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Plant density affects light interception and yield in cotton grown as companion crop in young jujube plantations

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ABSTRACT

Tree-crop mixtures may increase yield and revenue especially during the early years of tree plantations. Jujube is grown widely in China for their fruits, and cotton is gaining popularity as an understory crop in young jujube plantations. There is a need for information on productivity and optimal planting densities of cotton in these mixed systems. Field experiments were carried out in 2012 and 2013 in Hetian, Xinjiang, China. Three cotton plant densities (13.5, 18.0 and 22.5 plants m^{-2}) were tested in 6–7 years old jujube plantations, in which the cotton was grown in a 6 m-wide space between the tree rows. Cotton leaf area index increased but plant height decreased with plant density. Cotton light interception increased with density, but at early and mid-season, the difference in light interception between 18.0 and 22.5 plants m^{-2} was only marginal. Increasing plant density modified the distribution pattern of the light within the canopy, thus affected overall cotton light interception and use efficiency. The highest yield and light use efficiency of cotton were achieved at 18.0 plants m^{-2}. Spatial distributions of light intensities and extinction coefficients were affected by the shading of jujube trees within the cotton canopy in the intercrop. Jujube growth, yield and light utilization were not significantly affected by cotton plant density. We conclude that the productivity and light utilization of cotton in jujube-cotton intercropping can be increased by optimizing cotton plant density.

1. Introduction

Agroforestry provides the opportunity for the maintenance of food and fibre production, biodiversity increase (George et al., 2013). It offers a number of services and environmental benefits (Jose, 2009; Branca et al., 2013) and plays an important role for a multifunctional and sustainable agriculture landscape (Schroth and da Mota, 2013). Agroforestry systems may have a land equivalent ratio (LER) of up to 2.0 (productivity is 2 times higher than the monoculture) (Smith et al., 2012) due to reduced soil evaporation and crop transpiration (Lin, 2010), and enhanced soil fertility (Rivest et al., 2003). However, usually, the land equivalent ratio is below 2.0 due to competitive interactions between the crop and tree species (Graves et al., 2007). For instance, the productivity of cotton intercropped with a shea-based agroforestry system was reported with 13.1% less buds (number of young fruits) production compared to the monoculture (Gnangle et al., 2013).

Xinjiang (China) is a semi-arid region where the rainfall is limited, but light is abundant and irrigation water is available, which provides excellent growing conditions for high quality fruit production, e.g. jujube (*Zizyphus jujuba* Mill). Recently, the local government has sought ways to develop fruit industry with trees to mitigate wind erosion which is prevalent during winter in arable agriculture of wheat or cotton. Planting fruit trees could prevent desertification and boost the income of farmers. Growing wheat or cotton as companion crops between jujube tree rows is a common and profitable practice, especially during young stage of jujube trees (younger than 10 years), and was applied on around 32,000 ha in Hetian region (Xingjiang, China) in 2011 (Liu et al., 2012). Agroforestry with fruit trees (apples, pears, walnut, jujube) was introduced by the government in Xinjiang in 2008, and currently covers approximately 1.2 million ha in the whole of the province. While this is a large area, due to the recent introduction of the system, much knowledge and familiarity still needs to be developed, both in research and in farmers' practice. Farmers like

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Fig. 1. Photo of jujube tree and cotton intercropping system (13.5 plants m^{-2}) in Hetian, China.

to take opportunity of the space between young tree rows to cultivate arable crops. The jujube-cotton agroforestry system (Fig. 1) is considered a profitable system with high resource use efficiency (Zhang et al., 2013), but there is little quantitative information on profitability and resource use efficiency.

Light interception in canopies is affected by canopy structure (Mariscal et al., 2004). Aspects of cotton structure such as plant height, fresh biomass and number of buds decrease in agroforestry as compared to monoculture cotton (Gnangle et al., 2013). Cotton branch length is shortened at higher plant density (Mao et al., 2014) and therefore light interception may be reduced (Gwathmey and Clement, 2010). Increasing cotton density may increase leaf area index, total dry matter and lint yield (Kerby et al., 1990; Dong et al., 2006b; Gwathmey and Clement, 2010), as well as light use efficiency (LUE) (Mao et al., 2014). In contrast; Siebert and Stewart (2006) found that higher plant densities decreased LUE. LUE can be increased by reducing the amount of incident radiation and at the same time increasing proportion of diffuse radiation (Bange et al., 1997). LUE might also be affected by vapor pressure deficit (Gonias et al., 2012), temperature (Garcia et al., 1988), chemical control of plant development (Mao et al., 2014) and variation in partitioning of biomass between roots and shoots (Gimenez et al., 1994). Thus, there is a possibility for modifying light use efficiency when cotton is grown in the shade of jujube trees.

