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Nitrogen use efficiency of cotton (*Gossypium hirsutum* L.) as influenced by wheat–cotton cropping systems

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ABSTRACT

Wheat–cotton rotations largely increase crop yield and improve resources use efficiency, such as the radiation use efficiency. However, little information is available on the nitrogen (N) utilization and requirement of cotton under wheat–cotton rotations. This study was to determine the N uptake and use efficiency by evaluating the cotton (*Gossypium hirsutum* L.) N use and the soil N balances, which will help to improve N resource management in wheat–cotton rotations. Field experiments were conducted during 2011/2012 and 2012/2013 growing seasons in the Yangtze River region in China. Two cotton cultivars (Siza 3, mid-late maturity with 130 days growth duration; CCRI 50, early maturity with 110 days growth duration) were planted under four cropping systems including monoculture cotton (MC), wheat/intercropped cotton (W/IC), wheat/transplanted cotton (W/TC) and wheat/direct-seeded cotton (W/DC). The N uptake and use efficiency of cotton were quantified under different cropping systems. The results showed that wheat–cotton rotations decreased the cotton N uptake through reducing the N accumulation rate and shortening the duration of fast N accumulation phase as compared to the monoculture cotton. Compared with MC, the N uptake of IC, TC and DC were decreased by 12.0%, 20.5% and 23.4% for Siza 3, respectively, and 7.3%, 10.7% and 17.6% for CCRI 50, respectively. Wheat–cotton rotations had a lower N harvest index as a consequence of the weaker sink capacity in the cotton plant caused by the delayed fruiting and boll formation. Wheat–cotton rotations used N inefficiently relative to the monoculture cotton, showing consistently lower level of the N agronomic use efficiency (NAE), N apparent recovery efficiency (NRE), N physiological efficiency (NPE) and N partial factor productivity (NPFP), particularly for DC. Relative to the mid-late maturity cultivar of Siza 3, the early maturity cultivar of CCRI 50 had higher N use efficiency in wheat–cotton rotations. An analysis of the crop N balance suggested that the high N excess in preceding wheat (*Triticum aestivum* L.) in wheat–cotton rotations led to significantly higher N surpluses than the monoculture cotton. The N management for the cotton in wheat–cotton rotations should be improved by means of reducing the base fertilizer input and increasing the bloom application.

1. Introduction

Nitrogen (N) is the plant's most required nutrient, it plays a crucial role in the crop yield formation by establishing and maintaining photosynthetic capacity and sink capacity (Below, 2001). The additional N fertilizer is typically needed for crops to achieve optimum yields. However, excessive N fertilizer was applied to achieve high crop yields in local agricultural production (Ju et al., 2009). Excessive use of chemical N fertilizer causes serious environmental pollution, such as groundwater contamination and soil acidification (Vitousek et al., 2009). In addition to environmental cost, farmers spend more money on chemical fertilizer than they would need to do if fertilizer use efficiency could be raised

Abbreviations: MC, monoculture cotton; NAE, nitrogen agronomic use efficiency; NRE, nitrogen apparent recovery efficiency; NPE, nitrogen physiological efficiency; NPFP, nitrogen partial factor productivity; NIE, nitrogen internal use efficiency; W/IC, wheat/intercropped cotton; W/TC, wheat/transplanted cotton; W/DC, wheat/direct-seeded cotton.

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by improving management, e.g. optimizing application rate (Hou et al., 2007).

Previous studies have reported that higher cotton (*Gossypium hirsutum* L.) yield is closely associated with the N nutrient absorb (Milroy and Bange, 2003; Saleem et al., 2010). Cotton yield reached the peak when N rate was up to 300 kg ha^{-1} for the drip irrigated cotton with plastic film mulch in northern Xinjiang Autonomous Region in China (Wang et al., 2010). The optimum N rate for highest lint yield was 240 kg ha^{-1} in Nanjing (Yangtze River Valley) and 300 to 360 kg ha^{-1} in Anyang (Yellow River Valley) (Xue et al., 2006; Li et al., 2010). However, these studies most concerned with cotton monocropping, and less attention was paid to the wheat–cotton rotations which is widely practiced in the Yellow River and Yangtze River region (Zhang et al., 2008; Dai and Dong, 2014; Du et al., 2015). Zhang et al. (2008) have studied the crop N economy in the relay intercropping systems of wheat (*Triticum aestivum* L.) and cotton. Rochester et al. (2001, 2011) reported the N use efficiency for cotton under different cropping systems in Australia. Information on the N uptake and use efficiency of cotton in wheat–cotton rotations is rather incomplete. More data are needed to better understanding of how cotton use N in wheat–cotton rotations, which will help to improve the N use efficiency, decrease the farmers input, and thus minimize the adverse impact of fertilizer N.

