ANALYSIS OF SUITABLE FERTILIZATION LEVELS AND BENEFITS OF EARLY MATURING COTTON IN REGARD TO DIFFERENT PLANT TYPES

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Abstract. The optimum fertilizer application rate and economic benefit of early maturing cotton in the Yangtze River Basin were studied. The cotton varieties (Wankemian-1 and Wanmian-191) and fertilizer application rates (F1, F2, F3) were set in the main cotton producing area of Anhui Province by field split plot experiment. The effects of different fertilizer application rates on growth, yield, quality and economic benefit of early maturing cotton were analyzed. The results showed that the growth period, first fruit segment, fruit branch number and plant height of the two varieties increased significantly with the increase of fertilizer application amount. When the yield of seed cotton and lint reached F2 level, Wankemian-1 decreased, and Wanmian-191 increased slightly. Cotton fiber quality Wankemian-1 was more sensitive to the effect of fertilizer application. The suitable fertilizer application rates for early maturing cotton varieties in this area were N 160 kg ha^{-1}, P_2O_5 40 kg ha^{-1}, and K_2O 80 kg ha^{-1}. The economic benefit of 50% of conventional spring cotton fertilizer was significantly higher than that of the other two treatments, and the total economic benefit of Wanmian-191 was higher than that of Wankemian-1. The suitable fertilizer application rate can improve the planting efficiency of early maturing cotton in the Yangtze River Basin and has an important guiding effect on the cultivation of green cotton with high quality and high yield in this area.
Keywords: *early-maturing cotton, varieties, plant type, fertilization, benefit*

Introduction

Cotton is an important cash crop and plays an important role in the economic development of China and the world (Yu et al., 2016). An amount of cotton fertilizer has been recommended for the cotton region in the Yellow River Basin, the cotton region in the Yangtze River Basin and the inland cotton region in the northwest, and a combination of organic fertilizer and inorganic fertilizer has been advocated (Li et al., 2019). According to statistics, the average seed cotton yield in high-production areas of the Yangtze River Basin was 5919 kg·ha^{-1}, and the average application rates of N, P_2O_5 and K_2O were 277, 102 and 205 kg·ha-1, respectively (Li et al., 2019). The average seed cotton yield in the low-production area was 3664 kg·ha^{-1}, and the average application rates of N, P_2O_5 and K_2O were 259, 93 and 199 kg•ha^{-1}, respectively (Li et al., 2019). The amount of chemical fertilizer applied to cotton is high and the utilization rate is low. The amount of chemical fertilizer used in cotton production occupies first

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place in the main crops and remains high. The cost of cotton fertilizer accounts for more than 50% of the material cost (Zheng et al., 2020). Improving the utilization rate of cotton fertilizer and reducing the amount of fertilizer are crucial to the green and efficient production of cotton to fully implement the strategy of carbon peak and carbon neutrality. Fertilization can not only optimize the structure of the cotton canopy and improve the growing environment of cotton but can also improve the photosynthetic efficiency and increase the absorption and utilization of nutrients in cotton (Li et al., 2017a; Watts et al., 2017; Yao et al., 2013). The proper NPK ratio can significantly promote the growth and yield of cotton. The suitable fertilizer application rate of cotton varies greatly among different regions. The planting time of early-maturing cotton in the Anhui Yangtze River Basin is late. According to the planting habit of spring cotton, the fertilizer application rate of early-maturing cotton has the problems of late ripening, low yield and low economic benefits.

Fertilization is one of the most important measures to improve crop yield. According to statistics, the effect of fertilizer on increasing crop yield accounts for 30% ~ 50% (Wang et al., 2012). However, the effect of increasing fertilizer on crop yield has not been obvious, and excessive fertilizer not only increases the cost input but also causes serious environmental pollution (Zhu and Jin, 2013; Song et al., 2018; Ju and Gu, 2014). Therefore, the appropriate fertilizer application rate has always been the focus of crop production, agricultural science and technology workers (Song et al., 2018; Wang et al., 2019). At present, there are recommended fertilizer application ranges for different main cotton-producing areas in China (Li et al., 2019). However, the appropriate fertilizer application rate of different varieties in different regions varies greatly. For example, precocious varieties need to grow early and fast in the early stage and prevent greedy late ripening in the late stage; therefore, their nutrient requirements are inevitably different from those of conventional varieties (Yan et al., 2021; Zheng et al., 2022). Therefore, how to reduce the amount of fertilizer and improve the utilization rate of fertilizer has been one of the key research directions of green, high-yield and efficient cotton production.

