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# Comparison of yield and nitrogen use efficiency of different types of nitrogen fertilizers for different rice cropping systems under subtropical monsoon climate in China

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ABSTRACT

Controlled release urea (CRU) and urea with nitrification inhibitor could improve yields and nitrogen use efficiency (NUE) in a number of production systems. However, their effectiveness will be strongly influenced by environmental conditions. The objective of this research was to evaluate the effects of CRU and urea with nitrification inhibitors on grain yield and nitrogen use efficiency under different rice cropping systems. A five-year experiment on double rice cropping systems and a two-year experiment on single rice cropping systems were conducted using four treatments: not N fertilized (CK), prilled urea with split applications (PU), single basal application of polymer coating of sulfur-coated urea (PSCU) and prilled urea with the nitrification inhibitor 2-chloro, 6-(trichloromethyl) pyridine (NPU). The fertilizers were applied at the rate of 180 kg N $ha^{-1}$ under a subtropical monsoon climate in China. The results suggest that NPU significantly increased the five-year average grain yield and NUE when compared with the PU treatment by 9.7% and 10.3% for early rice, and 9.6% and 8.8% for late rice, respectively. However, PU treatment produced a similar two-year average rice grain yield and 3.1% higher NUE when compared with the NPU treatments for single rice. PSCU treatment significantly increased average grain yield by 5% and 3.7% compared to the PU treatment of late rice and single rice, respectively. In addition, PSCU treatment resulted in the highest total N uptake and NUE during 2012–2015 for late rice and 2014–2015 for single rice, indicating synchronized N release in accordance with the N requirement of rice. However, the use of PSCU was not effective in improving grain yield or NUE of early rice owing to the delayed release of N during the tillering-heading stage. Overall, our results suggest that urea with nitrification inhibitor is preferable to urea for double rice cropping systems, and that PSCU is more suitable for single rice.

## 1. Introduction

Rice is one of the three most important cereal crops in the world and is cultivated in a 30 million ha area in China (Xu et al., 2013). Nitrogen (N) is the most yield-limiting nutrient in rice production, and is generally used at very high rates. Currently, apparent N recovery (ANR) of rice in paddy soils of southern China is low (20–40%) (Yang et al., 2013; Bandaogo et al., 2015). The majority of applied N is lost through leaching, run off, and ammonia volatilization into the environment, which has a negative effect on ground water, surface water, and atmosphere (Galloway, 1998; Zhu and Chen, 2002; Ju et al., 2009). Yield and nitrogen use efficiency (NUE) can be improved through effective N management by choosing correct N sources and timing of application to synchronize N availability and uptake by rice crops (Grant et al., 2012). Split application of N fertilizers improves NUE (Hooper et al., 2014). However, its adoption is restricted owing to lack of sufficient

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**Table 1**
Selected chemical properties of the topsoil (0–20 cm) prior to planting in April 2011 for experiment 1 and June 2014 for experiment 2.

| | pH (1:2.5 soil:water) | Organic matter ($g\ kg^{-1}$) | Total nitrogen ($g\ kg^{-1}$) | Soil alkali hydrolyzable nitrogen ($mg\ kg^{-1}$) | Bray-P ($mg\ kg^{-1}$) | $NH_4OAc$-exchangeable $K^+$ ($mg\ kg^{-1}$) |
|---|---|---|---|---|---|---|
| Experiment 1 | 5.24 | 26.2 | 1.96 | 132.3 | 4.43 | 79 |
| Experiment 2 | 5.31 | 25.6 | 1.87 | 118.4 | 7.21 | 93 |

agricultural labor forces (Zhang, 2008). Therefore, several researchers have focused on slow or controlled-release N fertilizers which allow the achievement of higher NUE and the application of lower N rates than conventional urea (Shoji et al., 2001; Yang et al., 2012). Controlled-release urea (CRU) was designed to have a release pattern that matched the crop N demand. Several studies have reported the effect of controlled-release fertilizers on rice yield and N use efficiencies (Kiran et al., 2010; Grant et al., 2012; Ye et al., 2013). Fageria and Carvalho (2014) reported that nitrogen use efficiency was maximized for polymer coated urea compared to conventional urea for lowland rice production. In subtropical China, use of polyolefin-coated urea resulted in high yield and increased NUE in double rice cropping systems (Xu et al., 2013). However, the effectiveness of CRU may be influenced by climatic and soil conditions (Peng et al., 2015). Several studies have found that CRU could not lead to higher yield under specific conditions. A 2-year field study reported non-significant differences in potato yields between polymer coated urea and split applications of soluble N at equivalent rates on irrigated loamy sand (Wilson et al., 2009a). Kiran et al. (2010) showed that sulfur-coated urea did not result in higher grain yield than non-coated urea under flooded rice conditions.

