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Effects of planting pattern on growth and yield and economic benefits of cotton in a wheat-cotton double cropping system versus monoculture cotton

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ABSTRACT

The double-cropping system of wheat and cotton is widely adopted in the Yellow River Valley of China, but it remains unclear if and how planting patterns impact cotton yield and economic benefits in this system. Using monoculture cotton (CM) as the control, we conducted a 2-year field experiment to investigate the effects of three planting patterns, cotton intercropped with wheat (CIW), cotton transplanted after wheat (CTW), and cotton direct-seeded after wheat (CDW) under the wheat-cotton double cropping system on cotton growth, yield and economic benefits in two fields differing in soil fertility. The results indicated that double cropping significantly decreased cotton yield relative to monoculture irrespective of planting pattern and fields, but the decrements were considerably reduced in the high soil fertility field. Averaged across two years, cotton yields of CIW, CTW and CDW were reduced by 16.2, 30.0 and 38.8% in the low fertility field relative to that of CM, while they were reduced by 7.5, 22.4 and 22.7% in the high fertility field. The yield difference among planting patterns was attributed to the variation in both the number of bolls and boll weight, while the yield difference between two fields was largely due to the number of bolls. Similar differences in biomass accumulation were observed among planting patterns. Accelerated early development of cotton, extended duration of the fast biomass accumulation and the enhanced total biomass and accumulation rate were observed in the high fertility relative to those in the low fertility field. Economic analysis showed that, based on total costs and output values of two crops, the net revenue of CIW, CTW and CDW was increased by 28.5, 10.9 and 36.5% in the low fertility field; and by 56.3, 31.8 and 74.4% in the high fertility field, compared to CM averaged by two years. CDW might be a new alternative for cotton production in Yellow River Valley when taking both profitability and management simplification into consideration. Our results also support that good soil fertility is a prerequisite for high yield and net return in wheat-cotton double cropping, especially for CDW.

1. Introduction

With the increasing population and limited arable land area in China, great emphasis has been placed on developing farming technologies and cultural practices to improve crop yield (Dai and Dong, 2014; Dai et al., 2014). However, enhanced crop production, particularly the high yield of a single crop, is largely due to the adoption of chemical products (Feng et al., 2017). Although they have positively increased crop yield, chemical products have also significantly contributed to environmental pollution and the risks of food safety (Dai and Dong, 2014). To solve these problems, scientists need to shift their focus from enhancing the yield of a single crop to increasing the productivity per unit land area (Han et al., 2014; Zhang et al., 2007; Lu et al., 2017). Therefore, diverse cropping systems have been developed to increase productivity, with substantial benefits for the farmer's total income. Compared to monoculture of cotton, wheat-cotton double-cropping systems can increase crop production per land area by more than 20% (Zhang et al., 2007). These double-cropping systems have been widely adopted in the Yellow River Valley and the Yangtze River Valley, which are two of the three main cotton production areas in China (Dai and Dong, 2014; Mao et al., 1999; Wang et al., 2012). In addition, due to the increasing labor cost for cotton production, cotton acreage has been greatly reduced in the Yellow River Valley (Dai et al., 2017). The application of double-cropping systems has been recognized as an

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Table 1
Soil (0–20 cm) fertility of the two experimental fields at Anyang, Henan, in 2013 and 2014.

Year	Testing Time	Field	pH	Bulk density	Organic matter g kg^{-1}	Total N g kg^{-1}	Available P mg kg^{-1}	Available K mg kg^{-1}
2013	Before cotton planting	Low fertility	7.2	1.51	13.4	0.83	20.2	202.3
		High fertility	7.2	1.48	20.3	1.22	30.6	218.8
	After cotton harvest	Low fertility	–	–	12.0	0.79	17.4	189.5
		High fertility	–	–	19.4	1.21	29.0	196.7
2014	Before cotton planting	Low fertility	7.2	1.55	13.1	0.82	22.1	190.6
		High fertility	7.2	1.56	19.7	1.12	33.3	193.4
	After cotton harvest	Low fertility	–	–	11.7	0.80	15.1	178.1
		High fertility	–	–	18.3	1.07	28.1	178.8

effective way to slow the decrease of cotton production in the Yellow River Valley (Liu et al., 2015).