Cotton in the Yangtze River Basin in Anhui Province is mainly planted with spring cotton after (rape) wheat. The problems of high fertilizer consumption and low fertilizer-utilization rate are prominent in the production process (Zheng et al., 2020; Yang et al., 2018). At present, the average application rates of NPK to cotton in this area are 285.96 $kg \cdot ha^{-1}$ and 216 $kg \cdot ha^{-1}$, respectively (Li et al., 2017b). Excessive application of chemical fertilizers not only results in a low fertilizer-utilization rate but also aggravates agricultural nonpoint source pollution (Duan et al., 2012). At present, there have been many reports on the reasonable nitrogen application rate of cotton in the middle and lower reaches of the Yangtze River Basin. Tian showed that the suitable nitrogen application rate of first-cropping and high-yield cotton fields in the Yangtze River Basin is 300 $kg \cdot ha^{-1}$ (Tian, 2012). Zou proposed that the recommended nitrogen application rate for cotton production in coastal saline soil areas of the Yangtze River Basin was 301-374 $kg \cdot ha^{-1}$ (Zou et al., 2015). In regard to changes in cotton industry patterns and the new situation of reducing the weight and medicine of the main crops, research on the scientific fertilization of cotton is particularly important (Li et al., 2019). Therefore, this study focused on different plant types and appropriate fertilization techniques in the main cotton-producing areas of Anhui Province, which will provide technical support for reducing fertilizer application and increasing efficiency and producing high-quality seed cotton in this area. This study will have important practical

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significance for green and efficient cotton production and reducing agricultural nonpoint source pollution in this area.

Materials and methods

Experimental site and growth conditions

This experiment was set up at the experimental base of the Cotton Research Institute of Anhui Academy of Agricultural Sciences in 2017 (*Fig. 1*). The local area has a subtropical monsoon humid climate along the Yangtze River, with annual precipitation ranging from 1300 to 1500 mm and annual average temperature ranging from 14.5 to 16.6 °C. The soil at the test site is sandy loam, and the basic physical and chemical properties of the surface soil are as follows: pH of 7.9, organic matter of 12.65 g kg^{-1}, alkali-hydrolyzed nitrogen of 59.6 mg kg^{-1}, available phosphorus of 34.2 mg kg^{-1}, and available potassium of 102.8 mg kg^{-1}. The experiment was a split-plot design, with two cotton varieties in the main plot and three fertilization levels in the split plot. Both cultivars were early-maturing cotton. According to the characteristics of cotton varieties in Anhui's main cotton-producing areas, the fruit-branch types were selected as limited fruit-branch-type Wankemian-1 and unlimited fruit-branch-type Wanmian-191. There were three levels of fertilizer application, as shown in *Table 1*. The area of the plot was 20 m^2, each with 3 replicates, for a total of 18 plots.

a **b** **c**

Figure 1. *The field experiment. (a) General field experiment; (b) Wankemian-1; (c) Wanmian-191*

Due to the lack of relevant studies on the appropriate fertilizer application rate of early-maturing cotton in this area, the recommended fertilizer application rate of spring cotton (N, 320 kg•ha^{-1}, P_2O_5, 80 kg•ha^{-1}, K_2O, 160 kg•ha^{-1}) were used as reference standards (Liu et al., 2016, 2018). Combined with previous experiments carried out in this area, the recommended fertilization levels of F1, F2 and F3 were set according to the nutrient requirements of early cotton, and all fertilizers were top dressed once at the first flowering stage. The nitrogen content of urea used was 46%; the nitrogen, phosphorus and potassium contents of special slow-release fertilizer were 18%, 9% and 18%, respectively; and the nitrogen, phosphorus and potassium contents of rapeseed-cake fertilizer were 5.6%, 1.7% and 3.3%, respectively. According to the cultivar characteristics, the planting densities of Wankemian-1 and Wanmian-191 were 112,500 plants ha−1 and 82,500 plants ha−1, respectively. The

