



Full Length Article

Nitrogen Fertilizer Rates can be Lowered without Compromising Cotton Yield under Drip Irrigation System

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Abstract

The effects of reducing N fertilizer use on soil NO₃⁻-N content and cotton yield were studied through a three-year (2015 to 2017) field experiment in South Xinjiang of China. Cotton was sown under drip irrigation system using five N fertilizer reduction treatments as: conventional N application rate (N100), N application rate reduced by 16.67% (N-16.67), 33.33% (N-33.33), 50% (N-50), and 100% (N-100). The data were recorded for changes in soil NO₃⁻-N content, and the SPAD value of cotton leaves was recorded at the peak bolling stage. The total N content of the plant was recorded at the boll formation stage, while yield was recorded at maturity. The results revealed that the soil NO₃⁻-N content in N-16.67, N-33.33, N-50, and N-100 treatments decreased by 10.8, 45.5, 60.7 and 72.3% compared to N100 treatment, respectively. The SPAD values of N-16.67 and N-33.33 treatments were significantly higher than those of N100 treatment, while the SPAD values of N-50 and N-100 treatments were significantly decreased. The total N content of cotton was significantly decreased with the increase in the proportion of N fertilizer reduced. The seed cotton yield in N-16.67 and N-33.33 treatments increased by 9.2 and 7.9% compared to the N100 treatment, respectively. However, the cotton yield decreased significantly when the N application rate was reduced by 50 and 100%. The relationship between the N fertilizer reduction rate and cotton yield suggested that the N application rate can be reduced by 18.47–45.50% without compromising the cotton yield in South Xinjiang of China. © 2021 Friends Science Publishers

Keywords: Reducing N fertilizer application; Cotton; NO₃⁻-N content; Yield; SPAD value

Introduction

It is generally known that Xinjiang is the production base of high-quality cotton (*Gossypium hirsutum* L.) in China. In 2019, the planting area and output of cotton in Xinjiang accounted for 76 and 84.9% of the total in China, respectively (The National Bureau of Statistics of the People's Republic of China 2019). Xinjiang has ranked first in the country's total cotton output for many consecutive years. The income of planting cotton accounts for 50–70% of the total income of farmers in southern Xinjiang (NBSPRC 2019). Nitrogen application has become one of the important measures to improve cotton yield in Xinjiang, and its contribution to cotton yield accounts for 33.5–56.1% (Suo *et al.* 2017). However, studies have shown that improper N application can cause N loss through soil mineralization, ammonia volatilization, and leaching etc. (Resham *et al.* 2016; Qian *et al.* 2018; Minhas *et al.* 2020). Over dosing of N can cause potential pollution risks to soil,

groundwater, and other environmental factors (Babar *et al.* 2014; Nan *et al.* 2015). Reduced N application has practical significance to promote the "national double reduction" policy in South Xinjiang, which can benefit both cotton economic yield and the environment as well. The effect of reduced N application on crop yield and plant nitrogen content has been a topic of many studies (Benjamin *et al.* 2017; Ahmed *et al.* 2019; Solomon *et al.* 2019). Earlier studies have shown that under drip irrigation, when conventional N fertilizer application rate was decreased by 12 to 24%, no decrease in the corn (*Zea mays* L.) yield was observed: which indicates improved N use efficiency (NUE) (Seyed *et al.* 2020). Compared with the conventional N application rate in wheat (*Triticum aestivum* L.), the uptake of N in the above-ground part of the plant did not decrease when the N application rate was reduced by 20 to 30%, and improved NUE as well (Pilar *et al.* 2020). Other studies have shown that NUE, crop N productivity, and yield of tomato (*Solanum lycopersicum* L.) were significantly

increased when N application rate reduced by 20 and 30% (Li *et al.* 2018). From these studies, the effect of reduced N application on crop yield and efficiency is apparent.

Compared with other crops, the effect of reduced N application rate on cotton N content and yield is not well studied, and the appropriate range of reduced N application rate in South Xinjiang is not clear. Therefore, this field study was conducted for three years to monitor the changes in characteristics of soil such as NO_3^- -N content, leaf SPAD value, plant total N content, and seed cotton yield to clarify the appropriate range of reduced N application. Moreover, the findings of this study will provide scientific support for the technical model of the reduced N application rate in cotton fields in South Xinjiang.

