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Farming and Cultivation Technologies of Cotton in China

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Abstract

Cotton production in China has developed rapidly during the last 60 years. Using only 15% of the world's cotton land, China currently has produced 30% of the world's cotton. Such a great achievement is largely attributed to adoption of intensive farming technologies and cultural practices, including seedling transplanting, plastic mulching, double cropping, plant pruning, and super-high plant density technique. However, the intensive technologies are labor intensive and involve large input of materials such as fertilizers, pesticides, and plastic films. Thus, there are increasing challenges from labor shortage, soil pollution, and low competitiveness. Here, the achievements, challenges, countermeasures, and prospects for intensive cotton cultivation in China are reviewed. An important conclusion from this review is to reform the current intensive technology to be more light and simplified. Sustainable development of cotton production in China will be supported by the light and simplified farming and cultural system, and China cotton has a bright prospect.

Keywords: cotton, challenges and countermeasures, intensive farming technologies, sustainable development

1. Introduction

China is one of the largest cotton producers and consumers in the world [1]. The planting area of cotton in China was 4.35 million hectares in 2014 with an average lint yield of 1484 kg ha⁻¹ and total production of 6.53 million tons (mt). Currently, there are three major cotton-growing regions, including the northwest inland cotton region, the Yellow River valley region, and the Yangtze River valley region (**Table 1**). These three main cotton regions account for 99.5% of output and 99.3% of growing area in the nation [2].

Cotton agroecological zones	Provinces and regions	Planting area (million hectares)	Total output (million tons)	Lint yield (kg ha ⁻¹)
Northwest inland cotton region	Xinjiang and Gansu	1.76	3.64	2068
Yellow River valley region	Shandong, Hebei, Henan, Shanxi, Shanxi, Tianjin	1.45	1.61	1110
Yangtze River valley region	Hubei, Hunan, Anhui, Jiangsu, Jiangxi, Sichuan	1.11	1.25	1126
Source [3].				

Table 1. Main cotton planting areas, total output, and average lint yield for 2014/2015 in China.

Although cotton cultivation has a long history in China, scientific cultivation was not adopted until the founding of People's Republic of China in 1949. As a result, average unit yield increased by 3.12% annually, from 160 kg ha⁻¹ in 1949 to 1280 kg ha⁻¹ in 2009 [4]. Many factors have contributed to the increased average yield, including adoption of improved varieties and intensive farming technologies. Although such intensive farming technologies meet the need of a growing population under limited arable land in China, they are labor-intensive and involve large input of various kinds of chemical products like fertilizers, pesticides, and plastic films. Therefore, a transition has been occurring from intensive farming to light and simplified cotton cultivation to cope with the increasing challenges of soil pollution and labor shortage. The achievements, challenges, and the occurring transition of intensive cotton cultivation in China are reviewed in this chapter.

2. Intensive farming technologies and achievements

Intensive farming technologies have supported China to be one of the countries with the highest unit yield of cotton in the world. In 2014/2015, the average lint yield was 768 kg ha⁻¹ in the world, while it was 1484 kg ha⁻¹ in China, being 58%, 189%, 90%, and 93% higher than the yield in the US, India, Pakistan, and the world average (**Table 2**). These technologies include double cropping, seedling transplanting, plastic mulching, plant training, and “short-dense-early” high-yielding cultivation pattern in northwest inland which have played more important roles than cotton varieties and other contributors to the significant increase in lint yield for the past 60 years.

2.1. Double cropping

There has existed a strong competition for land between grain crops and cotton in China. The grain-cotton double cropping can ease such a competition by improving farmland and solar energy use efficiency, thus it becomes to be one of the most popular cropping systems in the nation. It ensures higher total output than monocropping, particularly the cotton-wheat double

cropping system [6], because it meets the need of farmers to grow a profitable cash crop and secure food supply [7]. According to seeding time (season) of cotton, the double cropping system consists of spring cotton (full-season cotton) double cropping and summer cotton (short-season cotton) double cropping. Of the double cropping, the summer cotton double cropping exhibits obvious advantages in alleviating plant diseases and insect pests by using short-season cotton varieties. Thus it was once widely adopted from the 1980s to the 1990s [8]. It was noted that double cropping of summer cotton and wheat was relatively lower in lint yield and fiber quality of short-season cotton. Therefore, double cropping of spring cotton and wheat began to replace summer cotton and wheat system from the 2000s [9], and currently occupies a dominant position in the cropping system in China (**Figure 1**). According to the different planting modes of cotton-wheat, three kinds of planting modes (3–1 planting modes: 3 rows wheat and 1 row cotton; 3–2 planting modes: 3 rows wheat and 2 rows cotton; and 4–2 planting modes: 4 rows wheat and 2 rows cotton) were commonly adopted in Huang-Huai-Hai Plain of China.