An alternative strategy was to add nitrification inhibitors to urea that slow down $NH_4^+$ oxidation, thereby limiting $N_2O$ production during the process of nitrification and denitrification (Majumdar et al., 2000). Evaluations of effects of different types of nitrification inhibitors (e.g., neem cake, thiosulfate, dicyandiamide, and dimethyl pyrazole phosphate) on N response and agronomic performance, demonstrated that their effectiveness was influenced by management practices, soil types and environmental conditions (Carreres et al., 2003; Malla et al., 2005; Peng et al., 2015). Carreres et al. (2003) summarized the previous research and reported that urea with nitrification inhibitors were more effective than urea alone in soils prone to high leaching and denitrification.

Rice cultivation in China is mainly carried out under single or double cropping systems. Rice planting area and yield in 2014 under double cropping system accounted for 39.5% and 34.9% of the national rice planting area and national rice production, respectively (NBSC, 2014). In contrast, single rice cropping systems accounted for more than 50% of national rice planting area and national rice production (NBSC, 2014). Double cropping systems involve two crops (early and late rice production) per year. In the single cropping system, there is only one rice crop per year. The growing seasons of early rice, late rice, and single rice are from April to July, July to November, and June to October, respectively. Previous studies have compared the agronomic performance of CRU or nitrification inhibitors with common urea in only one cropping system (Golden et al., 2009; Yang et al., 2012). However, to the best of our knowledge, no study has investigated the effects of CRU, nitrification inhibitors, and common N fertilizers on rice grain yield and NUE across single and double rice cropping systems. Temperature and rainfall varied substantially between both growing seasons in double cropping systems, and may thereby affect the effectiveness of CRU or urea with nitrification inhibitor. Therefore, the objective of the present study was to evaluate the effects of CRU and nitrification inhibitor on rice grain yield and NUE for single and double rice cropping systems.

## 2. Materials and methods

### 2.1. Site description

Two experiments were performed on yellow clayey paddy soil in Langya Town (29°01′N, 119°27′E), Zhejiang province, China. Experiment 1 was conducted for five consecutive years (2011–2015) under double rice cropping conditions using the early rice cultivar, “Jinzao 09” and the late rice cultivar, “Yueyou 9113”. Experiment 2 was performed during two consecutive rice growing seasons during the years 2014 and 2015 under the single rice cropping system (cultivar “Liangyoupeijiu”). The selected basic properties of top soil (0–20 cm) are given in Table 1. The region is characterized by a subtropical monsoon climate with an average annual temperature of 17.5 °C and a mean annual precipitation of 1424 mm. The monthly precipitation and temperature during the study are shown in Fig. 1. The polymer coating of sulfur-coated urea (PSCU, N 34%) was provided by Kingenta Ecological Engineering Group Co., Ltd., Shandong, China. Prilled urea with nitrification inhibitor (NPU, 2-chloro, 6-trichloromethyl pyridine, 0.25%) was provided by Zhejiang Aofutuo Chemical Co., Ltd., China. Other common fertilizers used in this study were urea (46% N), super phosphate (12% P), and potassium chloride (60% K).

### 2.2. Experimental design and treatments

Both experiments followed a randomized complete block design with four treatments and three replications: (1) without N fertilizer, CK; (2) common prilled urea, PU; (3) polymer coating of sulfur-coated urea, PSCU; (4) prilled urea with nitrification inhibitor, NPU. Treatments 2–4 received nitrogen at the rate of 180 kg ha$^{-1}$ per season. The complete doses of PSCU and NPU were used as single basal application at each season under two rice cropping systems. PU was applied in three split doses at ratios of 4:3:3 (basal: tillering: booting) for the early rice and single rice, and at ratios of 4:6 (basal: tillering) for the late rice. Phosphorus and potassium were applied uniformly for all the treatments in all seasons at the rate of 90 kg P ha$^{-1}$ and 120 kg K ha$^{-1}$ using super phosphate and potassium chloride respectively. These were applied as basal application one day before transplanting of rice. The plot size was 12.5 m$^2$ (5 m × 2.5 m) for double rice and 18 m$^2$ (4.5 m × 4 m) for single rice. Plastic film was used to isolate the plot boundaries (30 cm wide and 30 cm high) and to minimize seepage to adjacent plots. Seedlings were transplanted at a spacing of 16.5 cm × 19.8 cm with four seedlings per hill for early rice in late-April, and at 19.8 cm × 19.8 cm spacing with two seedlings per hill for single rice in mid-June and late rice in late-July. The crop was harvested in late-July for early rice, early-October for single rice, and early-November for late rice.

For experiments 1 and 2, irrigation and water management were performed by following alternate wetting and drying cycles. For the first 10 days after transplanting, water was maintained at a depth of 10–40 mm, followed by draining the soil to dryness for next 7 days to facilitate recovery of seedlings. Afterwards, irrigation was performed at intervals of 15 days, with drying periods of 3–5 days between each irrigation. This was practiced until 10 days before harvest of the crop (Cabangon et al., 2004).

The N release rate of PSCU in soil was determined by the buried mesh bag (15 cm × 10 cm) method (Wilson et al., 2009b). Mesh bags