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row spacing of Wankemian-1 was 65 cm × 13.7 cm, and that of Wanmian-191 was 65 cm × 18.7 cm. The seeds were sown on May 21, 2017 and harvest deadline on November 20, planted and managed according to local conventional cultivation techniques.

Table 1. *Different fertilization levels and fertilizer dosages*

Different processing	Fertilizer rate ($kg \cdot ha^{-1}$)					
	N	P_2O_5	K_2O	Urea	Special slow-release fertilizer	Rapeseed cake
F1	80	20	40	75	187.5	187.5
F2	160	40	80	150	375	375
F3	240	60	120	225	562.5	562.5

Index determination and methods

Ten cotton plants with the same growth were selected in each plot for the investigation of the growth period, and the seedling stage, budding stage, flowering stage and opening stage were recorded. On September 15, the main agronomic traits of cotton were measured. During the cotton maturity period, the plants in each plot were manually harvested three times from September to October, and the fiber quality parameters were measured according to Zhang (2006).

The total output value was cotton product income and cultivation subsidy income (Zhu, 2019), and the total cost input included material cost and management cost. All material and labor costs were calculated using current prices.

Data statistics

Microsoft Excel 2013 software was used for data calculation and mapping, SPSS 19.0 software was used for analysis of variance, and the least significant range method (LSD) was used to compare the differences between treatments.

Results

Effects of fertilizer application rate on the growth characteristics of cotton with different plant types

As shown in *Table 2*, the growth period of the two varieties was significantly prolonged by 4-5 days from the increase in fertilizer application rate. The days from emergence to budding of the two varieties also significantly increased with increasing fertilizer application rate, and the days from budding to flowering showed a trend of extension with increasing fertilizer application rate. Fertilization level had no significant effect on the days from flowering to floc opening of the Wankemian-1 plant, while the days from flowering to floc opening of the Wanmian-191 plant tended to decrease with the increase in fertilizer application rate. The seedling emergence time was the same among all treatments, and the fertilization rate had no effect on the seedling emergence of either cultivar. There was no significant difference in the growth period between the two varieties.

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Table 2. *Effects of fertilization amount on plant growth process of two cotton varieties*

Varieties	Fertilizer levels	Growth stage				Growth period (d)
		Emergence	Squaring	First bloom	Opening	
Wankemian-1	F1	05-26	36.7 c	20.0 b	50.0 a	105.7 c
	F2	05-26	38.0 b	21.3 ab	50.7 a	109.0 b
	F3	05-26	39.3 a	22.3 a	50.0 a	110.7 a
	Average					108.4 a
Wanmian-191	F1	05-26	38.3 c	20.0 b	50.7 a	108.0 c
	F2	05-26	40.3 b	20.0 b	50.7 a	110.0 b
	F3	05-26	42.7 a	20.7 a	49.3 b	111.7 a
	Average					109.9 a

As shown in *Table 3*, increasing fertilizer application significantly increased the first fruit-branch placement, fruit-branch number, and plant height of both cultivars. The increase in the fertilizer application rate increased the first fruit-branch position of Wanmian-1 more than Wankemian-191, and the first fruit-branch position of Wanmian-1 was more sensitive to fertilization than Wankemian-191. The effects of increasing the fertilizer application rate on increasing the number of fruit branches and plant height of the two cultivars were basically the same. There was no significant difference in the node position and plant height of the first fruit-branch between the two cultivars, but the number of fruit branches of Wankemian-1 was 10.6% higher than that of Wanmian-191.