Country	Area (million hectares)	Average yield (kg ha ⁻¹)	Total lint yield (million tons)
World	33.83	768	26.4
United States	3.78	939	3.55
India	12.7	514	6.53
Pakistan	2.95	782	2.18
Brazil	0.98	1563	1.52
China	4.35	1484	6.53

Source [5].

Table 2. Cotton area, average yield, and total lint yield for 2014/2015 in the world.



Figure 1. Double cropping systems in China. (a) Double-cropping of cotton-wheat; (b) multicropping of cotton-wheat-watermelon.

As a popular intensive cultivation technology, wheat-cotton intercropping significantly increases multiple crop index and reduces the competition between grain and cotton for land compared with monoculture. For example, the average seed cotton yield under wheat-cotton system in Huang-Huai-Hai Plain in China since 1959 was 2836 kg ha⁻¹, being roughly 88% of that under monocropping, but an extra harvest of 3861 kg wheat per hectare was also obtained compared to monocropping [10]. Thus the total output and economic benefits were significantly raised.

However, the planting area and the proportion of cotton-wheat double cropping system to traditional monocropping system was sharply reduced owing to the following disadvantages: (a) relatively low lint yield and poorer fiber quality owing to delaying seedlings growth at intergrowth stage of wheat-cotton and late senescence either in spring cotton double cropping system or summer cotton double cropping system; (b) relay intercropping of cotton into wheat being not conducive to mechanization; (c) decreased comparative benefits due to high labor input.

2.2. Seedling transplanting

In double cropping system of wheat-cotton, wheat is harvested in early or mid June, while cotton is directly sown in late April. Both crops overlap for approximately 7 weeks. The two crops in the system interact directly during the overlapping period, which usually delays plant growth and maturity, as well as reduces cotton yield due to shading and competition for water and nutrients between the two crops [11]. An investigation of the relationship between boll weight 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 and position of most bolls in the plant; temperature had an important influence on upper and top bolls, especially for double cropped short-season cotton [12]. Although a wider cotton belt may reduce crop interaction, it will definitely decrease wheat yield and not be adopted by farmers. Transplanting cotton seedlings into field just before or after wheat harvest can solve or alleviate the interaction effects of both crops [13].

The technology of seedling transplanting in cotton was initiated in the 1950s and was widely adopted from the 1980s in China [14]. It once accounted for 18% of the nation's total cotton growing areas in the 1980s. Traditionally, seedling nursery in the bed, transplanting seedlings to the fields, and field management after transplanting are the three main steps of seedling transplanting [15]. Seedlings were nursed in "columned soil blocks" (4–6 cm in diameter and 8–12 cm high) made of soil and organic fertilizer (9:1, w/w) in a 50 cm-high arciform hut. After emergence, the seedlings were allowed to grow in the hut until transplanting. Seedlings should experience cold acclimation by keeping the hut open for at least a week before transplanting. Soil blocks along with seedlings were then transplanted to the fields manually. Generally, seedling transplanting can be conducted about 35 days before wheat harvest with spring (full-season) cotton or soon after wheat harvest with summer (short-season) cotton, when the mean soil temperature at the 5 cm depth reaches 17–19°C and cotton seedlings have 2–4 true leaves on the main stem. Soon after transplanting, seedlings were watered to recover normal growth quickly. Intertillage and irrigation are conducted timely after transplanting [16].

Seedling transplanting has several advantages compared with direct seeding: (a) it reduces the quantity of seeds; (b) the growing process is accelerated and cotton maturity is fully guaranteed [17]; (c) water and nutrient uptake was improved with promoted lateral root growth. Also, the root weight and lateral root number of soil-cubes transplanting were 43.4% and 18.8% higher than those in direct seeding cotton [18]; (d) cotton germination, emergence, and early seedling growth are sensitive to salinity stress. Stand establishment was greatly improved by seedling transplanting with nonsaline soil as nursery substrate relative to direct seeding in saline soils [19]. Seedling transplanting is thus used as an efficient practice to increase stand establishment of cotton in saline soils.

