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Effects of wheat straw incorporation in cotton-wheat double cropping system on nutrient status and growth in cotton

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ABSTRACT

Soil potassium deficiency causes cotton (*Gossypium hirsutum* L.) yield decline, which China addresses through the importation of costly inorganic potassium. While applying inorganic potassium fertilizer in long-term would cause environmental issues. The feasibility of wheat straw incorporation replacing inorganic potassium for soil available potassium concentration in cotton-wheat double cropping system has been confirmed in the previous study. However, little is known about the dynamics of the nutrient concentrations and growth in cotton grown under wheat straw incorporation and inorganic potassium application. Based on the production reality in cotton-wheat double cropping system, total and half wheat straw incorporation (9000 and 4500 kg ha^{-1}), high- and super-high-yielding management requiring inorganic potassium application (150 and 300 kg K_2O ha^{-1}), and control (without wheat straw or inorganic potassium) conditions were set. The 3-year *in-situ* field experiments were conducted in Nanjing and Dafeng, China, on clay- and sandy-loam soil with initial (2011) available potassium of 155 and 316 mg kg^{-1}, respectively. The results indicated that nitrogen and phosphorus concentrations in cotton were little affected. Potassium concentrations in cotton under wheat straw incorporation of 9000 kg ha^{-1} in Nanjing and 4500 and 9000 kg ha^{-1} in Dafeng were consistent with those under inorganic potassium applications. Cotton biomass increments under inorganic potassium applications were greater than wheat straw incorporations at the late growth period. In Nanjing in 2013, seedcotton yield under wheat straw incorporation of 9000 kg ha^{-1} was similar to that of 150 kg K_2O ha^{-1}, but was markedly lower than that of 300 kg K_2O ha^{-1}. Wheat straw incorporation enhanced green leaf area duration (LAD) at the late period of cotton growth, while LAD remained longer under inorganic potassium. Relative growth rate (RGR) and net assimilation rate (NAR) of cotton under wheat straw incorporation were lower than those under inorganic potassium application. Greater cotton biomass increment at the late growth period under inorganic potassium applications were probably more because LAD remained longer, rather than RGR and NAR greater. These results showed that the short-term (3 years) strategy of incorporating 9000 kg ha^{-1} wheat straw to replace inorganic potassium (150 kg K_2O ha^{-1}) was effective for high-yielding cotton production.

1. Introduction

The optimal growth of cotton requires a large amount of potassium. Moreover, cotton is more sensitive to low potassium levels than most of other crops and often shows the symptoms of potassium deficiency even planted in the soil which is not considered low in potassium (Cassman et al., 1989). With applying more nitrogen and phosphorus fertilizer and higher-yielding cultivars, potassium deficiency has become more frequent and severe in China (Liu et al., 2009; Dong et al., 2010). On the other hand, the application of inorganic potassium fertilizer (with plenty of chloride and sulfate ion) in long-term might cause environmental issues, including soil degradation (Pernes-Debuyser and Tessier, 2004), soil crusts (Paradelo et al., 2013), soil acidification (Cleve and Moore, 1978; Tang, 1998; Paradelo et al., 2013), and underground water pollution

Abbreviations: LAD, leaf area duration; RGR, relative growth rate; NAR, net assimilation rate; DPS, days post sowing.

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(Ju et al., 2007; Udeigwe et al., 2015). Reflecting the increasing price, market shortage, and probable environmental issues of inorganic potassium fertilizer, it is urgently needed to develop a strategy to minimize dependency on this compound.

Crop residue contains abundant potassium (Singh et al., 2004) and release more than 76% potassium after 42 days post decomposition using a perfusion system (Pangga et al., 2000). The output of crop residue in China is estimated at six hundred million tons per year, and approximately 23% of the crop residue is openly burnt (Cao et al., 2008), only 16% of which is recycled to field (Zeng et al., 2007). Burning straw, which could be incorporated into soil, results in resource waste and air pollution (Cao et al., 2008). In addition, if crop residue incorporated into field could prevent soil erosion (Cassel et al., 1995) and acidification (Tang and Yu, 1999), improving environmental quality in long-term (Reganold et al., 1987).

The increasing price of inorganic fertilizer and awareness of environmental protection arouses the interest of producer in using crop residue as organic source of potassium. Numerous studies have reported that using crop residue as organic fertilizer could replace part or all potassium based on soil potassium form (Tan et al., 2007), potassium balance (Tan et al., 2007; Liu et al., 2010; Sun et al., 2011), potassium use efficiency (Sui et al., 2015), and crop yield (Zhao et al., 2014). It's obvious that these researches are most concerned about soil potassium nutrition conditions, no more than viewed from the crop yield point. Our previous study (Sui et al., 2015) investigated main soil nutrients under wheat straw incorporation and inorganic potassium application and discovered that soil water-soluble organic carbon, available nitrogen, available phosphorus, and available potassium were significantly improved by wheat straw incorporation; soil water-soluable organic carbon and available potassium concentration were markedly increased by inorganic potassium in short-term. Further, through analyzing linear mixed models, soil available potassium in the cotton field is the only significant influence factor among the main soil nutrients for cotton lint yield. This study explained that the effects of soil nutrients on cotton, however, the effects of the substitution of inorganic potassium with crop residue on the nutrients concentration and biomass dynamics of cotton remain unknown. After all, nutrients concentration dynamic and biomass accumulation have more directly influences on cotton yield formation. Hence, it is more necessary to study them for a better understanding of the comparison effects between wheat straw and inorganic potassium on the process of cotton yield formation on the basis of well-known soil condition changes.