The objectives of this study were to (i) determine the cotton N uptake and use efficiency in wheat–cotton rotations, (ii) clarify the effect of cropping system on the cotton N dynamics, and (iii) compare the N use of different wheat–cotton rotations (at crop and system levels) in Yangtze River Valley in China and explore opportunities for improving fertilizer N use efficiency in wheat–cotton rotations.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the cotton experimental station of Nanjing Agricultural University (33°20′N, 120°46′E), Dafeng City, Jiangsu Province, China, during two growing seasons in 2011/2012 and 2012/2013. Two–year field experiments were performed in the nearby fields. The total amount of precipitation in 2011/2012 and 2012/2013 growing seasons were 743 and 748 mm, respectively. Soil samples were collected at the start of the experiments. The field soil type was sandy loam, containing 16.5 and 16.1 g kg^{-1} organic matter, 1.1 and 1.0 g kg^{-1} total N, 22.7 and 20.9 mg kg^{-1} available N, 31.2 and 28.6 mg kg^{-1} available P and 189.5 and 172.4 g kg^{-1} available K before sowing wheat in 2011 and 2012, respectively.

2.2. Experimental design

The winter wheat (*T. aestivum* L.) cultivar, Yangmai 16 (Medium maturity with a germination-to-harvest time of 210 days), and two cotton (*G. hirsutum* L.) cultivars, Siza 3 (Mid-late maturity with a germination-to-harvest time of 130 days) and CCRI 50 (Early maturity with a germination-to-harvest time of 110 days), were used in field experiments. The field experiments were composed of four cropping systems: monoculture cotton (MC), wheat/intercropped cotton (W/IC), wheat/transplanted cotton (W/TC) and wheat/direct-seeded cotton (W/DC). In the MC, W/IC and W/TC systems, cotton was planted according to the methods of Dong et al. (2007) and Dai and Dong (2014). Briefly, cottonseeds were sown in the nutrition pots in a nursery bed on 15 April, and the seedlings were transplanted to the field as the experimental design. For the MC system, 30-day-old seedlings (approximately 3rd–4th leaf stage) were transplanted into bare soil on 15 May. The W/IC system was strip intercrops, with strips of 4 rows of wheat and 1 row of cotton alternating. Row distance in wheat was 15 cm and between cotton rows 110 cm, and 32.5 cm between the wheat and cotton rows. In W/IC system, the cotton seedlings were transplanted to the strips interspersed space on 15 May, and the wheat was harvested approximately 3 weeks later in early June. For the W/TC system, the winter wheat was sown in November as preceding crop in the field, and the cotton seedlings were transplanted (approximately the 5th–6th leaf stage) to the field immediately after the harvested of wheat at early June on the next year. For the W/DC system, the winter wheat was grown as described in the W/TC system, and the cotton was direct-seeded on early June immediately after the harvested of wheat. In 2011/2012 growing season, the winter wheat was sown on 12 November in 2011 and harvested on 4 June in 2012. In 2012/2013 growing season, winter wheat was sown on 16 November in 2012 and harvested on 9 June in 2013. The detailed description of experimental design was reported by Du et al. (2015).

A split-plot design and three replications were used with the four cropping systems in the main plots and two cotton cultivars in the subplots. Each plot included five cotton rows with 1.10 m in row spacing (5.5 m wide) and 10 m in length. The cotton was planted at a density of 30,300 plants ha^{-1} for Siza 3 and 60,600 plants ha^{-1} for CCRI 50. Winter wheat was fertilized with 200 kg N ha^{-1}, and cotton was fertilized with 300 kg N ha^{-1}. The N zero control (0 kg N ha^{-1}) was set to calculate N-use efficiency. Full doses of phosphorus (P_2O_5, 150 kg ha^{-1}), potassium (K_2O, 150 kg ha^{-1}) and half doses of nitrogen (N, 100 kg ha^{-1}) were evenly broadcast before seeding wheat and the remaining 50% N was applied at the jointing stage. N fertilizer for cotton was split into pre-plant application (30%), first bloom application (40%), and peak bloom application (30%). At pre-plant application, 125 kg ha^{-1} of phosphorus (P_2O_5) and 125 kg ha^{-1} of potassium (K_2O) were also applied. The fertilizers used were urea (46.3% N), triple superphosphate (44% P_2O_5) and potassium sulphate (50% K_2O). Fields were managed following the local cultural practices.

2.3. Measurements

Wheat samples of aboveground biomass were collected from 1-m sections of each plot at 15-day intervals from March 29 to June 3, 2012 and from April 1 to June 6, 2013. These samples were subsequently separated into leaves, stems and spikes. Samples of cotton were collected three plants per plot at 15-day intervals from July 15 to 3 October in 2012 and from July 13 to 2 October in 2013, and then separated into main stems, fruiting branches, leaves, buds, flowers and bolls.

Above samples were dried at 105 °C for 30 min and then at 80 °C in a fan-forced oven to constant weight to determine the biomass. Soil samples were taken before cotton planting and at maturity on 25 October in 2012 and 30 October in 2013 to determine the soil N balance. The plant samples were weighted and crushed to pass through a sieve before nutrient analysis. The N concentrations in plant and soil samples were determined by the Kjeldahl method (Ogg, 1960). Nutrient uptake was calculated from the dry weight and the concentration.

Wheat grain yields were determined at maturity by harvesting all the plants in a sampling area of 2.0 m × 2.2 m (row length × row width) for intercropped wheat and 2.0 m × 1.5 m for monoculture wheat. Grain yields were determined by accounting for a water content of 12%. Cotton yields were measured by hand picking all open bolls in a 2.0 m × 2.2 m (row length × row width) area for each plot. The lint yields were calculated after gin turnout.