Compared with direct-seeded cotton after wheat harvest, the yield of transplanted seedlings was increased by 20–30% [20]. Moreover, seed yield and quality parameters were significantly improved in the transplanting system through the increased number of bolls per square meter and earlier blooming; the net revenue for producers was also increased relative to direct planting. About 2 million hectares of cotton were covered with the seedling transplanting technology in the 1990s.

However, traditional seedling nursery and transplanting is considerably labor-intensive. The intensive process can be simplified by replacing nutrient soil clay with medium, and by transplanting naked seedling rather than soil-clay combined seedling to fields, and by mechanized transplanting instead of manual transplanting [21]. Because simplified seedling transplanting decreases labor cost and increases working efficiency, it is a promising alternative for transplanting.

2.3. Plastic mulching

Low temperature and drought at sowing as well as soil salinity stress and disease during the seedling stage usually decrease the rate of seed emergence and stand establishment [22, 23]. Low temperature combined with salinity stress can further reduce cotton emergence and stand establishment in saline fields [24]. Although late sowing may reduce environmental stress of early season chilling and disease incidence, cotton yield was decreased by shortening of growth period. Fortunately, all these problems can be solved by plastic mulching, because it functions well in increasing soil temperature, water conservation, salinity control in the root zone, and weed control [25].

Plastic mulching has been widely adopted for cotton production since the 1980s. Currently, about 70% of total cotton fields, equivalent to 2.7 million hectares, are covered with plastic film each year, especially in the arid and semi-arid regions of northern China and coastal saline-alkali areas. Plastic mulching increases soil temperature through greenhouse effect and conserves moisture through preventing direct evaporation of moisture from the soil, finally leading to improved seedling establishment, plant growth, and economical yield. Moreover, plastic mulching in saline field could effectively reduce the accumulation of salts in the surface soil by suppressing evaporation and salinity stress is thus decreased [26].

Plastic film coverage (mulching) is usually conducted soon after sowing manually or mechanically in the Yellow River and the Yangtze River valley region (**Figure 2a**). Seedlings are freed

from mulching cover by cutting film above hills at emergence (**Figure 2b**), and thinned to the planned population density by leaving one vigorous plant per hill at the two-leaf stage. It should be noted that with the development of cotton’s whole-course mechanization, plastic film coverage (mulching) before sowing can be interactively conducted with machine in the northwest inland cotton region (**Figure 2c**), which can avoid the process of seedling freed under rainless sowing stage (**Figure 2d**).



Figure 2. Row covering with plastic mulching. (a) Plastic mulching after sowing conducted with machine;(b) manually freeing seedlings from mulching cover at emergence; (c) plastic film coverage (mulching) before sowing conducted with machine; (d) avoiding the process of seedling freed.

Treatment	Biomass (g/plant)	Na ⁺ (mg/g)	Stand establishment (%)	Lint yield (kg ha ⁻¹)	Earliness (%)
No-mulching	1.47c	11.3a	47.8c	900c	64.0b
Conventional mulching	1.71b	10.0b	59.5b	1000b	71.4a
Early mulching	1.88a	9.2c	66.3a	1071a	73.0a

Source [27].

Table 3. Effects of early and conventional mulching on biomass, Na⁺ content, stand establishment, lint yield, and earliness of cotton.

Large evaporation usually occurs in naked land without coverage before sowing in spring, and a large quantity of salts would accumulate in the surface layer of saline soils. Plastic film mulching before sowing would reduce salt accumulation in soil surface layer and improve stand establishment in saline soils. As indicated in a previous report, row covering with plastic film 30 days before sowing (early mulching) greatly improved stand establishment, and increased lint yield by 19.0% and earliness by 14.1% relative to no-mulching (**Table 3**). Compared with conventional post-sowing coverage, early mulching reduced leaf Na⁺ levels by 8.0% and increased stand establishment by 11.4%, plant biomass by 9.9%, and lint yield by 7.1% in the saline Yellow River Delta. Furthermore, furrow seeding with plastic mulching was also a suitable cultural practice for enhancing cotton production in saline field owing to increase stand establishment, especially in moderate and high levels of saline-alkaline soil. Compared with flat-seeded cotton without mulching, the stand establishment and lint yield under furrow seeding with plastic mulching was increased by 92% and 22% in saline field with ECe of 12.8 dS m⁻¹.