Table 3. *Effects of fertilization amount on the agronomic traits of the two cotton varieties*

Variety	Fertilizer levels	First fruit node	Number of fruit branch	Plant height (cm)
Wankemian-1	F1	5.0 c	12.5 c	98.3 c
	F2	5.2 b	13.5 b	105.2 b
	F3	5.4 a	14.8 a	110.2 a
	Average	5.2 a	13.6 a	104.6 a
Wanmian-191	F1	5.0 c	11.2 c	100.5 c
	F2	5.5 b	12.5 b	109.1 b
	F3	5.9 a	13.2 a	115.3 a
	Average	5.5 a	12.3 b	108.3 a

Effects of fertilizer application rate on cotton yield of different plant types

As shown in *Table 4*, the boll number per plant and boll weight of the two varieties showed an increasing trend with increasing fertilizer application rate. The boll number per plant of the Wankemian-1 F3 treatment was increased by 22.1% and 54.7% compared with F2 and F1, respectively, and the boll number per plant of the Wanmian-191 F3 treatment was increased by 15.1% and 76.8% compared with F2 and F1, respectively. There was no significant difference in seed cotton yield and lint yield of the F3 and F2 treatments of the two varieties, but they were significantly higher than those of the F1 treatment. The highest seed cotton yield and lint yield of Wankemian-1 were found in the F2 treatment, while the seed cotton yield and lint yield of the Wanmian-191 F2 treatment and F3 treatment were basically the same. The boll yield of

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both cultivars decreased with the increase in fertilizer application rate, and the boll yield of the F1 treatment was significantly higher than that of the F2 and F3 treatments. The fertilizer application rate had no significant effect on the lint score of Wankemian-1, while the lint score of Wanmian-191 showed little difference among all treatments. The boll number per plant, lint percentage, seed cotton yield and lint yield of Wanmian-191 were significantly higher than those of Wankemian-1. There were no significant differences in boll weight or boll percentage between the two varieties.

Table 4. *Effects of fertilization amount on yield of the two cotton varieties*

Variety	Fertilization levels	Boll number (boll plant^{-1})	Boll weight (g boll^{-1})	Harvest boll rate (%)	Lint percentage (%)	Seed cotton yield (kg·ha^{-1})	Lint yield (kg•ha-1)
Wankemian-1	F1	7.5 c	4.8 b	95.2 a	39.2 a	2654.1 b	1040.4 b
	F2	9.5 b	5.2 a	90.1 b	39.5 a	3189.9 a	1259.9 a
	F3	11.6 a	5.3 a	84.5 c	39.2 a	3059.0 a	1198.9 a
	Average	9.5 b	5.1 a	89.9 a	39.3 b	2967.7 b	1166.4 b
Wanmian-191	F1	9.5 c	4.9 b	92.3 a	40.5 ab	2799.6 b	1133.9 b
	F2	14.6 b	5.3 a	87.4 b	40.8 a	3342.7 a	1363.8 a
	F3	16.8 a	5.4 a	80.2 c	40.2 b	3397.0 a	1365.8 a
	Average	13.6 a	5.2 a	86.6 a	40.5 a	3179.8 a	1287.8 a

Effects of fertilizer application rate on fiber quality of cotton with different plant types

As shown in *Table 5*, the cotton-fiber fracture specific strength of the two varieties was highest in the F2 treatment, and the average length of the upper half of cotton-fiber of Wankemian-1 in the F2 treatment was the longest, which was significantly longer than that of the F1 treatment. There was no significant difference in the average length of the upper half of cotton fiber in Wanmian-191 among all treatments. The fiber-length uniformity index of the two varieties was highest in the F1 treatment, while there was no significant difference between the F2 and F3 treatments. The fertilizer application rate had no significant effect on the cotton-fiber Macron value of the two varieties, and different fertilizer application rates had little effect on the cotton-spinning uniformity index. The breaking strength, length uniformity index and spinning uniformity index of Wankemian-1 were significantly higher than those of Wanmian-191.

