Field Crops Research 198 (2016) 112–121

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Effect of planting date and plant density on cotton traits as relating to mechanical harvesting in the Yellow River valley region of China

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ARTICLE INFO

Article history:
Received 2 August 2016
Received in revised form 5 September 2016
Accepted 5 September 2016

Keywords:
Cotton
Mechanical harvesting
Planting date
Plant density
Yellow River valley

ABSTRACT

Previous studies have indicated that mechanical cotton harvesting requires a compact plant habit without fiber yield and quality reduction. The objective of this study was to determine the effects of planting date and plant density on plant habit, yield, early maturity, and fiber quality of cotton in the Yellow River valley region of China, and thus to identify the appropriate planting date and plant density suitable for its mechanical harvesting. Field experiments were conducted in 2013 and 2014 in Hejian, Hebei Province, using a split-plot design with planting date as the main plot and plant density as the subplot. The results indicated that moderately late planting in late April or early May (P2) was appropriate for mechanical harvesting of cotton as relative to P1 (local traditional planting date, 10 d earlier than P2) and P3 (10 d later than P2). P2 showed a 2.4–5.7 cm greater height to the first fruiting branch (from the bottom) and a 4.7–11.3 cm higher lowest boll (harvestable boll nearest to the ground) compared with P1, which is helpful for decreasing yield loss and reducing intake of residual plastic mulch. In addition, P2 produced slightly greater yield than P1 and P3, and the percentage of open bolls in late September for P2 was similar to that of P1 and greater than for P3, suggesting a low risk of late maturity. For plant density, 8.9 plants m^{-2} (D2) was appropriate for mechanical harvesting compared with 6.6 plants m^{-2} (D1), the local traditional density for manual harvesting, and 12.3 plants m^{-2} (D3). D2 showed a 2.5 cm greater height to the first fruiting branch and a 4.2 cm higher lowest boll, and exhibited 2.9–3.6 and 2.6–3.9 cm shorter lengths of lower and middle fruiting branches than D1, respectively. This type of compact plant habit is conducive to efficient mechanical harvesting. Moreover, D2 produced a similar yield to D1 for both the rainy 2013 and the dry 2014, indicating yield stability. Although D3 had a more suitable plant habit for mechanical cotton harvesting, its yield level and maturity varied across years. There were no significant interactions between planting date and plant density in the majority of tested traits. The results will contribute to the development of integrated cotton management for upcoming mechanical harvesting in the Yellow River valley region of China.

1. Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important fiber crops in the world, and China is one of the leading producers. Agricultural practices for crops are based on a systematized body of knowledge (science) and require skills (technology). From a historical perspective, crop production practices have changed with developments in science and technology as well as socioeconomic status. For instance, the planting date of cotton in the Yellow River valley region and the northwest inland cotton growing region of China is now 7–10 d earlier than it was in the 1980s due to the universal adoption of plastic film mulching, which can markedly increase soil temperature (CRI, 2013; Dai and Dong, 2014). Excessive vegetative growth of cotton plants can be inhibited by mepiquat chloride (MC; *N*,*N*-dimethyl piperidinium chloride), a gibberellic acid (GA) synthesis inhibitor (Xi et al., 1981; He and Yang, 1983; Kerby, 1985; Reddy et al., 1992; Oosterhuis and Zhao, 1995). Therefore, with the application of MC in cotton production, cotton plant density in the Yellow River valley region and the northwest inland cotton region has increased from 30,000 to

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http://dx.doi.org/10.1016/j.fcr.2016.09.010
0378-4290/

more than 52,500 plants ha^{-1} and from 10,500 to 12,000 to more than 180,000 plants ha^{-1}, respectively (Chen, 1999; CRI, 2013). Labor in China has gradually shifted from rural areas to cities and towns over the last two decades. Consequently, traditional labor intensive pruning measures, comprising manual removal of vegetative branches, plant topping, and continuously excising of old leaves, excess buds, and growth tips of fruiting branches, have been greatly simplified and only manual removal of part of the vegetative branches and plant topping are currently being performed (Mao, 2010; Dai and Dong, 2014; Dai et al., 2014).

Compared with several years ago, the shortage of labor and rising labor costs in China have become extreme and have led to the recent rapid development of full mechanization of cotton production, mainly harvesting, in the Xinjiang Production and Construction Corps (XPCC) located in the northwest inland region of China. However, in the Yellow River valley region, cotton is still manually harvested. The reasons for the continuation of manual harvesting are that the production scale is still relatively small, and the cotton varieties, agricultural practices, and ginning processes are incompatible with mechanical harvesting. The delay of introducing mechanical harvesting has led to a rapid 73% reduction of the cotton area in the Yellow River valley since 2011 (MSNCM, 2012, 2016).