Plastic film mulching in combination with seedling transplanting was recommended because it had dual advantages of increasing soil temperature and promoting early maturity. In such a way, cotton seedlings are transplanted to film-covered fields rather than open fields. An integration of mulching and transplanting was demonstrated to significantly improve plant growth and development, yield, and earliness compared with transplanting or plastic mulching alone [28]. Lint yields were increased with a combination of both practices by 17.4% and 14.6% compared with individual use of plastic mulching and transplanting

2.4. Plant pruning

Plant pruning has been widely applied for more than 70 years in China. It mainly includes vegetative branch removal, plant topping, and excising empty fruit branches and old leaves. It is generally believed that plant training can reduce the nutrient consumption of surplus organs, decrease the number of boll abscission and boll rot, and increase cotton yield and fiber quality [29].

2.4.1. Removal of vegetative branches

Vegetative branches of cotton plants do not set fruit directly, thus they excessively consume nutrients and result in boll shedding especially at a medium plant population density of 4.5–7.5 plants m⁻². Vegetative branches can manually be removed after the first fruit branch appears in mid June (**Figure 3a**). It was reported that removal of vegetative branches decreased boll shedding rate of cotton plants by 9% and increased the boll weight by 7% and seed cotton yield by 8.7% [30]. It also improved the number of fruiting nodes per leaf area (31.1%) and dry mass of fruiting parts per leaf area (88.9%) [31].

2.4.2. Plant topping

Removal of growth tips on the main stem by hand (topping) inhibits apical dominance and vegetative growth, allowing more nutrients to be partitioned to reproductive organs, leading

to more squares, flowers, bolls, and lint yield. It is critical to identify the best topping time in practice. Topping later always caused an increase in ineffective fruit branches and ineffective flower buds in upper fruit branches; topping earlier always increases the abscission of squares and bolls in the upper fruit branches. It was suggested that topping should be conducted by mid- or late-July when the number of fruit branches achieve 8–10 per m² ground area. Plant topping is also suggested to be done in windless and clear day to facilitate wound healing (Figure 3b).



Figure 3. Intensive plant training measures. (a) Removal of vegetative branches; (b) manual plant topping.

2.4.3. Removal of early fruit branches

Fruit shedding or loss appears necessary to ensure normal development of retained bolls that are carried through to maturity because cotton produces many more fruits than they can mature [32]. Loss of early fruiting forms can elicit compensatory growth [33]. Early-fruit removal enhances vegetative growth and development, thus it can be used to coordinate relationship between vegetative and reproductive growth [34]. Removal of early fruiting forms is currently used in early squaring cotton to mitigate premature senescence because it increased levels of total nitrogen (N), soluble protein, as well as glutamic-pyruvic transaminase (GPT) activity in leaves [35], and lint yield was thus increased [36]. It was also reported that removal of early squares reduced the *verticillium* wilt disease indexes and early senescence indexes [37]. The lowermost two or three fruiting branches on the main stem are manually removed 5 days after squaring.

2.5. Super-high plant density technique

Northwest inland cotton region occupies abundant light and heat resources, but cotton growing season is very short due to low temperature in spring and autumn in this region. In order to avoid such a limitation, a cultivation pattern called “short-dense-early” was developed in the 1990s and has been widely adopted in the northwest inland cotton region. In this pattern, plant density is greatly increased as one of the most important practices. Plant height is reduced and early maturity is improved with the help of drip irrigation under plastic mulching.

In the “short-dense-early” pattern, the plant density usually ranges from 200,000 to 300,000 plants ha⁻¹, and the plant height is controlled to a range of 60–75 cm through chemical reg-

ulation, water and fertilizer management as well as using early-maturity variety, early planting and drip irrigation under plastic film mulching. The average lint yield in this region reached 1927 kg ha⁻¹. Currently, it is not difficult for farmers in Xinjiang to produce 2250 kg ha⁻¹ of lint yield with “short-dense-early” pattern [38]. It was also reported that a lint yield record of 4900 kg ha⁻¹ was obtained in a small area in Xinjiang in 2009 [39].