In wheat-cotton double cropping systems in the Yellow River Valley, cotton can be intercropped with wheat, transplanted to or directly seeded in bare fields after wheat harvest (Cotton Research Institute of Chinese Academy of Agricultural Sciences, 2013). Although the annual production per unit land area is improved, the cotton yield is somewhat reduced due to the limited resources in double-cropping systems. A wheat-cotton intercropping system slows cotton growth in the seedling stage and thus delays reproductive growth due to interspecific competition for light and water between the two crops (Van der Meer, 1989). An investigation of the relationship between seed cotton weight per boll in wheat-cotton double cropping and meteorological factors showed that hours of sunshine was the key meteorological factor in most wheat-cotton double-cropping patterns (Zhou et al., 2000). Although it was consistently reported that cotton yield was reduced in double-cropping systems, the degree of cotton yield reduction in double-cropping systems was variable in previous studies, ranging from 0% to 32% less than in monoculture cotton (Cotton Research Institute of Chinese Academy of Agricultural Sciences, 2013; Du et al., 2016; Zhang et al., 2008). Since short-season cotton cultivars were released, direct-seeding of short-season cotton after wheat has been consider an alternative in the Yellow River Valley, but lint yield was even lower than that of intercropped full-season cotton due to reduced period of cotton growth and development (Hodges et al., 1993; Zhou et al., 2000). To extend the period of cotton growth in the wheat-cotton system, seedling transplanting technology was adopted, which increased the cotton yield by 20–30% through an increased number of bolls (Dong et al., 2005). Thus, plant patterns of a cropping system greatly impact cotton yield. Understanding the formation of cotton yields in different cropping systems as affected by planting patterns is important. However, most studies have only focused on a certain planting pattern or cropping system; few, if any, have simultaneously studied different planting pattern and cropping systems related to cotton (Du et al., 2016).

Soil fertility is one of the most important factors in modern agricultural activities (Sawan et al., 2006). Additionally, soil fertility greatly contributes to yield differences for the same agronomic practices (Cotton Research Institute of Chinese Academy of Agricultural Sciences, 2013). As the comprehensive indicator of soil physical, chemical and biological properties, soil fertility is mainly expressed as the contents of organic matter and mineral nutrients (Xiong et al., 2004). It is well known from numerous fertilizer experiments that cotton yield is strongly dependent on the supply of organic matter and mineral nutrients; this knowledge has been used in crop cultivation to exploit the full genetic potential of the plant (Lyu et al., 2011; Pei et al., 2013; Shen et al., 2004). For example, Yang et al. (2015) reported that the application of fertilizers and crop residues for 22 years substantially increased soil organic matter by 11% and corn yield by 75% on the North China Plain. Zhang and Li (1997) also noted that the decreased cotton yield in intercropping systems could be prevented with appropriate management and high fertilization inputs. Although numerous studies have focused on the variation in yield with fertilizer application (Kazemeini et al., 2016; Stamatiadis et al., 2016), there are limited studies on cotton yield variations of different cropping systems under different soil fertility.

Therefore, our objectives in this study are (i) to investigate the effects of planting pattern on growth and yield of cotton in a wheat-cotton cropping system versus monoculture cotton; (ii) to clarify if such effects of planting pattern were dependent on soil fertility; and (iii) to determine the input, output and net returns of different treatments in two fields with different soil fertility. This work will provide further guidance for improving cotton yield and benefits in wheat-cotton double cropping system, and also provide a reference for selecting new profitable planting pattern in the Yellow River Valley.

2. Materials and methods

2.1. Experimental sites

The field experiment was conducted during the growing season of 2013 and 2014 at the research station of Institute of Cotton Research, Chinese Academy of Agricultural Sciences, Anyang, Henan, China (36°07′N, 116°22′E). Two cotton fields (approximately 1 km apart) with different historical yields were selected. The soil of both fields was clay loam. Soil samples were collected at depths from 0 cm to 20 cm to test the soil fertility. Chemical analysis showed that the field with a higher historic yield had significantly higher amounts of soil organic matter, total N and available P than the other field, although the available K content in both fields was comparable (Table 1). A comprehensive appraisal of soil fertility was completed using the method of Lu et al. (2003) and indicated the different soil fertility levels of the two fields. In this study, the two fields were referred to as "high fertility" and "low fertility" for convenience. The relevant soil characteristics prior to sowing cotton and after were presented in Table 1. Weather data were acquired from a weather station located near the experimental field (Campbell Scientific, Logan, UT, USA). The climatic variables were provided in Table 2.

Table 2
Weather information during the cotton growth season at Anyang, Henan, in 2013 and 2014.

Meteorological variable	Year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Total
Precipitation (mm)	2013	6.1	57.1	76.5	226.0	36.6	16.0	10.6	429
	2014	45.6	31.8	37.2	129.4	46.1	156.1	4.3	451
Daily mean temperature (°C)	2013	14.1	21.6	25.8	27.3	28.0	21.5	15.4	22.0
	2014	16.0	22.8	26.0	26.9	25.1	20.6	16.7	22.0
Solar radiation (MJ m^{-2} - d^{-1})	2013	15.9	12.8	17.0	15.5	19.1	12.3	10.6	11.5
	2014	14.9	20.3	18.3	18.2	16.4	10.6	9.9	13.7