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Yield and economic benefits of late planted short-season cotton versus full-season cotton relayed with garlic

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ABSTRACT

Relay intercropping of garlic with full-season cotton is currently one of the dominant cropping systems in China, but the net benefit is decreasing because the system is labor-intensive. Direct planting of short-season cotton after garlic harvest may increase net revenue through reducing labor and material input. Three field experiments were consecutively conducted in Jinxiang County of China, to determine the effects of plant density and soil fertility on yield, yield components, boll load and leaf senescence in the 1st and 2nd experiments. In the third experiment, we compared the economic benefits of the two cropping systems. Data from the 1st experiment showed that plant density affected yield and yield components, with the optimum plant density being 3.0 plants m^{-2} for full-season cotton and 9.0 plants m^{-2} for short-season cotton. In the 2nd experiment, the seedcotton yield of full-season cotton was 9.1% higher under high than medium soil fertility, but there was no yield difference between the two soil fertility levels for short-season cotton. Full-season cotton exhibited larger boll load, earlier leaf senescence and lower boll weight under medium than high fertility. Results of the third experiment showed that seedcotton yield or output value of short-season cotton was 14.5% lower than that of full-season cotton, but the gross return for short-season cotton was 69.2% higher than that for full-season cotton because the short-season cotton required 27.3% less labor and material inputs. The overall results showed that late planted short-season cotton after garlic harvest can be a promising alternative for enhancing the benefits of garlic-cotton production in China.

1. Introduction

With a large population and limited arable land, China has widely adopted double or multi-cropping systems to raise land productivity and profitability in regions with relatively abundant water and heat resources (Mao et al., 2015; Zhang et al., 2008). Garlic-cotton double cropping is currently one of the most popular cropping systems in Huang-huai-hai plain of China, particularly in southwest of Shandong province (Xie et al., 2014). In this system, garlic is sown in late October and harvested in late May of the following year, while seedlings of full-season cotton, raised in late March or early April, are transplanted to garlic fields in late April or early May before harvest of garlic. Although transplanting has been proven to significantly improve cotton yield by extending the duration of cotton growth and development without interference with garlic yield (Dong et al., 2005), this labor-intensive intercropping system is currently faced with reduced labor availability in rural areas of China (Dai and Dong, 2014). It is also not amenable to current trend of mechanization of field management and harvest. Therefore, it is necessary to reform the intensive technology or find new alternatives to deal with labor shortage in the garlic-cotton production area of China.

In the traditional double cropping systems like relay intercropping of cotton and garlic, early maturity of cotton is essential for the timely harvest of cotton and planting of garlic. Typically, a full-season cotton variety requires a 180-day season from planting to harvest in this area; late planting of conventional full-season cotton cultivars after garlic harvest cannot guarantee normal maturity and acceptable lint yields and fiber quality (Dai and Dong, 2014). Historically, late planting of short-season cotton can minimize the risk of late maturity as well as poor lint yield and fiber quality in saline fields (Dong et al., 2010a). If cotton is successfully managed under short-season production system, several aspects of yield, input, and revenue may be optimized. Previous reports have indicated a num-

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ber of possible advantages for short-season cotton in a monoculture system (Peabody et al., 2002), such as lower input cost and higher seed emergence, convenient insect pest control for the current and next growing season, and broader options to the grower in terms of double-cropping possibilities (Dong et al., 2010a, 1994; Silvertooth and Farr, 2001). Late planting of short-season cotton has been considered a promising option for cotton production in saline areas of the Yellow River delta (Dong et al., 2010a). However, it is not clear if direct seeding of short-season cotton after garlic is feasible in the cotton-garlic system in the Yellow River valley of China.

Plant density plays an important role in the formation of biological and economical yield of cotton (Bednarz et al., 2006; Siebert et al., 2006; Dai et al., 2015). Although the final lint yield of cotton is relatively stable across a wide range of plant population densities through manipulating yield components as well as biological yield and harvest index (Bednarz et al., 2000; Dai et al., 2015), maximum lint yield is achieved at an optimum plant density range which depends upon cropping system (Bridge et al., 1973), planting date (Wrather et al., 2008), irrigation regime (Zhang et al., 2016), environmental condition (Halemani and Hallikeri, 2002; Feng et al., 2014) and cultivar type (El-Shinnawy and Ghaly, 1985). In the Yellow River valley, a plant density range of 4.5–7.5 plants m^{-2} in non-saline fields and 7.5–9.0 plants m^{-2} in saline fields, 4.5–6.0 plants m^{-2} for early planted full-season cotton and 7.5–9.0 plants m^{-2} for late planted short-season cotton in monoculture were recommended (Dong et al., 2006, 2010a, 2010b). In the northwest inland cotton region of China, the high-yielding cultivation pattern called "short-dense-early" is always in the range of 20–30 plants m^{-2} (Dai and Dong, 2014). Maximum yields were obtained in the Mississippi Delta within a population range of 7.0–12.1 plants m^{-2} (Bridge et al., 1973). Maximum lint yields in Texas occurred within ranges of 7.9–15.5 plants m^{-2} (Fowler and Ray, 1977). Feng et al. (2014) documented appropriate combination of plant density and irrigation for the highest yield in the Texas High Plains. If weather conditions are predicted to be favorable for cotton production, the 15 plants m^{-2} plus 5.08 mm d^{-1} irrigation treatment appears to be the optimum combination. However, the 7.5 plants m^{-2} plus 5.08 mm d^{-1} is the optimum combination when the weather is to be cooler than normal and rainfall is to be near average. Under deficit irrigation in an arid area of Xinjiang, 24 plants m^{-2} produced 9.1–17% greater yield and 9.3–16.8% higher irrigation water productivity than 12 plants m^{-2} or 18 plants m^{-2}, and Plant density ranging from 18 to 24 plants m^{-2} produced more seedcotton than 12 plants m^{-2} under regular irrigation (Zhang et al., 2016). Thus, establishment of an acceptable population of cotton seedlings is paramount for high yields for both full-season cotton and short-season cotton whether in monoculture or double cropping.

