

Cotton N rate could be reduced further under the planting model of late sowing and high-density in Yangtze River Valley

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Research

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Abstract

Background: An optimal N rate is one of the basic determinants for high cotton yield. The purpose of this study was to determine the optimal N rate on a new cotton cropping pattern with late-sowing, high density and one-time fertilization at first flower in Yangtze River Valley China. A 2-year experiment was conducted in 2015 and 2016 with a randomized complete blocks design, and cotton growth process, yield and biomass accumulation were examined.

Results: The results showed that N rate had no effect on cotton growing progress or periods. Cotton yield was increased with N rate increasing from 120-180 kg·hm⁻², while the yield was not increased when N was beyond 180 kg·hm⁻², or even decreased (9-29%). Cotton had the highest biomass at N180 due to its highest accumulation speed during the fast accumulation period (FAP).

Conclusions: The result suggests that cotton N rate could be reduced further to be 180 kg·hm⁻² under the new cropping pattern in Yangtze River Valley China.

1. Background

China was the second largest cotton producer with net production value among 10 main cotton producers in the world (FAO, 2016), but the highest yield was obtained from a large amount of N consumption (FAO, 2017). Therefore, minimizing the investment, including reducing fertilizer application is becoming more and more important to ensure sustainable agricultural development in China (Dai et al., 2017; Luo et al., 2018). N is a vital nutrient for cotton, an optimal N rate is conducive to cotton growth for different growing patterns (Rochester et al., 2007). However, more N was applied than cotton needed, because farmer always worries about a possible consequent yield reduction due to reduced N rate (Larson et al., 2004).

Cotton biomass and yield were significantly affected by N rates. The highest cotton yield was achieved under the optimal N rate (Stamatiadis et al., 2016). Excessive N would promote the vegetative growth, delay maturity and/or increase rotten/fallen bolls (Edmisten, 2005, Gerik et al., 1998; Jackson and Gerik, 1990), and on the other hand, insufficient N would result in a lower biomass, a poorer plant development, a premature senescence and/or a yield reduction (Clawson et al., 2008; Zhang et al., 2012). The highest yield was observed closely associated with a higher biomass and its accumulation speed during FAP, especially for reproductive organs (Xue et al., 2008). Read et al. (2006) reported that cotton vegetative growth could be coordinated with its reproductive growth should an appropriate N rate applied.

In recent years, in line with the reduction of investment, a new cotton planting pattern was practiced successfully, which is characterized with direct sowing in middle May, higher density of 6 plants m⁻² and lower N rate of 225 kg ha⁻¹ in Yangtze River Valley without compromising cotton yield (Yang et al., 2011; Yang et al., 2012; Yang et al., 2013). In addition, one-time fertilization at the first flower was proved

sufficient under this planting model (Khan et al., 2017; Tung et al., 2018 a, b). However, could the N rate be reduced further as reported by Boquet and Breitenbeck (2000) and Rochester et al. (2009)?

We hypothesized that lower N rate than 225 kg ha⁻¹ should be possible under this planting model due to shorter growing season and bigger population. Therefore, this study was to verify the hypothesis based on cotton yield and its components, and dry matter accumulation.

2. Materials And Methods

2.1. Experimental site and cultivar

This study was conducted in 2015 and 2016 growing season at the experimental site of Huazhong Agricultural University (30°37-N latitude, 114°21-E longitude, 23 m above sea level) in the middle reaches of the Yangtze River valley with Huamian-3109 (*Gossypium hirsutum* L.). The soil was a yellow-brown clay loam and contained within (0–20 cm) 11.6 g kg⁻¹ organic matter, 95.5 mg kg⁻¹ available N, 15.1 mg kg⁻¹ P₂O₅, and 132.4 mg kg⁻¹ K₂O. The weather data of average temperature and rainfall from April to November was presented in (Fig. 1).

2.2. Experimental design and field management

There were five treatments (N rates): N120, N150, N180, N210, N240 represents applied nitrogen 120, 150, 180, 210, 240 kg ha⁻¹, respectively. Fertilizers were used to supply N, P₂O₅ (54 kg ha⁻¹), K₂O (180 kg ha⁻¹) and B (15 kg ha⁻¹) with urea (46.3% N), superphosphate (12% P₂O₅), potassium chloride (59% K₂O) and borate (10% B). All the fertilizers were mixed and applied in wide rows at the appearance of first flower (58 DAE in 2015 and 60 DAE in 2016, DAE shows days after emergence).