Material and Methods

Experimental details and treatments

Experimental site description: The experimental site located in the cotton breeding base of Xinjiang Academy of Agricultural Sciences (41.6933°N, 85.8667°E) at Baotouhu Farm, Korla, Bazhou, South Xinjiang. The study was carried out from 2015 to 2017. This site is located in the mid-latitude region, and its cotton planting scale, technology, and yield are representative of South Xinjiang. The experimental area has a typical arid climate, with an average annual rainfall of 56.20 mm, average annual evaporation of 2,497.40 mm, average annual sunshine of 2,878 h, accumulated temperature ($\geq 10^\circ\text{C}$) of 4,252.20°C, a frost-free period of 205 days, and a groundwater level of 2.00–2.50 m. The previous crops were all cotton, and the experimental soil was sandy loam, which was a medium-fertility soil. The topsoil (0–30 cm) had soil organic matter 10.24 g kg^{-1} , available N 48.78 mg kg^{-1} , available phosphorus 20.36 mg kg^{-1} , available potassium 139.00 mg kg^{-1} , and pH 8.20. Xinluzhong 23 was used as the test cotton variety.

Experimental details: According to the proportion of N fertilizer reduction, the field experiment was set as five N application levels: (1) 476 kg ha^{-1} , conventional N application rate (N100); (2) 395 kg ha^{-1} , N application rate reduced by 16.67% (N-16.67), (3) 317 kg ha^{-1} , N application rate reduced by 33.33% (N-33.33); (4) 238 kg ha^{-1} , N application rate reduced by 50% (N-50); and (5) 0 kg ha^{-1} , N application rate reduced by 100% (N-100). The conventional N application rate (476 kg ha^{-1}) was determined according to the results of the fertilizer effect experiment. Urea (containing 46.4% N) was used as N fertilizer, and 186 kg ha^{-1} of calcium phosphate primary (TSP, containing 46% of P_2O_5) and 68 kg ha^{-1} of K_2O (potassium sulfate, 40% of K_2O) were applied in all treatments. For all treatments, phosphate and potassium fertilizers were used as the base fertilizers. Phosphate fertilizer and potassium fertilizer were mixed and spread into the soil before sowing. Of the total N fertilizer applied,

40% was used as base fertilizer and 60% as topdressing. The experiment was laid out following a randomized complete block design, with three replications per treatment and a net plot size of 4.8 m \times 6.9 m.

Plastic film mulching planting was used, with a row spacing of (10 + 66 + 10 + 66 + 10 + 66) cm, plant spacing of 10 cm, and precision sowing of six rows with one film. In each plot, there were two films and 12 rows of cotton plants. Cotton was sown in early April and harvested in late October each year. The pressure drip irrigation under film was used as the irrigation method. Submersible pumps were used to supply water with an irrigation quota of 4,800 m^3 ha^{-1} . During the growing season of cotton, irrigation was conducted ten times from mid-June (cotton bud stage) to late August (cotton boll opening stage). The irrigation amount was controlled by a water meter in each plot. Nitrogen fertilizer (urea) was applied with eight applications from mid-June to mid-August through the drip irrigation system. Other agricultural management techniques, including pest control, chemical regulators, and topping, were the same as in the local area.

Data recorded

Collection and determination of NO_3^- -N from samples of cotton field soil: Soil samples were taken from each treated plot at the peak boll stage of cotton. A total of five soil samples were collected from each plot. The soil was taken 20 cm apart for each sample, and the fresh soil samples were prepared by layer mixing, with a sampling depth of 0–100 cm. Fresh soil samples (200 g) were taken and cryopreserved. For determination of NO_3^- -N content of the soil, fresh soil samples were thawed, mixed, and sieved by a 2 mm sieve, 12 g of soil samples were weighed and put into a shaking flask. Afterward, extraction was carried out with 100 mL of 0.01 mol/L CaCl_2 solution. After shaking for 1 h, the filtrate was filtered and cryopreserved. Finally, to determine the NO_3^- -N content from the filtrate, the extract was thawed, and a flow analyzer was used (Ruth *et al.* 2020). The N content was expressed in terms of the mass fraction.

Determination of the SPAD value of cotton leaves: Minolta SPAD-502 chlorophyll meter made in Japan was used to determine the SPAD value (Marenco *et al.* 2009). On the 6th day after the last drip fertilization with water at peak boll stage of cotton, SPAD values were determined between 10:00–14:00 h in sunny weather. The instrument was calibrated with a SPAD instrument calibration card to meet the requirements of instrument accuracy before any measurements. SPAD values from 60 randomly selected leaves per plot determined, *i.e.*, 60 SPAD samples. The SPAD value of each leaf was the average value of the four measurements taken at four different sites on the functional leaves of cotton.