On the other hand, except as potassium fertilizer, crop residue has been reported as a replacement for nitrogen and phosphorus fertilizer and as an addition with balanced nutrient management to further enhance crop nitrogen (Liebman and Gallandt, 2002; Takahashi et al., 2003; Northup and Rao, 2015), phosphorus (Suriyagoda et al., 2014), potassium (Wang et al., 2007; Rafique et al., 2012) uptake and to improve crop growth (Baruah and Baruah, 2015). Moreover, the effects of inorganic potassium fertilizer on cotton nutrient uptake and biomass accumulation have been frequently studied (Makhdum et al., 2007; Sawan et al., 2008; Gwathmey et al., 2009; Yang et al., 2014). Nonetheless, a comparative study of how crop residue and inorganic potassium affect the dynamics of the nutrient concentration and biomass accumulation in cotton needs further elucidation.

Classical growth analysis indices of leaf area duration (LAD) and net assimilation rate (NAR) represent leaf source quantity and quality, respectively (Zhao et al., 1995). The former represents the photosynthetic potential of plant, while the latter measures the net photosynthesis assimilation in the daytime minus respiration consumption in the nighttime. Indicative of the carbohydrate supply capacity, leaf source strength is the product of LAD and NAR (Zhao et al., 1995). Relative growth rate (RGR) determines the average efficiency of each unit of biomass in the rate of new biomass production. Therefore, LAD, NAR, and RGR are important indices to measure and investigate the formation and utilization of photosynthates. Potassium deficiency is probably the most important factor causing cotton leaf premature senescence in Australia (Wright, 1999; Pettigrew, 2003). The obvious performances of that are leaves net photosynthetic rate decline even shed, which could be understood as NAR and LAD decreased. However, only few researches investigated them under crop residue incorporation. Peltonen-Sainio et al. (1997) reported that green manure crop residue incorporation increased the LAD of spring cereals by enhancing tillers growth. It is still unknown that which contributes more to the cotton biomass accumulation and yield formation between LAD and NAR under the situation of crop residue as organic potassium source.

The working hypotheses are first based on the fact of soil nutrients changed (mainly available potassium concentration declined with experimental years), nitrogen, phosphorus, and potassium nutrient uptake in cotton might be limited; Second, both photosynthesis duration (LAD) and intensity (NAR) would be the reasons of the variation in cotton biomass and yield under wheat straw incorporation and inorganic potassium application. Through a comparative study between wheat straw incorporation and inorganic potassium application, the effects of these strategies on the nutrient concentration and biomass accumulation in cotton under contrasting soil potassium conditions were discussed. The objectives were to investigate the differences of cotton nutrition uptake condition and explore the mechanism of cotton biological and economic yield formation by classical growth analysis under different potassium source managements.

2. Materials and methods

The detail of experimental site description, climate, and field experiment design have been described in previous paper (Sui et al., 2015) and are briefly described as follows.

2.1. Experimental sites description

Field experiments were conducted at the Experimental Station of Jiangsu Academy of Agricultural Sciences in Nanjing (32°20′ N, 118°52′ E) and Dafeng Basic Seed Farm in Dafeng (33°24′ N, 120°34′ E), Jiangsu from 2011 to 2013. Two experimental sites are located in the lower reach of the Yangtze River, China. Soil types in Nanjing and Dafeng are acidic clay loam and alkaline sandy loam, respectively. The nutrient concentration of experimental soil in 0–0.2 m depth were determined before cotton transplantation and after cotton harvest (Table 1, Sui et al., 2015).

2.2. Climate

During cotton growth period in 2012 and 2013, total rainfall and monthly mean temperature were higher in Nanjing than those in Dafeng. The rainfall in Nanjing and Dafeng were 31 and 172 mm less in 2013 than those in 2012, respectively. Irrespective of experimental sites, the mean of monthly mean temperatures from July to September was 1.9°C higher in 2013 than that in 2012.

2.3. Experimental design

In cotton-wheat double cropping system of 3-yr field experiments, Siza 3, a widely planted cotton cultivar (transgenic insects-resistant hybrid cotton) in the Yangtze River Valley, wheat cultivars of Ningmai 13 and Yangmai 16 were planted in Nanjing and Dafeng, respectively. Cotton seeds were sown in a nursery