°29′30″). The area was characterized by a subtropical monsoon climate with an annual average temperature of 16.50 °C and annual mean precipitation of 1041.8 mm, and the precipitation was mainly in June and July. The crop rotation was rice (*Oryza sativa L.*)-oilseed rape (*Brassica napus L.*). Main properties for top-layer soil (0–20 cm) at the experimental site in 2006 before planting were: pH, 6.35 (1:5, the ratio of soil to water), soil total N concentration, 1.2 g kg^{-1}, NO_3^--N concentration, 7.1 mg kg^{-1}, NH_4^+-N concentration, 14.2 mg kg^{-1}; available P concentration, 7.5 mg kg^{-1}, organic matter concentration, 22.4 g kg^{-1}, and available K concentration, 141.8 mg kg^{-1}, respectively.

The conventional fertilizers used were urea (containing 46% N) as N fertilizer, superphosphate (containing 5.2% P) as P fertilizer, and potassium chloride (containing 49.8% K) as K fertilizer, respectively. The polymer coating of sulfur-coated urea (hybrid coatings with sulfur and a thin polymer-coating containing 33% N, made by Kingenta Ecological Engineering Co. Ltd., Shandong, China) was used as CRU for crops. The CRU used in this paper was a mixture of

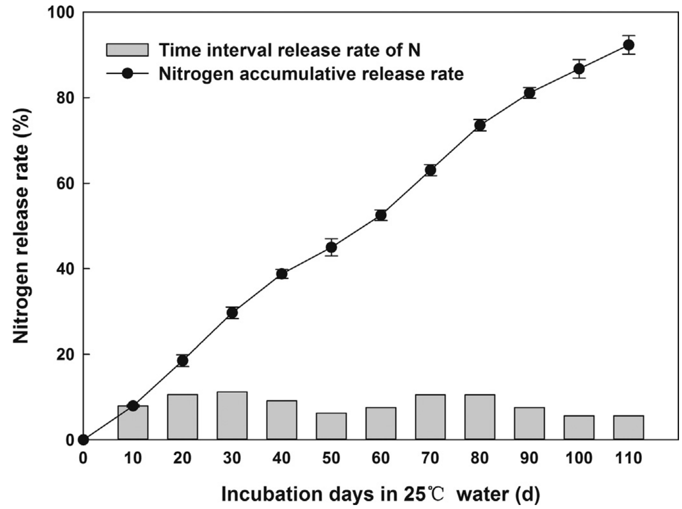

Fig. 1. Nitrogen release rate for period of time and accumulative release rate of CRU in 25 °C water.

2 months and 4 months longevity of CRU, the weight ratio was 1:1. So, there were two release peaks during the release time. The same products were used throughout 7 years. The N release longevity of CRU in water of 25 °C was showed in Fig. 1. The cultivar used in the present study was 'Fengeryou 1' for rice and 'Huaza 9' for oilseed rape. They are currently major cultivars widely cultivated in the Yangtze River valley of China.

2.2. Experimental design and management

In this study, there were 7 treatments with triple replicates: the control with no N application (CK), a traditional fertilization of CRU with a N rate of 180 kg ha^{-1} (CRU100%), CRU with a N rate of 126 kg ha^{-1} (CRU 70%), CRU with a N rate of 90 kg ha^{-1} (CRU50%), in comparison with the traditional urea fertilization that with a N rate of 180 kg ha^{-1} (Urea100%), urea with a N rate of 126 kg ha^{-1} (Urea70%) and urea with a N rate of 90 kg ha^{-1} (Urea50%). All the treatments were ranked in a randomized block design. The CRU was used as basal fertilizer once before planting rice and oilseed rape. While urea was used as split fertilization, it was split in two development stages of the rice crop: one was at preplant (70%) and the other was in tillering stage (30%), three for oilseed rape that was at preplant (50%), seedling stage (20%), and bolting stage (30%), respectively. Phosphorus and K fertilizers in all treatments were applied as basal dressings at the rate of 26.2 (P) and 74.7 (K) kg ha^{-1}, respectively.

The rice and oilseed rape were cultivated with a density of 195,000 plants ha^{-1} and 120,000 plants ha^{-1}, respectively. Plots were arranged randomly with an area of 25 m^2 (5 m × 5 m). Oilseed rape was transplanted in October of each year and harvest in May next year, and then rice was transplanted, which was harvested in mid-September in the same year.

2.3. Sampling and measurement

The N content and longevity of CRU in water were determined by the method of "State Standard of the People's Republic of China-Slow Release Fertilizer" (Liu et al., 2009), 10 g CRU was placed in a glass bottle containing 500 ml distilled water in three replicates, and then keep in a constant temperature incubator at 25 °C. The content of released N from CRU was determined using Kjeldahl method, and the solution samples were collected at 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 d when the accumulative N release rate of CRU was more than 80%. For field conditions, the N cumulative

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