Experience gleaned from the United States, Australia, and XPCC indicates that the height of a cotton plant should be less than 120 cm for spindle-pickers and less than 80 cm for stripper-pickers, respectively (Williford et al., 1994; Van Der Sluijs, 2013), because excessively tall plants decrease the efficiency of mechanical harvesting. A compact plant habit and thinner main stem are also necessary for efficient mechanical harvesting by spindle- or stripper-pickers. Considering that the lowest spindle height of a cotton picker is 15 cm (Jiu, 2013), higher positions (>20 cm) of the first fruiting branch (sympodium) and the lowest harvestable boll favor a lower loss of yield. In addition, increased heights of the first fruiting branch and the lowest boll permit the lift of spindles more than 15 cm, which can reduce the intake of residual plastic mulch which is widely used in cotton production of the Yellow River valley region and the northwest inland cotton region. To avoid loss of yield and weathering of the fiber resulting from longer exposure of open bolls to inclement weather, earlier maturity is a characteristic of cotton that is necessary for mechanical harvesting. Moreover, a loss of fiber length and strength can occur during the ginning of machine-harvested cotton because of the extra cleaning of seed cotton and lint that is required compared with hand-harvested cotton. Therefore, for mechanical harvesting of cotton, it is essential to improve fiber quality by using good quality cultivars or appropriate practices. Of course, all the above requirements must be met without a resultant reduction in yield.

Planting date and plant density can significantly affect plant habit, yield, and quality of cotton (Cathey and Meredith, 1988; Jones and Wells, 1998; Siebert and Stewart, 2006; Boquet and Clawson, 2009). For example, temperature or heat units are highly dependent on planting date (Gormus and Yucel, 2002). Planting later increases the likelihood of warm temperatures, and a crop established under warm conditions has the potential to produce larger plants and hence greater leaf and stem area to sustain boll development later in the season (Quinn, 2015). Plant density can alter the interception of photosynthetically active radiation, the distribution and quality of light within the canopy, and the amount of resources (e.g. water, nutrients, and soil volume) available per plant, and thus affect canopy development and yield (Heitholt and Sassenrath-Cole, 2010). Compared with low plant density, high density planting usually results in a slower rate of leaf appearance, less main stem nodes, and shorter fruiting branches (Constable, 1986).

Although there have been some recent reports focusing on the planting date and plant density of cotton in the Yellow River valley region (Dong et al., 2006; Ren et al., 2013; Mao et al., 2014, 2015), little attention was paid to requirements of mechanical harvesting. Therefore, the objective of this study was to determine the appropriate planting date and plant population for mechanical cotton harvesting in this region in terms of plant habit, yield, earliness, and fiber properties. We hypothesized that moderately late planting and high density as compared to the traditional manual harvesting practices would result in a plant habit more suitable for mechanical cotton harvesting without loss of yield, early maturity, and fiber quality. The results of this study will contribute to the development of integrated cotton management for upcoming mechanical harvesting in this traditional cotton growing region of China.

2. Materials and methods

Field experiments were conducted in Hejian, Hebei Province (38°41′ N, 116°07′ E and elevation 11 m), during two cotton growing seasons in 2013–2014. The soil was a clay loam. The soil organic matter, total nitrogen (N), available N, Olsen-phosphorus (Olsen P), exchangeable potassium (K), and pH of topsoil (20 cm) were determined following the procedures of Bao (2000), the concentrations of which are presented in Table 1.

The climate of Hejian is warm-temperate and sub-humid continental monsoon with cold winters and hot summers. The rainfall is variable, with most occurring in July and August. Cotton is usually planted in mid- to late April and harvested at the end of October. The monthly average air temperature and rainfall during the growing seasons are presented in Fig. 1.

The cotton (*G. hirsutum* L.) cultivar used in this study was Shikang126, a high-yielding commercial *Bt* (*Bacillus thuringiensis*) transgenic cotton cultivar developed by the Shijiazhuang Academy of Agriculture and Forestry Sciences and the Institute of Genetics and Development Biology, Chinese Academy of Sciences. Shikang126 has medium maturity, a compact plant habit, and was found to be relatively suitable for mechanical harvesting in our previous testing. Acid-delinted seeds (germination percentage > 80%), provided by the Shijiazhuang Academy of Agriculture and Forestry Sciences, were treated before sowing with 70% thiamethoxam WS (Syngenta (China) Investment Co., Ltd., Beijing, China).

2.1. Experimental design

A split plot design with three replications was used. The main plots were planting date (P1, P2, P3: traditional, 10 d later, and 20 d later, respectively), and subplots were plant density (D1, D2, D3: 6.75, 9.00, and 11.25 plants m^{-2}, respectively). Each subplot consisted of six (in 2013) or seven (in 2014) 7-m rows spaced 90 cm apart.

Because of the influence of precipitation, the actual planting dates for P1-P3 were 22 April, 30 April, and 10 May in 2013, respectively; and correspondingly, 21 April, 30 April, and 9 May in 2014. After sowing, 42 kg N ha^{-1}, 90 kg K_2O ha^{-1}, and 128 kg P_2O_5 ha^{-1} were plowed into the soil. At the full blooming stage, 63 kg N ha^{-1} was top-dressed. The sources of N, P_2O_5, and K_2O were urea (46% N), single superphosphate (14% P_2O_5), and potassium chloride (60% K), respectively.

One vigorous plant per stand was retained at the two-leaf stage, and the final plant populations for D1–D3 were 6.6, 8.9, and 12.3 plants m^{-2}, respectively.