This experiment was arranged in a randomized complete block design with four replications, each plot was 12 m in row length and 2.28 m in row width, and 6 rows including both narrow (10 cm) and wide (66 cm) rows. Cotton was sown on 20 May 2015 and 18 May 2016, with manual hill-dropping 3–5 seeds per hill to obtain 10 plant m⁻², the field management according to local agronomic practices.

2.3. Data collection

2.3.1. Growth period

The date of emergence, squaring, flowering, and boll-opening was investigated within fifteen successively and fixed hills/plants of each plot.

2.3.2. Yield and yield components

Seed cotton was harvested four times (23 September, 14 and 21 October and 2 November) in 2015 and twice (9 October and 5 November) in 2016, which was weighed after drying of each plot, including the fallen open bolls from the ground. The number of bolls per square meter was recorded from whole plot

before plant withdrawal (the last harvest) while boll weight and lint percentage were calculated by 100 bolls was randomly sampled at the second harvest.

2.3.3. Biomass accumulation and distribution

Biomass was sampled at 20, 40, 60, 80, 100, 120, 140 DAE in two growing seasons, Nine continuous plants (twenty seven plants at 20 DAE) were taken from each treatment and separated into three parts, including vegetative (root, stem, stem leaves), reproductive (square, flower, boll) and reproductive relative organs (branch, branch leaves). Biomass was determined after oven drying at 105 °C for 30 min and turn to 75 °C to a constant weight before weighing.

2.3.4. Data processing and analysis

Microsoft® Excel® 2019 was used for data processing and figure drawing. SPSS Statistics 21.0 software was applied to determine ANOVA analyses, means were separated using LSD test at 5% probability level. DPS software was used to describe the progress of logistic equation for biomass accumulation (Yang et al., 2011)

$$Y = \frac{K}{1 + ae^{bt}} \quad (1)$$

where Y (g m⁻²) means the biomass at t, t (d) means DAE, K (g) is the maximum biomass, a and b are constants from formula (1):

$$t_1 = -(a - \ln(2 + \sqrt{3})) / b, \quad t_2 = -(a + \ln(2 + \sqrt{3})) / b, \quad t_0 = \frac{a}{b} \quad (2)$$

$$V_{\max} = \frac{-bk}{4} \quad (3)$$

When, t = t₀, biomass accumulation has the fastest speed V_M,

The period was defined as the biomass fast accumulation period (FAP), at FAP 58% biomass accumulated, which begins at t₁ and terminates at t₂. During FAP, the average speed of biomass accumulation was described as:

$$V_f = \frac{Y_2 - Y_1}{t_2 - t_1} \quad (4)$$

3. Results

3.1. Cotton growth period

N rate had no effect on cotton growth periods in both years (Table 1). However, as compared to the year of 2015, the period from sowing to seedling emergence in 2016 was 2 d longer due to lower temperature

in May, the squaring period was 2–5 d shorter due to enough water supply and higher temperature in July, while boll setting period was 4–7 d longer due to less rainfall in August and September 2016 (Fig. 1).

Table 1 Cotton growth stage and period under different N rate in 2015 and 2016

Growth stages (m-d)				Growth period (d)			Total
Emergence	Squaring	First bloom	Boll opening	Seedling	Squaring	Boll setting	
5-27	7-13	8-5	9-21	47a	23a	47a	117a
5-27	7-13	8-5	9-21	47a	23a	47a	117a
5-27	7-13	8-4	9-20	47a	22a	47a	116a
5-27	7-13	8-4	9-20	47a	22a	47a	116a
5-27	7-13	8-3	9-20	47a	21a	48a	116a
5-27	7-13	8-1	9-23	47a	19a	53a	119a
5-27	7-13	7-31	9-22	47a	18a	53a	118a
5-27	7-13	7-31	9-23	47a	18a	54a	119a
5-27	7-13	7-31	9-23	47a	18a	54a	119a
5-27	7-13	8-1	9-22	47a	19a	52a	118a

Means in the same column and year followed by different letter are significantly different ($p < 0.05$) according to LSD test at 0.05 probability level.

Means in the same column and year followed by different letter are significantly different ($p < 0.05$) according to LSD test at 0.05 probability level.