The northwest inland of China is an arid inland with little precipitation but high evaporation, thus drip irrigation under film mulching is well adopted in the region. In the drip irrigation system, one tube can be responsible for two or four rows of cotton. Currently, the most commonly used pattern is four rows of cotton per drip irrigation tube (**Figure 4**). On the one hand, drip irrigation under film effectively reduces moisture loss and improves water and nutrient use efficiency [40]. Compared with flood irrigation, the water saving and yield increase with drip irrigation under film were improved by 20–50% and 10–30%, respectively [41], and water and nitrogen use efficiency were also greatly improved in Southern Xinjiang; on the other hand, it effectively alleviates weeds, diseases, and insect pests; decreases the number of boll rots; and improves seed cotton yield and fiber quality.

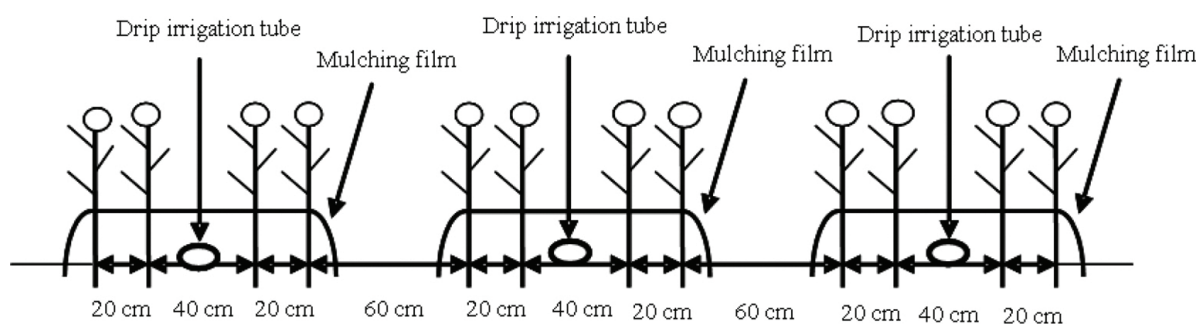


Figure 4. Drip irrigation system with four rows per drip irrigation tube.

In saline fields, drip irrigation under film could induce low salinity distribution around the root zone, which significantly alleviated salinity stress and enhanced seedling establishment and plant growth [42]. It was reported that cotton roots were mainly distributed in the mulched area [43]. Unequal salt distribution decreased Na⁺ concentration in leaves owing to higher root Na⁺ efflux in the low salinity side, and increased leaf photosynthesis, transpiration and water and nutrient uptake. It thus greatly improved cotton biomass, lint yield, and earliness compared with equal salt distribution in the root zone [44].

3. Problems and challenges

Even though intensive farming technologies have played crucial roles in supporting China to become the largest cotton producer in the world, it is currently facing great challenges, such as soil pollution caused by plastic film and chemicals, labor shortage due to urbanization and competition for land from grain crops.

3.1. Soil pollution

In cotton fields, soil pollutants mainly come from plastic mulch, fertilizers, and pesticides.

3.1.1. Plastic pollution

Plastic mulching has been one of the most important intensive farming and cultural measures, but its residue in the soil destroys soil structure and inhibits crop growth, and has become a common soil pollution phenomenon in China.

As plastic coverage is used year after year, more and more plastic film residues accumulate in the plow layer, which destroys soil integrity and permeability, inhibits the infiltration of soil capillary and free water, and impairs microbial activity and plant growth [45]. It was reported that the germination rate, number of plants at harvest and cotton yield in film-polluted soil were decreased by 9.9–19.1%, 7.3–16.5%, and 7.3–21.6%, respectively [46]. Thus, plastic pollution is a big challenge for intensive farming of cotton in China.

3.1.2. Fertilizer pollution

Nitrogen (N) as an essential macronutrient is more required consistently and in larger amounts than other nutrients for cotton production [47]. Nitrogen fertilization had significant impacts on cotton growth, lint yields, and fiber quality, making it be excessively applied by cotton growers in China. In the northwest inland cotton regions, an overdose of 450 kg N ha⁻¹ was applied to cotton fields, leading to excessive vegetative growth and delayed maturity [48]. In addition, excessive nitrogen application decreases the uptake of other nutrient elements and use efficiency of nitrogen; it also destroys the granular soil structure and compact soil, which finally leads to decreases in cotton yield and fiber quality. An overdose of nitrogen fertilizer and the resulting pollution also commonly exist in saline-alkali cotton fields [49].