Under tree canopies, the distribution of light in cotton is affected by shading by the tree layer. This may be a very important limiting factor for growth and development of intercropped cotton (Leroy et al., 2009). An intense belowground competition for resources has been found in agroforestry (Livesley et al., 2000; Zhang et al., 2013) especially if the crop grows near the trees (Schroth, 1999).

In agroforestry systems, quantifying the competition for light is a prerequisite towards understanding the impact of shading by trees on the productivity of the under-crop (Charbonnier et al., 2013; Varella et al., 2011; Gao et al., 2013). Models for homogeneous canopies and shade/full-sun approaches do not address the intra-plot heterogeneity, typical of agroforestry systems (Charbonnier et al., 2013). We evaluated and used a simple and powerful strip (row) structured model (Zhang et al., 2008a) for quantification of light utilization in cotton-jujube agroforestry.

To be able to quantify and optimize radiation use and productivity in jujube-cotton agroforestry systems, it is necessary to find an optimized cotton configuration and density in systems in which the tree configuration is already fixed following the demands to obtain high value fruits, and how to take advantage of the space between the trees during the young stages to grow arable crops. Therefore,

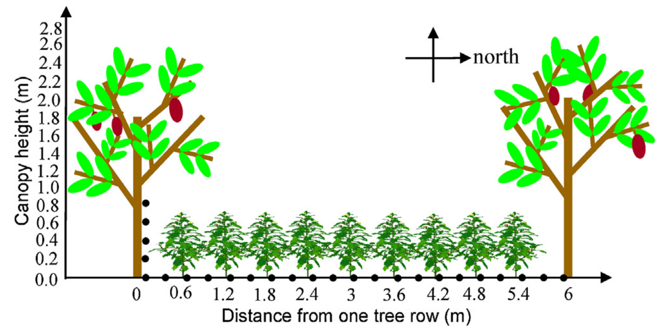

Fig. 2. Layout of jujube tree and cotton intercropping system. The points indicate placements and heights of the setting of the light sensors. The measurement heights indicated at the left jujube tree row were used for all placements as indicated.

the objectives of this study are to (1) assess the effect of cotton plant density on crop growth and yield in cotton intercropped with jujube trees; (2) measure and quantify the spatial distribution of light interception and light use efficiency in relation to cotton density; (3) calculate theoretical light interception with a simple row canopy model and validate the results; (4) determine the optimal cotton plant density in terms of light capture, light use and crop production in jujube-cotton intercropping.

2. Materials and methods

2.1. Field experiments

Field experiments were conducted at Agricultural Science Institute of Agricultural Technology Promotion Center, Hetian, Xingjiang, China (latitude 37°9′N, longitude 79°53′E, altitude 1350 m) in 2012 and 2013. The climate is warm temperate desert. The frost-free season is about 220 days. The soil of the field of experimental site is sandy Arenosol. Soil nutrient status in 0–30 cm soil layer is: total N 5.8 g kg^{-1}, Olsen P 21.2 mg kg^{-1} and NH_4OAc-extractable K 51.3 mg kg^{-1}. The cotton (*Gossypium hirsutum* L.) cultivar was an early-mature variety called 'XLZ46'. Jujube tree (*Z. jujuba* Mill) was 6-year-old in 2012 and 7-year-old in 2013. Distance between two adjacent tree rows was 6 m, and plant distance of the trees was 1.0 to 1.5 m. The jujube trees in two testing years had a height of 2.68 to 2.81 m and crown width of 2.07 to 2.16 m. Nine rows of cotton were intercropped between the tree rows with an equal row space of 60 cm. The distance between jujube tree row and adjacent cotton border row was 0.6 m (Fig. 2).

The experiments comprised three treatments with different homogenized cotton plant densities (expressed for the total ground area): 13.5, 18 and 22.5 plants m^{-2}. Densities were achieved by choosing the appropriate plant distance within a row, thus row distance was maintained. The whole experiment was a randomized block design including four replicates. Plastic film mulching was applied in all the plots as farmer's practice due to the limitation of heat resource, especially in early spring. The row orientation was east to west.

Cotton was sown by hand on 23 April 2012 and 21 April 2013. The harvest dates were 15 October in 2012 and 13 October 2013. The jujube sprouted at the beginning of May and flowered after 30 days. The trees were pruned annually. A basal fertilizer at a rate of 300 kg ha^{-1} N and 150 kg ha^{-1} P was used in both years. The same amount (300 g ha^{-1}) of growth regulator mepiquat chloride (MC) was applied to all plots according to farmer's practice to control cotton growth. The experimental plots were irrigated 10 times at a 15 days interval with 50 mm water each time. A top fertilizer with 30 kg ha^{-1} N and 15 kg ha^{-1} P was applied at the time of irrigation.