Table 5. *Effects of fertilization amount on fiber quality of the two cotton varieties*

Variety	Fertilizer levels	Upper half fiber length (mm)	Fiber strength (cN•tex-1)	Micronaire value	Uniformity index (%)	Spinning consistence index (SCI)
Wankemian-1	F1	30.3 b	29.7 b	4.96 a	88.3 a	149.0 a
	F2	31.5 a	30.8 a	5.14 a	86.6 b	145.0 b
	F3	30.8 ab	30.5 ab	5.19 a	86.5 b	143.0 b
	Average	30.8 a	30.3 a	5.10 a	87.1 a	145.7 a
Wanmian-191	F1	29.6 a	28.7 c	5.19 a	86.8 a	138.0 a
	F2	30.3 a	30.4 a	5.34 a	85.9 b	136.0 a
	F3	30.7 a	29.4 b	5.32 a	86.0 b	138.0 a
	Average	30.2 a	29.5 b	5.28 a	86.2 b	137.3 b

Effects of fertilizer application rate on planting efficiency of different cotton plant types

As shown in *Table 6*, the material input, labor cost and total input of the two varieties increased with increasing fertilizer application rate. The product income of the

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Wankemian-1 F2 treatment was highest, and the product income of the Wanmian-191 F2 and F3 treatments was basically the same, which was higher than that of the F1 treatment. The net income of the Wankemian-1 F2 treatment was 60.3% and 243.8% higher than that of the F1 and F3 treatments, while the net income of the Wanmian-191 F2 treatment was 49.5% and 53.3% higher than that of the F1 and F3 treatments, respectively.

Table 6. *Effects of fertilization amount on the economic performance of the two cotton varieties (Yuan ha^{-1})*

Variety	Fertilizer levels	Input materials	Labor	Total cost	Product value of the main crop	Income from cropping subsidies	Net income
Wankemian-1	F1	- 5700.	- 10350.	- 16050.	16986	1515	2451 b
	F2	- 6750.	- 11250.	- 18000.	20415	1515	3930 a
	F3	- 7800.	- 12150.	- 19950.	19578	1515	1143 b
	Average	- 6750.	- 11250.	- 18000.	18993	1515	2508 a
Wanmian-191	F1	- 5550.	- 10800.	- 16350.	17917	1515	3082 b
	F2	- 6600.	- 11700.	- 18300.	21393	1515	4608 a
	F3	- 7650.	- 12600.	- 20250.	21741	1515	3006 b
	Average	- 6600.	- 11700.	- 18300.	20351	1515	3566 a

Discussion

The rate of fertilizer application significantly affected the growth process of cotton, and the growth period, especially the flowering period, of both cultivars was significantly prolonged by 4-5 days with the increase in fertilizer application. Some studies have shown that the growth period of cotton lengthens with increasing nitrogen application rate in a certain range (Zhang et al., 2014a). Some research suggested that the amount of fertilizer applied had little effect on the duration of the cotton growth period and flowering boll period, and the after effect of nitrogen fertilizer was not obvious (Song et al., 2018), which may be because the gradient of the fertilizer application rate was smaller, the previous crop had more fertilizer residue, and the soil basal fertility was higher. Due to the low potassium-fertilizer dosage in the F1 treatment, the insufficient potassium supply caused the cotton growth process to be advanced, flowering to be earlier, and even the phenomenon of early senescence to be earlier (Dong et al., 2005; Liu et al., 2017). Previous studies have found that with a low potassium level, cotton would have fruit-branch-beginning-node decline and early bud appearance (Liu et al., 2017). Therefore, appropriate fertilizer application rates, especially nitrogen and potassium application rates, are essential to ensure the growth and development of cotton.

