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Research paper

Controlled release urea improved crop yields and mitigated nitrate leaching under cotton-garlic intercropping system in a 4-year field trial

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ABSTRACT

Nitrogen fertilization is important for improving crop yields, but excessive amounts lead to high N losses through nitrate (NO_3^--N) leaching. Controlled-release urea (CRU) has been shown to increase crop yields, yet the long term effects of CRU on soil NO_3^--N distribution are not well known. A 4-year field experiment applied 50% (100 kg ha^{-1}), 100% (200 kg ha^{-1}) and 150% (300 kg ha^{-1}) of the local practice N rates with CRU and urea was conducted under cotton-garlic intercropping system in Shandong Province, China. The linear increase in garlic yield and curvilinear increase in cotton yield indicates that crop yields increased as the input N rate increased with both urea and CRU while exceeded N application decreased cotton yields. The successive release of N from CRU permitted the meeting of the full N requirements of crops grown. Consequently, the lint cotton yield of CRU treatments was increased by 5.2%-17.3%, and garlic bulb yield increased by 2.0%-7.4%, compared with urea treatment. Although the CRU100% supplied one-third less N than Urea150%, the CRU100% produced −0.6%-5.6% more cotton, and −4.0%-2.6% more garlic than Urea150%. The NO_3^--N contents of CRU treatments were augmented in 0–40 cm soil, but the opposite trend was found in 60–100 cm soil. The organic matter and total N contents in 0–40 cm profile were increased with CRU fertilization over 4-year fertilization. However, no prominent difference of available P and K contents in 0–20 cm soil was observed between CRU and urea treatments. Thus a one-third decrease in the recommended N application rate of urea is possible with CRU while maintaining crops yield, decreasing NO_3^--N leaching to deep soil layer and preserving the soil fertility in North China plain.

1. Introduction

Cotton is the major fiber crop while garlic is an important vegetable widely grown all over the world (Wu et al., 2015). Cotton-garlic intercropping system is popularly used in North China plain (Tian et al., 2015), where the current high crop yields are mainly obtained through large inputs of chemical fertilizer (Dong et al., 2010). Nitrogen (N) is the major essential element for plant growth development (Bhattacharyya et al., 2012; Lyu et al., 2011). Plenty results have proved that more than 55% of the N applied through fertilizer was not taken up by crops under field conditions (Chikowo et al., 2004; AmonaArmah et al., 2015), the "wasted" N is thought to be lost mainly through surface runoff, ammonia volatilization or inorganic N leaching. As a result, overdose of N application has become one of the significant sources for water contamination (Grignani et al., 2007; Silva et al., 2013). Hence, a reduction of N application rate to a reasonable rate on the behalf of maintains crop yields and N use efficiency should be suggested.

Numerous studies have been well demonstrated that crops yield was undisputed effected by N rates (Perego et al., 2012), N sources (Grant et al., 2012) and N managements (McKenzie et al., 2007; Deng et al., 2015). Improved management practices that maximize crop yield and minimize environmental impact while maintaining soil productivity are urgently needed (Hou et al., 2007; Du et al., 2016). Crop growth needs continuous N supply but plants absorb differently N in different periods (Dong et al., 2012). Concerning cotton, the maximum absorption period of N was appeared from late square to bolling stage (Hu et al., 2011), while there was little N demand at the seeding stage (Geng et al.,

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2015a). However, common urea, the instant fertilizer used all over the world, increased soil NO_3^--N content rapidly after application into soil in 2 weeks (Zheng et al., 2016), and the premature senility of cotton frequently occurs due to N deficiency in China (Geng et al., 2015b). Although split application of fertilizer increased N use efficiency and improved crops yield (Gao et al., 2015), it was more costly than one-time fertilization.

Recently, controlled release urea (CRU), which provides a gradual N supply as crop requirements for a long period, has been extensively used in China (Ye et al., 2013; Tian et al., 2015). Meanwhile, CRU has been widely adopted as effective mitigation alternatives to improve crops productivity and reduce the labor/time inputs (Yang et al., 2011, 2012). Plenty experiments demonstrated that N released of CRU synchronize with the N requirements pattern of cotton (Geng et al., 2015a), thus enhanced soil inorganic N supply, especially in the late growth periods (Wang et al., 2013). In addition, Zareabyaneh and Bayatvarkeshi (2015) revealed that the application of sulfur coated urea reduced nitrate leaching levels by 9.9% and increased the potato yield by 49.8% relative to common urea in a 2 year experiment. Hence, the use of CRU showed great potential for avoiding soil N accumulation and leaching by matching soil N supplies and crop N uptake.

Studies on the traits of CRU in crop yield and soil N supply was conducted in various crops system (Yang et al., 2011; Geng et al., 2015b). It has been proved that the release rate curves of CRU were ideal patterns which could synchronize N release with N requirements pattern of cotton (Geng et al., 2015a), rice (Yang et al., 2012), corn (Zheng et al., 2016) and potato (Gao et al., 2015). However, most researchers focused on the effect of signal type CRU on crops yield (Geng et al., 2016) as well as soil nitrate leaching (Zheng et al., 2016), it is crucial to develop CRU that can synchronize nutrient release with the cotton's growth, thus maximize crop yield and minimize environmental impact with decreased N fertilization rate. A 4-year field trail applied CRU and urea with 50% (100 kg ha^{-1}), 100% (200 kg ha^{-1}) and 150% (300 kg ha^{-1}) of the recommended N fertilizer to explore its effects on crops yield as well as soil nutrients distribution in North China plain. It was hypothesized that application of CRU (1) decreased the contents of NO_3^--N in the deeper soil profile while increased its contents of the lower soil, and (2) a decreased N application rate is possible with CRU while maintain or even enhance crops yield under cotton-garlic intercropping system.

