Productivity and resource use in cotton and wheat relay intercropping systems

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Abstract
This study aims at analyzing the productivity and resource use of cotton-wheat relay intercropping systems. Crop growth, phenology, productivity, quality, resource use efficiencies and profitability of mono- and intercrops were studied at the plant, field and system levels. The measurements were carried out in field experiments during three consecutive years with monocultures of wheat and cotton and four intercropping designs differing in strip and path width as well as number of rows per strip. The intercrop systems were identified by the number of rows per strip of wheat and cotton, respectively, as 3:1, 3:2, 4:2 and 6:2.

All intercropping systems showed an advantage in land productivity compared to growing of monocrops. The land equivalence ratio was 1.39 in the 3:1, 3:2 and 4:2 systems, and significantly lower, 1.28, in the 6:2 system. Light and nitrogen use efficiencies of intercropped wheat were similar to the monoculture; however, the resource capture decreased, because part of the land space was assigned to cotton. For intercropped cotton, light use efficiencies were similar to the monoculture; the amount of light intercepted decreased due to a delay in development and growth during the seedling stage and by the extent of canopy closure after the wheat harvest. The relative nitrogen yield total of intercrops was higher than the land equivalence ratio. Nitrogen use efficiency of cotton was decreased. The findings suggest that the productivity and resource use efficiencies of cotton-wheat intercropping can be improved by modifying the conventional management practices and by system optimization.

Media summary
Relay intercropping of cotton and wheat showed a clear advantage in land productivity over sole crops. Options for further improvement of productivity and resource use were studied.

Key words
Grain yield, lint yield, phenology, developmental delay, light use, nitrogen use efficiency

Introduction
China accounts for 22 percent of the world’s population but it has access to only 7 percent of the world’s arable land. Cotton occupies a crucial position in the national economy and the livelihood of many Chinese farmers. From the early 1980s onwards, farmers in the Yellow River cotton producing region started to intercrop cotton and winter wheat because of the need to increase household income by growing cotton as a cash crop, while continuing the production of wheat as a major staple food. A relay strip wheat-cotton intercropping system is used to grow both wheat and cotton on the same field in one year. In this system, strips of winter wheat, sown in the fall, are intersown with cotton in the spring. After the wheat harvest in early summer, cotton occupies the whole land. Several intercropping patterns are used in practice. They are named after the numbers of rows of wheat and cotton that are
alternated, e.g. the 3:2 system is an intercropping system consisting of 3 rows of wheat and 2 rows of cotton alternating. Other systems in use include 3:1, 4:2 and 6:2. In addition, some variability in the row distances exists. These systems are characterized by differences in production and competitive relationships among cotton and wheat, but these differences have not been quantitatively documented. We analyzed the productivity and resource use of cotton-wheat relay intercropping systems. Crop growth, phenology, productivity, and resource use efficiencies of mono- and intercrops were studied at the plant, field and system level.

**Methods**

Field experiments were conducted in 2001/02, 2002/03 and 2003/04 at the Cotton Research Institute of Chinese Academy of Agricultural Sciences (CRI, CAAS), Anyang city, Henan province, China at 36°07´N and 116°22´ E. Field experiments comprised six treatments including four different intercropping patterns and monocultures of wheat (*Triticum aestivum* L.) and cotton (*Gossypium hirsutum* L.). Width of the wheat strip, as measured between the outer wheat rows was 100 cm in the 6:2 system, 60 cm in the 4:2 system, and 40 cm in the 3:2 and 3:1 systems. The interspersed space for sowing cotton was 100 cm in the 6:2 system, 90 cm in the 4:2 system, 80 cm in the 3:2 system, and 60 cm in the 3:1 system. The yield, quality, dry mass, LAI, light intensity, nitrogen content and temperatures in the canopy were measured and analysed (Zhang, 2007).

**Results and Discussion**

The land equivalence ratio (LER) of the four tested wheat-cotton intercropping systems ranged from 1.28 to 1.39 (Zhang et al., 2007a). Thus, all intercropping systems showed a clear advantage in land productivity. Among the four intercropping systems, the 3:1, 3:2 and 4:2 were the most productive systems with regard to yield; the 6:2 system was the least. In intercropping systems the grain yield of wheat was 61% higher in border rows than in inner rows. The yield advantage resulted from more light capture and a better acquisition of nutrients by wheat at the expense of the dry mass growth of cotton during the intercropping period. This confirms the findings reported for strip intercropped soybean, corn and wheat systems (Iragavarapu and Randall, 1996; Li et al., 2001).

In wheat-cotton intercropping systems, cotton is sown in April in the path assigned at wheat sowing in November of the previous year. The duration of the intercropping period is relatively short, only seven weeks, but a fully developed wheat canopy competes for light and nutrients with cotton seedlings. Therefore, the utilization of resources such as light interception, nitrogen and water uptake by intercropped cotton during this period is affected by the competitive strength of the wheat crop. As a result the development rate, canopy size, amount of light interception and total N uptake of intercropped cotton were decreased. Cotton development in the intercropping systems was delayed by 10-15 calendar days. This delay corresponded with 4.7 physiological days (days with optimal temperature conditions) or 115 degree-days expressed as thermal time for the duration from sowing to the first square (Zhang et al., 2008d). The magnitude of the delay was the same in all tested intercrops. The developmental delay of cotton in wheat-cotton intercropping systems is long compared to the developmental delays reported for other intercropping systems (Bukovinszky et al., 2004; Gethi et al., 1993). It is associated with a 2.7°C decrease of air temperature on a sunny day during the intercropping period, as a consequence of shading by the wheat canopy. The delay in development reduced the number of fruit branches, nodes and fruits before ‘cut out’ (removal of topmost buds of main stems), thus, decreasing harvest index and lint yield, which was also reported in literature (Lei and Gaff, 2003; Sadras, 1995).