The grain cotton yield and lint yield of the two varieties showed an increasing trend with increasing fertilizer application rate. However, when the fertilizer application rate reached a certain level, the cotton yield did not increase. There was no significant difference in the grain cotton yield and lint yield between the F2 and F3 treatments. The yield of cotton increased with increasing nitrogen application rate, but the nitrogen application rate reached 180 (kg·ha^{-1}). It was found that the increase in boll number per plant and boll weight, especially boll number per plant, contributed to the increase in cotton yield due to increasing the fertilizer application rate. Compared with F1, the boll number per plant of Wankemian-1 and Wanmian-191 in the F3 treatment increased by 54.7% and 76.8%, respectively, while the boll weight per plant in the F3 treatment increased by 10.4% and 10.2%, respectively (Zhang et al., 2014b). It was found that increasing the nitrogen application rate could significantly increase the boll number per plant and yield of cotton. In addition, some studies have shown that boll weight and seed

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cotton yield of cotton with high potassium levels were significantly higher than those with low potassium levels (Liu et al., 2017). Yield components such as boll number, boll weight and lint percentage determined the yield of cotton (Dai et al., 2016; Zhang et al., 2012). According to this study, the increase in boll number per plant was the most important factor affecting cotton fertilizer yield. The harvested boll rate of both cultivars decreased with increasing fertilizer application rate, indicating that excessive fertilizer application may lead to ineffective boll setting, which may reduce economic benefits. This study found that the net returns of both cultivars were highest at the F2 fertilization level, and the excess fertilizer rate did not increase seed cotton yield and increased cost input significantly. However, the lower fertilizer application rate resulted in a lower cost input, and the seed cotton yield was significantly reduced. Therefore, it is further indicated that only with a suitable fertilizer application rate can cotton achieve high yield and economic efficiency. The F2 fertilization level was the suitable amount of fertilizer applied to cotton of the two fruit-branch types in this area to obtain high yield. The application rate of NPK at this level was lower than that at the same yield in the cotton region of the Yangtze River Basin (Li et al., 2019). In this study, cotton slow-release fertilizer and rapeseed-cake fertilizer, which accounted for a high proportion of the total fertilizer amount, were applied. The two varieties tested in the experiment were early-maturing cotton, which had a lower nutrient requirement than spring cotton; otherwise, it would mature later. However, more research needs to be carried out to determine whether the optimization of the ratio of fertilizer and slow-release fertilizer and their application methods can further reduce the amount of fertilizer to ensure a high cotton yield.

An appropriate fertilizer application rate can increase cotton yield and improve cotton-fiber quality to a certain extent (Li et al., 2016). This study showed that the average length and specific breaking strength of the upper half of fiber of the two cultivars were higher under the F2 fertilization level, and the spinning uniformity index was not significantly different from that under the F3 treatment. Some studies have found that compared with a low K application level, increasing the K application level could improve cotton-fiber quality, mainly reflected in the average length of the upper half of the fiber, breaking specific strength and length uniformity index (Liu et al., 2017; Yang et al., 2016). It was concluded that the effect of potassium application on boll-setting characteristics of medium-ripe cotton cultivars was greater than that of super-early cotton cultivars. The effects of the potassium application rate on the cotton quality of the two different fruit-branch types were quite different. The fiber quality of Wankemian-1 was more sensitive to the effect of the potassium application rate than that of Wanmian-191, especially the average length of the upper half and the spinning uniformity index (*Table 5*). In addition, under the same fertilization level, the cotton-fiber quality of Wankemian-1 was better than that of Wanmian-191, which was mainly reflected in the fiber-breaking specific strength, length uniformity index and spinning uniformity index of Wankemian-1 being significantly higher than those of Wanmian-191. The influence of fertilization level on cotton-fiber quality of the two plant types is mainly due to genetic factors or nutrient absorption differences, which need to be further studied.

Conclusion

This study examined the effects of different fertilization rates on the growth, development, yield, quality and economic benefits of cotton. The results showed that the growth period, node position of the first fruit branch, number of fruit branches and

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plant height of the two early-maturing cotton varieties increased significantly with increased fertilization. The suitable fertilization rates of the two early-maturing cotton varieties with different plant types in this area were 160 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}. The economic benefit from 50% fertilization of the two varieties of conventional spring cotton was significantly higher than that of the other two treatments. Through the appropriate amount and proportion of fertilization, the planting benefit of early-maturing cotton can be improved, which plays an important guiding role in the green, high-quality and high-yield cultivation of cotton in the Yangtze River Basin.

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