3.2. Yield and yield components

Cotton yield both in seed cotton and lint increased as N rate increased from 120 to 180 kg ha⁻¹, but remained (2015) or decreased (2016) after 180 kg ha⁻¹, and the yield difference was resulted from bolls per ground area (Table 2). Averaged across the treatments, seed cotton yield was higher in 2016 than that in 2015, while lint yield performed the other way round due to higher lint percentage in 2015.

In cotton yield components, N180 achieved more or the most bolls per square meter as compared to other treatments in two growing seasons. N120 significantly reduced bolls by 12.3% and 21.9% in 2015 and 2016, respectively, while higher N rate than N180 treatments caused fewer bolls in rainy season (2016). N rate showed no differences in boll weight and lint percentage, however, boll weight was 12.2% lower, but lint percentage was 17.5% higher in 2015 than those in 2016, respectively.

Table 2 Cotton yield and its components for different N rate in 2015 and 2016

Treatments	Bolls (m ⁻²)	Boll weight [g]	Lint percentage [%]	Yield (kg ha ⁻¹)	
				Seed yield	Lint yield
2015					
N120	67.6b	3.43a	46.1a	2319.0c	1066.7c
N150	74.8ab	3.29a	47.2a	2457.5b	1155.0b
N180	77.1ab	3.78a	47.0a	2912.4a	1368.8a
N210	86.2a	3.37a	47.1a	2900.7a	1363.3a
N240	86.2a	3.43a	47.2a	2956.1a	1389.4a
2016					
N120	61.2b	3.91a	40.3a	2390.9c	962.9c
N150	72.6ab	3.94a	39.1a	2859.6ab	1117.7b
N180	78.4a	4.01a	40.1a	3142.4a	1260.1a
N210	70.5ab	4.04a	38.9a	2849.5b	1109.7b
N240	58.5b	3.81a	41.3a	2226.9c	920.4c

Means in the same column and year follow by different letter are significantly different ($p < 0.05$) according to LSD test by SPSS 21.0.

3.3. Cotton plant biomass (CPB) accumulation

Patterns of CPB increase resembled an "S"-shaped growth curve over time for the entire growing period, differing in rates of accumulation after fertilization treatment (Fig. 2). Prior to fertilization, the CPB rate of accumulation was slow with no differences observed among treatments in both years. After fertilization, N rate significantly affected CPB, causing rapid accumulation of biomass among the treatments. About 20 days after fertilization (80 DAE), the differences of CPB among treatments were apparent, although there were no differences among N240, N210 and N180. However, from 97 DAE to the last sampling date, these treatments' CPB were all significantly higher than that of N150 and N120. Moreover, this trend was seen in the second growing season, and CPB in 2016 was greater than that in 2015.

The pattern of accumulation of vegetative organ biomass (VOB) across treatments displayed a quadratic curve. Clearly, VOB was influenced by rainfall; VOB in 2016 was nearly twice as much as that in 2015 at 139/138 DAE. VOB rates of increases were slow and similar for all treatments prior to 60 DAE and then treatment rates branched after fertilization, differing widely as plants reached the last sampling date in both years. In this experiment, VOB increased over time and more so after N application. In addition, the highest VOB was observed from N240 after fertilization across the different growing seasons (Fig. 2).

Accumulation of reproductive organ biomass (ROB) began at the square stage at 47 DAE in both years of study (Table 1); ROB in 2016 was slight lower than ROB in 2015 (Fig. 2). A small amount of ROB accumulated at 60 DAE (in the squaring stage). Subsequently, ROB rates of increase escalated with plant growth and N application, especially in the latter growing season. As the amount of N increased across

treatments, the maximum ROB was observed in N180 in the second growing season compared to that in all other treatments. Treatments were sorted and ranked by ROB values into three groups: N210, N180 > N120, N240 > N150.

Fig. 2. Effect of varying N rate on cotton plant biomass (CPB); vegetative organs biomass (VOB); reproductive organs biomass (ROB) and reproductive relative organs biomass (R.ROB) accumulation in 2015 and 2016. Error bar shows SE of means.

Treatments in the first two sampling dates (20 and 41 DAE) lacked accumulation of relative reproductive organs biomass (R.ROB). Values of R.ROB were very similar among treatments at 60 DAE. After 60 DAE, RROB gradually increased with plant growth and N application. In the two growing seasons, N application benefitted RROB, particularly in the latter growing season. Faster rates and more accumulation of R.ROB occurred in the rainy season and the values of R.ROB differed greatly among the treatments. Trends in R.ROB were similar to trends in VOB across the different treatments (Fig. 2).