Light use efficiencies (LUE) of both wheat and cotton were not affected by intercropping. Wheat and cotton intercropping systems captured more light than monoculture of cotton. Compared to a cropping system of sole cotton, in relay intercropping systems a substantial amount of light (420 to 490 MJ m⁻² from early spring to wheat harvest) is captured by the wheat crop before cotton plants emerge. From a spatial point of view, the wheat strips in the intercrops captured about 20% more light than the canopy.
of monocropped wheat per unit of strip area, thus compensating in part for the spare paths between the wheat strips. Narrow strips (60 cm) give greater light interception and higher yields than wider strips (120 cm) due to a greater number of border rows with an increased compensation ability. Wheat monocrops intercepted 618 MJ m\(^{-2}\) photosynthetically active radiation (PAR) from Mar-18 to harvest in 2002. Averaged over three years, wheat in the four intercrops (3:1, 3:2, 4:2 and 6:2, respectively) intercepted 83, 71, 73 and 75% as much PAR as the sole wheat. Cotton monocrops intercepted on average 444 MJ m\(^{-2}\) PAR from sowing to harvest in three years. Cotton in the four intercrops (3:1, 3:2, 4:2 and 6:2, respectively) intercepted 73, 93, 86 and 67% as much PAR as the sole cotton. No differences in LUE of wheat or cotton were found between systems (Zhang et al., 2008c).

Total nitrogen uptake of wheat in the intercropping strips was approximately 15% higher, expressed per unit strip area, than in monoculture. The increased nitrogen uptake is due to additional growth of wheat in the border rows, and the capture of extra nitrogen from the strips allocated to cotton. The N uptake of cotton in the intercropping systems was reduced during the intercropping period. However, the loss of N uptake by intercropped cotton at the seedling stage recovered during the post-wheat period due to ‘compensatory growth’ of the vegetative plant parts resulting from the reduced fruit setting. A similar compensatory growth was reported for loss of reproductive organs (Lei and Gaff, 2003; Sadras, 1995). The relative N uptake of cotton in the intercropping systems, compared to monoculture, was 8 to 21% higher than the relative lint yield, compared to monoculture. Differences in N-uptake by intercrops and sole crops are also reported by Szumigalski and Van Acker (2006). Internal N use efficiencies (IE) of wheat did not differ between intercropping systems and monoculture. The IE of cotton was significantly (P<0.05) lower in intercrops than in monoculture (Zhang et al., 2008b). The lower IE of intercropped cotton is due to a decrease of harvest index (HI). The cotton in the 3:2 and 4:2 intercrops showed the highest lint yield and therefore utilized nitrogen more efficiently than in other intercropping systems.

The water productivity (WP), kg grain or lint yield per unit delivered rainfall plus irrigation, ranged from 0.95 to 1.28 kg m\(^{-3}\) for wheat, and from 0.11 to 0.22 kg m\(^{-3}\) for cotton in the intercropping systems, 27% and 40% lower than the WP in the monocultures of wheat and cotton, respectively (Zhang, 2007). The lower WP of wheat in the intercropping systems was due to a decline in yield per unit of homogenized land area under ‘full’ irrigation. The lower WP of cotton in the intercropping systems was due to a lower biomass yield and a reduced harvest index.

**Conclusion**

The aggregated results lead to the following interpretation of growth processes in cotton-wheat intercropping: (i) dry matter accumulation is driven by light interception as determined by crop leaf area; (ii) the growth rate per unit of intercepted light is similar in all systems; (iii) wheat-cotton systems with a narrow path between the wheat strips results in a developmental delay in the cotton, probably as a result of lower temperature, that is not compensated for after wheat harvest, and which results in a delay and decrease in fruit set, fruit production and harvestable yield; (iv) intercropping systems with a high density of cotton, such as the 3:2 and 4:2 system, show a more rapid recovery and increase of LAI after the wheat harvest than systems with a lower density of cotton; (v) there are no developmental effects of intercropping on the wheat crop; (vi) systems with a wide path between the wheat strips enable cotton to advance quickly in development and produce a high fruit biomass; these systems have a higher nitrogen use efficiency; (vii) the nitrogen use efficiency of wheat is unaffected by intercropping, as wheat is the first and dominant crop, and resource uptake and use efficiency in wheat are a pure response to density, and are not affected by interference from the second, submissive crop, cotton. Although not experimentally tested, it can be easily seen that a very wide path width for cotton would lead to a lower light interception, reduces photosynthesis and as a consequence a lower yield (see also: Milroy and Bange, 2003).
Prospects for optimizing intercropping systems are: (i) modifying the microclimate of cotton seedlings (film cover, transplanting); (ii) genetic selection for earliness of both component crops and (iii) a site-specific demand based nitrogen supply.

References