Collection of cotton plant samples and determination of total N content: At boll formation stage of cotton, samples

of plants from each plot were collected, and the part above the first leaf of above-ground parts of the cotton plant was removed, and the remaining sample was cut into small pieces. Three cotton plant samples were taken for removing the chlorophyll and were incubated at 105°C for 30 min and then dried at 80°C until a constant weight was reached. The dried sample was then weighed and crushed. Then concentrated H₂SO₄-H₂O₂ method was used to prepare the test solution and the semi-micro-Kjeldahl method (Li 2000) was used to determine the total N content of the plant.

Cotton yield: The total number of bolls and the total number of plants in the plot were determined at the boll opening stage of cotton. The number of bolls per plant and the number of plants harvested per hectare were calculated; 50 bolls from the upper, middle, and lower parts of cotton plants were randomly selected from each plot to determine the single boll weight. This was repeated three times. After the actual harvest of cotton in each plot, the cotton yield was measured.

Statistical analysis

Microsoft Excel and S.P.S.S. 19.0 were used for data analysis. One-way ANOVA was used to determine the significant differences among different treatments for each year. LSD-tests were carried out to determine if there were significant differences between individual treatments at $P < 0.05$.

Results

Soil NO₃⁻-N mass fraction

The mass fraction of soil NO₃⁻-N in 0–20 and 20–40 cm depths under different treatments is shown in Table 1. In general, with the proportion of N fertilizer reduction increasing (from 16.67 to 33.33, 50 and to 100%), the mass fraction of soil NO₃⁻-N was significantly decreased. Compared with N100 treatment, the NO₃⁻-N content in 0–20 cm soil under N-16.67, N-33.33, N-50 and N-100 treatments decreased by 10.8, 45.5, 60.7 and 72.3% in three-year experiments (2015, 2016 and 2017), respectively. However, the NO₃⁻-N content of each treatment in 0–20 cm soil was not significantly different between 2015, 2016 and 2017. The differences in the soil NO₃⁻-N content in 20–40 cm under different treatments were similar to that in 0–20 cm. The NO₃⁻-N content of N-16.67, N-33.33, N-50, and N-100 treatments were 9.6, 46.1, 66.4 and 73.8% lower than that of N100, respectively (Table 1).

SPAD value of cotton leaves

The SPAD value of cotton leaves can reflect the N level of cotton leaves (Uchino *et al.* 2013). The SPAD value of cotton leaves for each treatment was not significantly different between 2015, 2016 and 2017 (Table 2). The

average SPAD value of N16.67 and N33.33 treatments were 58.7 and 57.3, which were 15.5 and 12.7% higher than that of N100 treatment (50.8), respectively. In contrast, the SPAD values of N50 and N100 treatments were significantly lower than those of N100 treatment, which decreased by 14.8 and 28.9%, respectively (Table 2).

Total N content of cotton plant

In general, the plant total N contents of each treatment in 2015 were significantly higher than those in 2016 and 2017. With the proportion of N fertilizer reducing increasing (from 16.67 to 33.33%, and 50 to 100%), the total N contents of the plant were significantly decreased. In the three-year experiment, total N contents of N-16.67, N-33.33, N-50 and N-100 treatments were 1.5–9.8%, 13.8–21.3%, 38.3–45.4%, and 47.2–52.7% lower than that of N100 treatment, respectively (Table 3).

Cotton yield

The cotton yield under different treatments is shown in Table 4. In 2015, the cotton yield of N-16.67 and N-33.33 treatments was significantly higher than that of N100 treatment by 8.20 and 7.91%, respectively. In contrast, the cotton yield of N-50 and N-100 treatments was 6.47 and 39.48% lower than that of N100, respectively. The cotton yields under different treatments in 2016 and 2017 were similar to those in 2015.

Relationship between N fertilizer reduction and cotton yield

The functional relationship between the proportion of N fertilizer reduction and cotton yield change was $y = -0.0069x^2 + 0.2549x + 3.012$, $R^2 = 0.9517$ (Fig. 1). The analysis of the functional relationship showed that cotton yield reached the maximum value and increased by 5.19% compared to the conventional N rate (476 kg ha⁻¹) when the proportion of reducing N fertilizer application was 18.47%, and cotton yield showed no change when the proportion of N reduction was 45.50%. This indicated that the risk of cotton yield loss was small when the reducing N application was within the range of 18.47–45.50%.

Discussion

Nitrogen fertilizer use in agriculture has resulted in significant negative environmental and social impacts. Although management strategies and technologies focus on reducing the application of N fertilizer have been developed to increase N use efficiency and reduce negative impacts, farmers are wary of reductions in N fertilizer application that might result in any yield loss (Stuarta *et al.* 2014). Therefore, it is necessary to better understand how to reduce N fertilizer use without affecting crop yield.