Another important factor influencing cotton growth, yield and yield components is soil fertility, especially under double or multi-cropping systems (Kintchéa et al., 2015; Singh and Ahlawat, 2014). Soil fertility mainly includes levels of organic matter, available N (Nitrogen), P (Phosphorus) and K (Potassium) (Dong et al., 2010b). N is the nutrient that is required most consistently and in larger amounts than other nutrients for cotton production (Ali et al., 2007; Hou et al., 2007; Dong et al., 2012). It is an essential element for canopy area development and photosynthesis (Wullschleger and Oosterhuis, 1990; Bondada et al., 1996; Boquet et al., 1993). Both P and K play vital roles in cotton growth and metabolism (Pettigrew, 2008). K also plays an important role in the maintenance of osmotic potential and water uptake during fiber development, and a shortage will result in poorer fiber quality and lower yields (Oosterhuis, 2001). Many previous reports have indicated that soil fertility is more important under double cropping than monoculture, because the production of two crops consumes more nutrients than a single crop (Kintchéa et al., 2015; Singh and Ahlawat, 2014). Higher biological yield of cotton intercropped with groundnut in New Delhi of India was due to higher uptake of N than sole cotton (Singh et al., 2009). Compared with unfertilized control treatments, fertilized treatments gave maximum yields in cotton-sorghum-groundnut rotation (Ripoche et al., 2015). Increased soil fertility enhanced grain yield and lowered production variability simultaneously in maize-wheat, rice–rice and rice-wheat cropping systems (Shang et al., 2014). Although there is a significant positive correlation between biological yield and soil fertility, it is still not clear if higher fertility may improve economic yield of cotton under garlic-cotton double cropping system.

Planting system, plant density and soil fertility greatly affect plant growth and yield of cotton, and their effects on full-season cotton have been well documented. However, the effects of these factors on late planted short-season cotton after garlic harvest in a garlic-cotton double cropping system were seldom studied. It is necessary to determine if direct seeding of short-season cotton after garlic harvest can be more profitable than intercropped full-season cotton in the Yellow River valley of China. Thus, the objectives of this study were to determine: (i) the effects of plant density and cropping system on yield and yield components, with a particular interest on the optimum plant density under different cropping systems; (ii) how soil fertility influences the productivity of both cropping systems and (iii) input-output scenarios and net returns of the two cropping systems.

2. Materials and methods

2.1. Experimental sites and cultivars

Three field experiments were consecutively conducted in 2012–2013, 2014–2015 and 2015, respectively, in Jinxiang County (116°7′ E, 34°52′ N), Shandong province, China. Soil fertility parameters for the experimental sites are presented in Table 1. The climate in the experimental area is temperate and monsoonal with an average rainfall of about 600–700 mm with greater distribution in July and August. SCRC 25, a full-season cotton (*Gossypium hirsutum* L.) cultivar with high yield potential, and SCRC 532, a short-season cotton cultivar with early maturity, were used in the three experiments.

2.2. Experimental design

The first experiment was arranged in a split plot design with three replications from 2012 to 2013. The main plots were two cropping systems: relay intercropping of garlic with full-season cotton, and direct seeding of short-season cotton after garlic. Subplots were assigned four density gradients of 1.5, 3.0, 4.5, and 6.0 plants m^{-2} for full-season cotton, and 3.0, 6.0, 9.0 and 12.0 plants m^{-2} for short-season cotton, hereafter referred to as low, medium, high, and super-high plant densities (Xie et al., 2014; Dong et al., 2010a). The area of each subplot was 50 m^2 with four rows of full-season cotton or five rows of short-season cotton.

Treatments for the second experiment were also arranged into a split plot design with three replications from 2014 to 2015. The main plots were the planting systems – relay intercropping of full-season cotton at 3.0 plants m^{-2} and direct planting of short-season cotton at 9.0 plants m^{-2} after garlic; subplots were soil fertility levels of medium and high (Table 1). From results of the first experiment, the plant densities of 3.0 and 9.0 plants m^{-2} were the optimum for full- and short-season cotton. The two fields with high and medium soil fertility were 200 m apart. The area of each subplot was 50 m^2 with four rows of full-season cotton or five rows of short-season cotton as in the first experiment.