3.4. Simulation of biomass accumulation

Logistic Eq. (1) was used to describe biomass accumulation over time (DAE), and the unknown parameters of equations (a and b) were calculated from (2)-(4). Although different coefficients of determination were calculated among different cotton parts or treatments, all P values were < 0.005 for the two years (Table 3).

Table 3 Equation of cotton plant biomass accumulation in field grown cotton affected by varying N rate in 2015 and 2016.

Trt.	2015		2016	
	Regression equation	<i>P</i>	Regression equation	<i>P</i>
Cotton plant biomass (CPB)				
N120	$y=786.9829/(1+5.5986e^{-0.062273t})$	0.0003	$y=980.7333/(1+5.6917e^{-0.061461t})$	0.0001
N150	$y=811.2928/(1+4.9713e^{-0.059909t})$	0.0007	$y=1027.8667/(1+6.1482e^{-0.057452t})$	0.0000
N180	$y=975.7703/(1+7.9451e^{-0.093036t})$	0.0006	$y=1186.7867/(1+6.3845e^{-0.059150t})$	0.0000
N210	$y=969.2711/(1+7.1607e^{-0.079408t})$	0.0008	$y=1236.6667/(1+5.1290e^{-0.043108t})$	0.0000
N240	$y=1027.8458/(1+7.9633e^{-0.081425t})$	0.0001	$y=1221.9000/(1+5.3042e^{-0.051483t})$	0.0001
Vegetative organs biomass (VOB)				
N120	$y=260.4752/(1+9.3474e^{-0.136101t})$	0.0016	$y=436.2500/(1+4.5808e^{-0.044042t})$	0.0001
N150	$y=304.0221/(1+8.1854e^{-0.124564t})$	0.0006	$y=454.4667/(1+4.3784e^{-0.034633t})$	0.0003
N180	$y=368.6669/(1+7.5235e^{-0.104923t})$	0.0049	$y=520.4333/(1+4.7996e^{-0.041825t})$	0.0000
N210	$y=335.5458/(1+5.7505e^{-0.080168t})$	0.0015	$y=574.2000/(1+4.5248e^{-0.036627t})$	0.0002
N240	$y=423.9513/(1+4.6583e^{-0.068321t})$	0.0009	$y=569.8667/(1+4.6434e^{-0.046620t})$	0.0000
Reproductive organs biomass (ROB)				
N120	$y=441.8445/(1+10.2346e^{-0.105497t})$	0.0003	$y=405.6093/(1+11.4065e^{-0.107567t})$	0.0000
N150	$y=414.2006/(1+10.5009e^{-0.111224t})$	0.0003	$y=411.2000/(1+11.8352e^{-0.114011t})$	0.0000
N180	$y=498.3757/(1+10.8553e^{-0.117894t})$	0.0003	$y=481.1033/(1+13.8421e^{-0.131804t})$	0.0000
N210	$y=507.5453/(1+10.7610e^{-0.111712t})$	0.0003	$y=453.4667/(1+14.8640e^{-0.137449t})$	0.0000
N240	$y=441.0662/(1+11.0700e^{-0.119538t})$	0.0001	$y=438.1000/(1+15.8604e^{-0.144476t})$	0.0000
Reproductive relative organs biomass (R.ROB)				
N120	$y=84.6632/(1+5.8641e^{-0.067732t})$	0.0039	$y=138.8833/(1+7.4336e^{-0.076408t})$	0.0000
N150	$y=93.0701/(1+5.0729e^{-0.059136t})$	0.0016	$y=162.2000/(1+7.2416e^{-0.071859t})$	0.0000
N180	$y=108.7277/(1+5.0113e^{-0.054274t})$	0.0001	$y=185.2500/(1+6.8369e^{-0.065929t})$	0.0000
N210	$y=126.1800/(1+4.8353e^{-0.058124t})$	0.0048	$y=209.4167/(1+5.7517e^{-0.050508t})$	0.0001
N240	$y=162.8283/(1+4.6066e^{-0.050356t})$	0.0036	$y=213.9333/(1+5.8288e^{-0.050712t})$	0.0000

Table 4 Eigen values of cotton plant biomass accumulation in field grown cotton affected by varying N rate in 2015 and 2016.