3.1.3. Pesticide pollution

Cotton is considered a high pesticide consumer crop; about 25–30% of total pesticides produced in China is used for cotton [50]. Pesticide is so indispensable to cotton production, yet while only 1% of the sprayed pesticides is effective, 99% of pesticides applied is released to nontarget soils, water bodies, and atmosphere [51]. Although Bt (*Bacillus thuringiensis*) transgenic cotton has effectively helped to control cotton bollworm (*Helicoverpa armigera* Hübner), other pests like mirid bugs (Heteroptera: Miridae) have progressively increased in population sizes in association with a regional increase in Bt cotton adoption [52]. Organochlorined pesticides (OCPs) such as HCH, DDT, HCB, aldrin, endrin, and chlordane, were commonly used to control pests in China, and were still detected in some cotton fields although OCPs have been banned since 1983. In addition, much more herbicide was excessively applied to control weed in cotton fields, resulting in soil, water, and atmospheric pollution [53].

3.2. Labor shortage

Intensive farming and cultivation is depending on a huge labor power. With the rapid urbanization in the nation, more and more rural laborers have migrated to cities and towns to work in secondary and tertiary industries, leaving only the elderly, women, and children to be engaged in agriculture. According to the statistics, about 0.24 billion rural laborers migrated to cities from 1996 to 2007 in China. Thus, the intensive cultivation techniques are facing severe challenges of labor shortage and low level of mechanization for cotton production in China.

3.3. Food safety and climate change

Rapid urbanization has gradually reduced the total cultivated land in China. The Chinese government is facing a growing pressure of "food security" and pays more attention to grain crops than cotton. A lot of supporting policies and measures such as improving grain price and providing grain subsidy were taken in China to stimulate grain production. This resulted in more cotton fields being converted to grain fields in China. Intensive farming techniques of cotton also have to face a challenge from relatively extensive and simple cultivation techniques of food crops.

Global warming has also resulted in temperature change in the cotton production area of China, especially in fall and winter seasons. As the temperature increases, cotton plants grow and develop more quickly than before. As a result, on the one hand, cotton is subject to premature senescence; on the other hand, more rainfall occurred with increases in water evaporation owing to temperature increase. *"The pollination of cotton is influenced by high rainfall during the reproductive growth stage, which causes more bud, flower and boll abscission. High and/or prolonged rainfall duration also causes plant lodging and serious boll spoiling diseases, further decreasing seed cotton yield and fiber quality"* [4]. Therefore, the increasing area of waterlogging, more serious pest incidence and premature senescence resulting from climate change are also strong challenges which the intensive farming must face.

4. Countermeasures and prospects

In order to support sustainable and green production of cotton in China, the traditional intensive farming technologies should be reformed.

4.1. Reducing soil pollution

Measures to decrease plastic film residues in soils include (a) plastic film recovery. Timely removal of plastic film could effectively increase its residual recovery. This may be achieved by increasing the current film thickness of 0.004–0.006 mm to 0.012 mm or above. It was reported that the recovery of plastic film residues with 0.012 mm was higher (69.2%) than that with 0.006 mm [54]; (b) mechanic collection of plastic film residues after harvest or before planting. Plastic film residues in the soil can be greatly reduced with the help of a cleaning machine. This is usually conducted in combination with tillage; (c) application of degradable

plastic film. Photodegradable or biodegradable films have attracted wide interests of researchers and farmer. Once the photodegradable or biodegradable films get to be commercialized, the pollution problems will be solved.

Sustainable development of cotton production also needs to reduce pesticide-and fertilizer-caused soil pollution. Application of Bt transgenic cotton and transgenic herbicide-resistant cotton is an effective alternative to reduce pesticide contamination; Applying low-toxicity and low-residue pesticides can be another effective way to reduce chemical contamination. Appropriate application of fertilizers, especially nitrogen fertilizer inputs, is able to decrease fertilizer contamination of soil. Application of organic fertilizer, increasing plant density as well as fertilization improvement favor lower input of fertilizers without cotton yield reduction.

4.2. Simplifying field management

Cotton is intensively cultivated currently in China with more than 40 procedures during the whole growth period. The amount of labor input for cotton is 3.5 and 3 times that for wheat and corn, respectively. Only simplifying the intensive farming technologies and mechanization of the whole production process can effectively deal with the challenges of the current labor shortage for cotton production.