2. Materials and methods

2.1. Experimental site and materials

The study was conducted over a period of 4 years from April 2013 to October 2016 at the experimental farm located in Jinxiang, Shandong province, China (34°58′42″N, 116°10′56″E). This region has the monsoon climate of medium latitudes, with an annual average temperature of 14.0°C. There is an annual precipitation of 600–800 mm, a mild winter climate and a relatively humid, hot and rainy summer, with rainfall concentrated in July and August. As a local conventional cropping system, cultivation of summer cotton, winter garlic had been rotated since 1980s' at the site. The soil was Typic Ochri-Aquic Cambosols in the Chinese soil taxonomy and was Inceptisols in American soil taxonomy (Gong et al., 2007). The selected basic soil physical and chemical properties of the 0–20 and 20–40 cm soil before planting were as follows (Table 1).

The conventional fertilizers used were urea (containing 46% N) and diammonium phosphate (DAP, containing 48% P_2O_5 and 18% N) as N fertilizer, DAP as P fertilizer, and potassium sulfate (containing 60% K_2O) as K fertilizer, respectively. The epoxy resin coating of sulfur-coated urea (PSCU, N 38%, coating thickness 17.5%, the longevity was 2 months) and epoxy resin-coated urea (PCU, N 42%, coating thickness 4.0%, the longevity was 3 months) freely provided by Kingenta Ecological Engineering Co., Ltd., China were used as CRU. The longevity of PCU and PSCU in 25 °C water was 70 and 90 days, respectively, according to "State Standard of the People's Republic of China-Slow Release Fertilizer" (Liu et al., 2009). The same types of product were used throughout 4 years. The cultivar used in the present study was "Lu Yanmian 28" for cotton and "Jinxiang White skin" for garlic. They are currently major cultivars widely cultivated under the cotton-garlic intercropping system in North China plain.

2.2. Experimental design and field managements

The experiment was designed as a completely randomized block with three replicates and seven fertilizer treatments: CRU50% (100 kg ha^{-1}), CRU100% (200 kg ha^{-1}), CRU150% (300 kg ha^{-1}), Urea50% (100 kg ha^{-1}), Urea100% (200 kg ha^{-1}), Urea150% (300 kg ha^{-1}) and CK (a control without fertilizer). The N rates tested were 0, 100, 200 and 300 kg N ha^{-1} in both cotton and garlic season. Both the urea and CRU were single applied once as per usual on-farm practice. 90 kg ha^{-1} P_2O_5 and 180 kg ha^{-1} K_2O at each season were basally applied in all fertilization treatments. In CRU treatments, 50% of the total N was applied by PCU and PSCU at equal proportion and another part was provided by urea and DAP. The N source in urea treatments were urea and DAP.

Plots were arranged randomly with an area of 22 m^2 (4.4 m × 5 m). The garlic was sowed in mid-October with a density of 75,000 plants ha^{-1}, and harvested in early June, while cotton was soil bowl seedling in mid-April, transplanted garlic row space in early May with a density of 20,800 plants ha^{-1}, fertilized in mid-June and harvested in early October (Fig.S1). There was about 30 coexisted days for the two crops growing together in field. After garlic harvested, the chemical fertilizers for cotton were deep-strip till applied in soil at a depth of 15–20 cm. Meanwhile, the tillage practice for garlic was spread on the surface, and then plowed to a depth of over 15 cm before sowing. All the agronomic practices were applied equally for all plants as per usual on-farm practice.

2.3. Sampling and measurement

The N content and longevity of CRU (PCU and PSCU) in water were determined by the method of "State Standard of the People's Republic of China-Slow Release Fertilizer" (Liu et al., 2009). The N release characteristics of CRU in water showed in Fig.S2. Under field conditions, the N cumulative release rates were measured by a weight loss method (Wilson et al., 2009; Gao et al., 2015). Briefly, 42 mesh bags each containing 10 g PCU or PSCU particles were buried before cotton fertilization and 60 bags before garlic fertilization. Three bags were randomly collected 10, 20, 30, 50, 70, 90 and 110 d after buried in cotton season in 2015 and collected 10, 20, 30, 60, 90, 120, 150, 180, 200 and 220 d after buried in garlic season in 2015–2016. The N release rates were determined as Geng et al. (2016) (Fig. 1). As reported previously (Hara, 2000), the Richards function enables the calculation of

Table 1
Some properties of pre-planting soil (0–20 and 20–40 cm depth) at the site in 2012.

Depth (cm)	pH	Organic matter (g kg^{-1})	Total N (g kg^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
0 – 20	7.67	15.06	0.61	10.68	18.09	34.70	117.5
20–40	7.70	11.36	0.39	10.34	17.54	14.32	101.2