l)					2016				
	t ₂ DAE(d)	Δt (d)	V _T (g m ⁻² d ⁻¹)	V _M (g m ⁻² d ⁻¹)	t ₁ DAE(d)	t ₂ DAE(d)	Δt (d)	V _T (g m ⁻² d ⁻¹)	V _M (g m ⁻² d ⁻¹)
mass									
	111.0	42.2	10.75	12.25	71.2	114.0	42.9	13.21	15.07
	104.9	43.9	10.66	12.15	84.1	129.9	45.8	12.94	14.76
	99.5	28.3	19.90	22.69	85.7	130.2	44.5	15.39	17.55
	106.7	33.1	16.88	19.24	88.4	149.5	61.1	11.69	13.33
	113.9	32.3	18.35	20.92	76.9	127.7	50.8	13.88	15.84
	107.2	35.9	15.31	17.45	81.3	130.3	49.0	13.42	15.31
s biomass (VOB)									
	78.3	19.3	7.78	8.86	60.4	109.1	48.7	5.17	5.89
	76.2	21.1	8.31	9.47	68.6	127.6	59.0	4.45	5.07
	84.2	25.0	8.48	9.67	67.2	118.0	50.8	5.91	6.74
	88.0	32.8	5.90	6.73	68.8	125.3	56.5	5.87	6.69
	87.4	28.5	6.57	7.24	58.7	105.3	46.5	7.07	8.07
	82.8	25.3	7.41	8.39	64.7	117.1	52.3	5.69	6.49
ans biomass (ROB)									
	109.4	24.9	10.22	11.65	93.8	118.3	24.5	9.56	10.91
	106.2	23.6	10.10	11.51	92.3	115.4	23.1	10.28	11.72
	103.2	22.3	12.89	14.69	95.0	115.0	20.0	13.90	15.86
	108.1	23.5	12.43	14.17	91.9	109.7	17.9	13.66	15.58
	103.6	22.0	11.56	13.18	94.1	111.2	17.1	13.87	15.82
	106.1	23.3	11.44	13.04	93.4	113.9	20.5	12.26	13.98
ative organs biomass (R.ROB)									
	106.0	38.8	1.26	1.43	80.0	114.5	34.5	2.33	2.65
	108.0	44.5	1.21	1.38	82.4	119.1	36.7	2.55	2.91
	116.4	48.4	1.29	1.48	83.7	123.7	40.0	2.68	3.05
	105.8	45.2	1.61	1.83	87.8	139.9	52.1	2.32	2.64
	117.4	52.1	1.80	2.05	89.0	140.9	51.9	2.38	2.71
	110.7	45.8	1.43	1.63	84.6	127.6	43.0	2.45	2.80

DAE indicates days after emergence (d). t₁ and t₂ are the beginning and terminating days of the fast accumulation period (FAP), respectively. Δt indicates the duration of FAP, Δt=t₂ - t₁. V_T and V_M are the average and maximum accumulation speed during FAP, respectively.

There was a fast accumulation period (FAP) of CPB throughout the entire duration of plant growth, the average start and termination dates of the FAP were 71 DAE and 107 DAE in the first growing season, respectively, and 81 DAE and 130 DAE in the latter growing season, respectively. Totals of FAP in 2015 was 36 days and in 2016 was 49 days. The average rates of accumulation during the FAP differed

among the treatments. The maximum average rate was observed in N180 for both growing seasons, but the duration of the FAP was shorter in N180 than in the rest of the treatments. Although N120 and N150 had the longest durations of FAP, the rates of accumulation were significantly lower in 2015. In the rainy season, the average rate of accumulation was lower than but exhibited a similar trend to that of the previous year. The increasing application rate of N across treatments prolonged the duration of the FAP in 2016. The maximum rate of accumulation was consistent with the average rate of accumulation in the two growing seasons (Table 4).

On average, the start and end dates of VOB accumulation during the FAP were 13 d and 24 d earlier and lasted 11 d shorter than their corresponding dates and FAP for CPB in 2015, and were 16 d and 13 d earlier and lasted 3 d shorter than the respective dates and FAP for CPB in 2016 (Table 4). Average and maximum rates of accumulation of VOB during the FAP were half that of CPB, and a few treatments had rates three times lower than rates of CPB across the two seasons. For N treatments within the application range of 120–210 kg ha⁻¹, N application positively correlated with duration of VOB accumulation in 2015 but not in 2016. However, the common feature observed of rates of accumulation was the pattern of increase and then decrease in both years. Among the treatments, the highest rates occurred in N180 (average and maximum rates were 8.48 and 9.67 g m⁻² d⁻¹, respectively) in 2015.