Year	Seeding patterns	Experimental sites				Means
		Linqing	Xiajin	Huimin	Dongying	
2011	Conventional seeding	3445a	3741a	3673a	3805a	3666a
	Precision seeding	3403a	3720a	3665a	3264b	3513b
2012	Conventional seeding	3295a	3877a	3845a	3639a	3664a
	Precision seeding	3258a	3850a	3632b	3615a	3589a
2013	Conventional seeding	3514a	3445a	3370a	3287a	3404a
	Precision seeding	3490a	3366a	3328a	3232a	3354a

Source [56].

Table 4. Effects of precision seeding on seed cotton yield at four experimental sites from 2011 to 2013.

4.2.1. Precision seeding without thinning

Traditionally, the seeding rate of cotton is usually 35–45 kg ha⁻¹ in China, and the resulting number of seedlings is always much larger than the targeted plant density. It thus requires one or two times of manual thinning to remove the extra seedlings after emergence. It is known that cotton yield is not influenced within a certain plant density range owing to its broader adaptability to plant density [55], thus precision seeding can be an important simplification measure. Compared with conventional seeding, the precision seeding on the one hand, significantly reduced the seeding rate without decreasing yield (Table 4) and fiber quality; on

the other hand, the labor input is also reduced by eliminating the process of thinning. Precision seeding is usually conducted soon after mulching in the northwest inland of China because of dry weather in spring there, while it should be conducted before plastic mulching in the Yellow River valley to avoid interference of raining weather in spring.

Additionally, a precision seeding with double mulching (**Figure 5**), in which seeds were inserted into the mulched soil and re-covered by plastic film above the first mulch and the re-coverage was removed soon after full emergence. Double mulching is an important practice to improve stand establishment in case of rainfall after seeding in the Yellow River valley of China.



Figure 5. Conventional seeding (a) and precision seeding with double mulching (b).

4.2.2. Application of controlled-release fertilizer

Cotton is traditionally fertilized at least three times with rapid release fertilizers in China. The conventional split fertilization with rapid release fertilizer always results in a great deal of labor input and fertilizer loss. Application of slow- or controlled-release fertilizer reduces labor input and fertilizer loss, because it can be applied only once before planting (basal application) without yield loss [57].

4.2.3. Simplified plant pruning technology

Plant pruning including removal of vegetative branches, old leaves and redundant buds and growth terminals of the main stem is labor intensive. In practice, removal of vegetative branches can be replaced without yield reduction either by retaining vegetative branches at lower plant density or by inhibiting their growth with high plant density [58]. The application of chemical substitutes instead of manual pruning can effectively regulate the relationship between vegetative and reproductive growth without decreasing yield and fiber quality, especially the application of chemicals in plant topping [59].

4.2.4. *Reduced intertillage*

Intertillage is traditionally conducted 5–10 times from seedling to harvest in cotton in China. Some recent studies have shown that the reduced number of intertillage did not affect final lint yield. It can be reduced to two times, the first at full emergence and the second at full squaring, in the whole season without yield reduction. Intertillage can be conducted in combination with weeding, earthing up, plastic film uncovering, and fertilization with the help of machinery at full squaring.

4.2.5. *Harvest-aid application technology*

Cotton is a perennial plant that will shed its mature leaves naturally as the growing season progresses and the crop matures. With the demonstration and extension of machine-harvested cotton, harvest-aid application technologies play an important role in stimulating defoliation and boll opening. Harvest-aid application decisions largely are based on crop maturity, crop condition, weather conditions, desired harvest schedule, and harvest-aid choices and rate. Ethephon is effective in accelerating the opening of mature cotton bolls. Though not labeled as defoliant, satisfactory defoliation may result from applications made under favorable weather conditions or at higher use rates. Commonly, in order to enhance the efficacy of harvest-aid products, ethephon was tank-mixed with defoliant, such as tribufos, thidiazuron, and dimethipin. In cotton with a dense canopy, ethephon can be applied at the boll-opening rate with a low rate of defoliant to achieve both boll opening and leaf drop.

Thorough spray coverage is necessary for good defoliation, because harvest aids are not able to be translocated from one leaf to the other. Each leaf must be sprayed to initiate the abscission process. A second application is usually needed on rank cotton with dense foliage. Additionally, adjuvants were usually added to harvest-aid chemical formulation or tank mixes to enhance performance by improving leaf-surface wetting and penetration and uniformity of deposit.