In the first growing season, ROB accumulation initiated and terminated 25 d and 23 d later and continued for 2 d less than those of VOB. In the second season, ROB had a higher rate of accumulation than VOB in the FAP, despite having the later start date as the previous year; however, the end date was 7 days later. Both the average and maximum rates were faster compared with those of VOB, especially in 2016 (Table 4). In the two growing seasons and among all treatments, N180 had the highest rate of accumulation. At N application rates greater than 180 kg ha⁻¹, rates of accumulation did not increase significantly, and at the application rate less than 180 kg ha⁻¹, the rate of ROB accumulation in the FAP was significantly lower.

The start date of R.ROB always occurred between that of VOB and ROB, and the end date of R.ROB was the latest in both years (Table 4). Large differences were observed between start and end dates of the FAP and rates of accumulation between the different years for R.ROB. In the rainy season, the main observations of FAP and the rate of accumulation of R.ROB were clearly greater compared to those in 2015. The duration of the FAP was similar between the two growing seasons and did not exceed three days. Overall, greater N application rates were more beneficial to prolonging the duration and increasing rates of accumulation; however, they may delay the timing of FAPs under certain conditions.

4. Discussion

Our new cotton cultivation model of N application had no effect on cotton growth stages and periods in both years (Table. 1). Previous study have reported boll-setting period can be prolonged by increasing N application rate (Yeates et al., 2010), however, Bange and Milroy (2004) showed that excessive N will shorten the boll-setting period. Results of this experiment at the highest N application rates supported

Bange and Milroy's (2004) results (Table 1). In addition, squaring and boll-setting periods were quite different across the two years. More rainfall occurred during the seedling stage in 2016 and the highest temperature occurred in the squaring stage, resulting in early flowering. Thus, the squaring period was shortened and boll-setting period was prolonged.

A high cotton yield was observed in N180 across the two growing seasons, and N rates greater than 180 kg ha⁻¹ N was not beneficial to yield. Indeed, greater rates resulted in serious reductions in yield (Table 2). Both N deficiency and excess are not conducive to increasing cotton yield (Gerik et al., 1998). Nitrogen deficiency causes reductions in yield, leaf area and carbon dioxide assimilation capacity (Reddy et al., 2004). On the other hand, excess N causes spindly plant growth and bolls to fall off (Roland et al., 2006). Therefore optimal applications of N must be determined to increase cotton yield (Dong et al., 2012). Boquet and Breitenbeck (2000) found positive correlations between yield and N application rates from 0 to 80 kg ha⁻¹; we obtained a similar conclusion where the better N rate was less than 180 kg ha⁻¹ (Table 2). The increase in yield achieved in this study was primarily attributed to the increase in number of bolls per unit area (Bondada et al., 1996).

Biomass accumulation is vitally important to achieve greater cotton yield (Zurwellera et al., 2019) and the supply of N was important to biomass accumulation. In our study, dry matter production was positively affected by particular N rates for the measures of VOB and R.ROB. However, excessive N negatively affected ROB accumulation (Fig. 2), Across the treatments, N180 showed the highest or higher dry matter accumulation in both years, the second lowest application rate tested for this study. N180 had the highest rates of accumulation during the FAP for CPB, VOB, and especially ROB (Tables 4). Thus, N application rates influence cotton yield by affecting biomass accumulation. Reports have indicated that N application enhances cotton yield by increasing the rate of accumulation of reproductive organs measured in dry weight (Yang et al., 2012; Brodrick et al., 2012; Dexter et al., 2017). Our results show large differences between the two growing seasons. Of the rainy season in 2016, ROB was lower than that in 2015, We surmise that the greater amount of rain caused the cotton to grow too vigorously, resulting in an imbalance in the source-sink relationship in plant growth and massive shedding of reproductive organs (Li et al., 2017; Wang et al., 2018). At the same time, amount of bolls fallen of in rainy season cased maturity delayed. In this study the main source of yield variation was number of bolls per unit area (Table 2). Overall, results suggest that applying 180 kg ha⁻¹ N in this new cotton cropping pattern was feasible and effective in achieving greater cotton yield.

5. Conclusions

Under the new cotton cropping patterns, high yields were obtained from N180 compared to that of the other N treatments in both years. Application rates greater than 180 kg ha⁻¹ resulted in drastically lower yields. The most prominent feature in biomass accumulation was observed in N180 which had the highest rate of accumulation during FAPs of CPB, VOB, and ROB. In summary, study data suggest that for field-grown cotton that were late-sown at a high density in Yangtze River Valley of China, it is feasible to

decrease the N application rate to 180 kg ha⁻¹ and apply the fertilizer once to fields when plants begin to flower.

Declarations

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request

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Contributions

Yang GZ designed the study. Song XH wrote the main manuscript text and prepared all figures. Huang Y, Yuan Y, Shahbaz Atta Tung, Biangkham Souliyanonh carried out the experimental work and Song XH analysed data. All authors reviewed the manuscript. All authors read and approved the final manuscript.

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Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

All the authors confirm that the work described here has not been published previously, and is not under consideration for publication elsewhere. The manuscript is approved by all authors, and has no actual or potential conflict of interest with other people or organizations.

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Figures

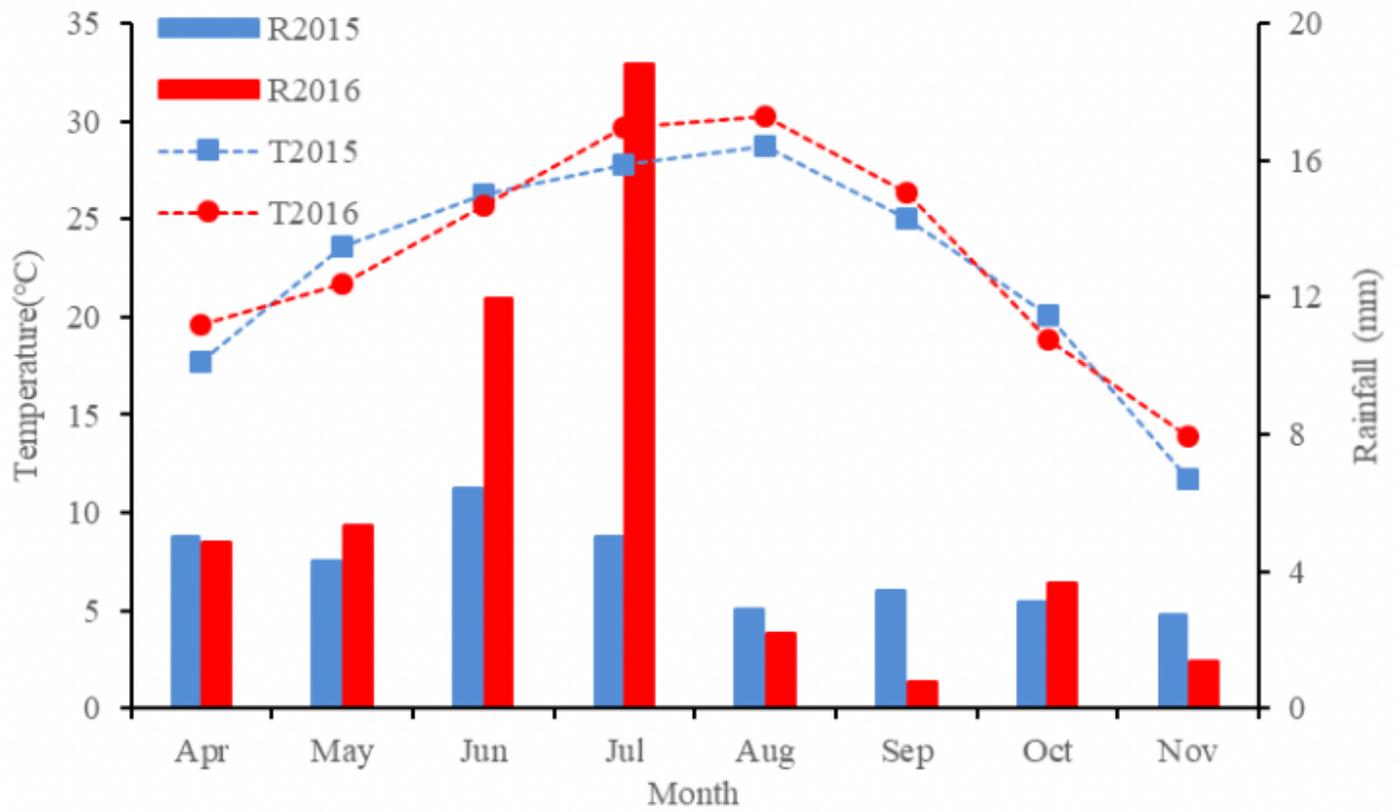


Figure 1

Monthly weather summary during the cotton growing season in 2015 and 2016. T and R represented temperature and rainfall, respectively.