4.2.6. *Development of mechanization*

Because of high labor input and labor shortage, intensive cotton farming will inevitably be reformed with mechanization. There exist large differences in mechanization rate among regions in China. The northwest inland cotton region is the highest in the integrated ratio of mechanized cotton farming, while the Yangtze River valley cotton region is the lowest.

A full mechanization for cotton production mainly consists of mechanical tillage, soil preparation, seeding, plant protection, intertillage and fertilization, harvesting, and straw returning. At present, some machineries for soil preparation, seeding, intertillage, plant protection, and straw returning have been developed and widely used in cotton production in China. Although cotton pickers from abroad basically meets the mechanic harvest demand of cotton in China, other supporting measures or equipments such as adaptive varieties, techniques of cultivation and defoliation and machine-picked cotton cleaning lines need to be further developed. The integration of agricultural machinery and agronomic measures should be strengthened to accelerate mechanized cotton harvesting. These measures include: (a) im-

proving cotton picker performance and seed cotton quality through developing more efficient harvesting machinery and equipment suitable for different cotton regions; (b) development of cotton varieties suitable for mechanized harvesting; (c) development of new agricultural cultivation technologies well matched to mechanic harvesting; (d) establishment of quality standards for machine-picked cotton.

4.3. Reform of planting system in double cropping

In a traditional double-cropping system, it is mainly implemented through direct seeding or transplanting before harvest of wheat, garlic, or rape (intercropping). This not only takes a large amount of labor input, but also inhibits mechanization. Traditional plant system should be reformed to meet the demands of mechanization and reduced labor inputs (**Figure 6**). The first alternative is cotton seedling transplanting after wheat or rape. Traditional seedling nursery and transplanting is labor-intensive. The intensive process can be simplified by replacing nutrient soil clay with commercialized medium, and by transplanting naked seedlings rather than soil-clay combined seedlings to fields, and by mechanized transplanting instead of manual transplanting. The second alternative is to use direct seeding of short-season cotton after the harvest of wheat, garlic, or rape instead of intercropping.



Figure 6. Mechanized transplanting of full-season cotton after harvest of garlic (a) and direct seeding of short-season cotton after harvest of garlic (b).

5. Conclusions

Intensive farming technologies including seedling transplanting, plastic mulching, plant pruning, double cropping, and “short-dense-early” have been widely applied for the past 50 years in China. These intensive technologies have played key roles in supporting China to be the largest cotton producer in the world. However, it should be noted that current cotton production in China is facing a series of challenges, such as soil pollution, labor shortage, and intense competition for land from food crops. Therefore, it is essential to reform the traditional intensive farming technologies. New farming and cultural technologies should be established to reduce soil pollution through rational use of plastic film and chemicals, save labor through

simplifying managements and intensifying mechanization, and increase benefit through reforming the cropping system and management mode. It is believed that China cotton has a good prospect with the support of new farming technologies (Table 5).

Measures	Present	Prospect
Planting and thinning	Conventional seeding, 30–45 kg seed per hectare, and 2–3 times of manual thinning	Precision seeding, 15–18.75 kg seed per hectare, and no-thinning
Intertillage	8–10 times during the whole growth season	2–3 times at the full post emergence and full squaring or flowering stage
Fertilization	3–4 times at planting, squaring, or flowering stage and after topping with rapid release fertilizers. With more labor input and lower fertilizer use efficiency	One time at planting with slow- or controlled-release fertilizer. Labor saving and higher fertilizer use efficiency
Plant training	Manual removal of vegetative branches, old leaves and redundant buds and growth terminals of the main stem	Retaining vegetative branches at lower plant density or inhibit growth of vegetative branches through increased plant density, or using chemical substitutes for plant training
Plastic mulching	Film thickness of 0.004–0.006 mm, lower film residual recovery	≥0.012 mm in film thickness for recovery, or using film substitutes instead of conventional plastic film
Planting pattern	Double-cropping through direct seeding or transplanting before harvest of wheat/garlic/rape	Direct seeding of short-season cotton after the harvest of wheat/rape, or transplanting after wheat/garlic /rape
Management mode	Scattered distribution and small-scale plantation	Concentrated distribution and scaling up plantation
Mechanization	40% level, including tillage, sowing, fertilization and intertillage, straw returning	≥70% level in ten years, including tillage, sowing, fertilization and intertillage, harvesting, and straw returning

Table 5. Current status and prospect of cotton cultivation measures in China.

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