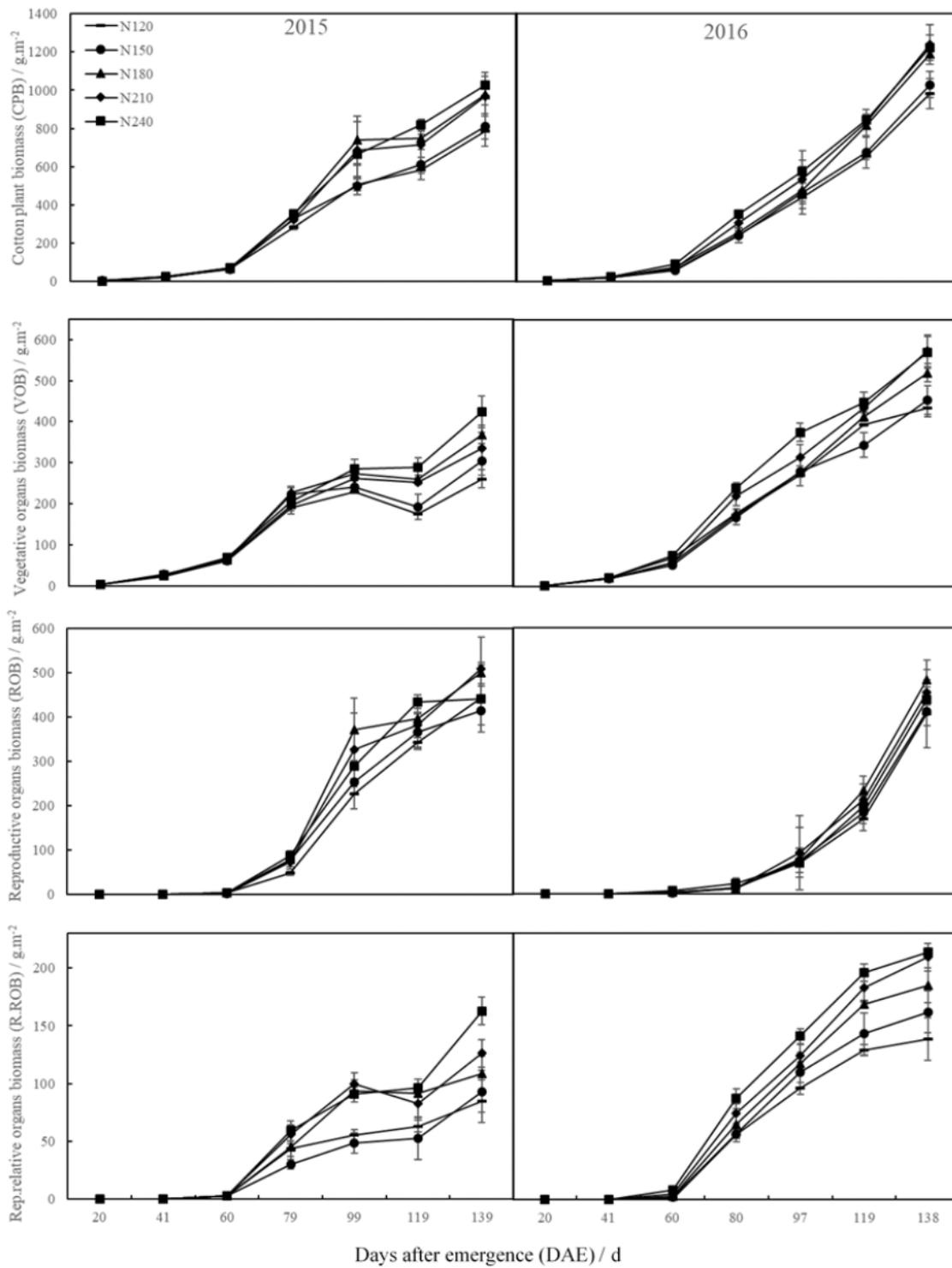


Figure 2

Effect of varying N rate on cotton plant biomass (CPB); vegetative organs biomass (VOB); reproductive organs biomass (ROB) and reproductive relative organs biomass (R.ROB) accumulation in 2015 and 2016. Error bar shows SE of means.