Table 1: Effect of reduced doses of nitrogen application on soil NO₃⁻-N mass fraction in 0–20 and 20–40 cm depths at full boll stage of cotton

Treatments	Soil NO ₃ ⁻ -N mass fraction (mg kg ⁻¹)					
	0–20 cm			20–40 cm		
	2015	2016	2017	2015	2016	2017
N100	3.29 ± 0.06a	3.30 ± 0.12a	3.25 ± 0.07a	2.99 ± 0.09a	3.04 ± 0.06a	2.91 ± 0.09a
N-16.67	3.05 ± 0.04b	2.97 ± 0.03b	2.76 ± 0.03b	2.87 ± 0.05b	2.85 ± 0.03b	2.69 ± 0.09b
N-33.33	1.78 ± 0.06c	1.82 ± 0.09c	1.76 ± 0.04c	1.57 ± 0.06c	1.68 ± 0.03c	1.58 ± 0.03c
N-50	1.59 ± 0.04d	1.10 ± 0.04d	1.18 ± 0.04d	0.93 ± 0.02d	1.42 ± 0.03d	0.98 ± 0.02d
N-100	0.96 ± 0.04e	0.81 ± 0.01e	0.95 ± 0.04e	0.74 ± 0.01e	1.21 ± 0.04e	0.76 ± 0.03e

Mean ± standard deviations followed by different lowercase letters in the same column are significantly different from each other at $P \leq 0.05$

N100= 476 kg N ha⁻¹ (conventional N application); N-16.67= 395 kg N ha⁻¹ (16.67% reduced N rate); N-33.33= 317 kg N ha⁻¹ (33.33% reduced N rate); N-50= 238 kg N ha⁻¹ (50% reduced N rate); N-100= 0 kg N ha⁻¹ (100% reduced N rate)

Table 2: Effect of reduced doses of nitrogen application on SPAD Value of cotton leaves at the full boll stage

Treatments	SPAD Value cotton leaves		
	2015	2016	2017
N100	50.44 ± 0.64 c	50.87 ± 30.53b	51.23 ± 0.89c
N-16.67	58.51 ± 0.37 a	58.70 ± 0.51 a	59.00 ± 0.72 a
N-33.33	57.27 ± 0.15b	57.32 ± 0.14 a	57.31 ± 0.37b
N-50	43.71 ± 0.71d	42.97 ± 0.60c	43.28 ± 1.08d
N-100	35.97 ± 0.37e	36.86 ± 1.60d	35.63 ± 0.72e

Mean ± standard deviations followed by different lowercase letters in the same column are significantly different from each other at $P \leq 0.05$

N100= 476 kg N ha⁻¹ (conventional N application); N-16.67= 395 kg N ha⁻¹ (16.67% reduced N rate); N-33.33= 317 kg N ha⁻¹ (33.33% reduced N rate); N-50= 238 kg N ha⁻¹ (50% reduced N rate); N-100= 0 kg N ha⁻¹ (100% reduced N rate)

Table 3: Effect of reduced doses of nitrogen application on total N content of cotton plant at the full boll stage

Treatments	Total N content of cotton plant (g kg ⁻¹)		
	2015	2016	2017
N100	39.69 ± 0.54a	27.36 ± 0.73a	27.38 ± 0.19a
N-16.67	37.13 ± 0.68b	24.68 ± 0.60b	26.33 ± 0.13b
N-33.33	32.47 ± 1.17c	21.52 ± 0.67c	22.95 ± 0.73c
N-50	23.24 ± 0.65d	15.71 ± 0.59d	14.96 ± 1.20d
N-100	19.90 ± 0.81e	13.02 ± 0.51e	12.95 ± 0.85e

Mean ± standard deviations followed by different lowercase letters in the same column are significantly different from each other at $P \leq 0.05$

N100= 476 kg N ha⁻¹ (conventional N application); N-16.67= 395 kg N ha⁻¹ (16.67% reduced N rate); N-33.33= 317 kg N ha⁻¹ (33.33% reduced N rate); N-50= 238 kg N ha⁻¹ (50% reduced N rate); N-100= 0 kg N ha⁻¹ (100% reduced N rate)

In this study, a three-year experiment (2015–2017) was conducted to determine the relationship between the reducing N fertilizer application and cotton yield in South Xinjiang of China, and soil NO₃⁻-N content and plant N status were also evaluated. The results showed that the content of NO₃⁻-N in soil decreased slightly when the reduction ratio of N fertilizer was in the range of 0–16.67%. When the reduction ratio of N fertilizer exceeded 33.33%, the content of NO₃⁻-N in soil decreased rapidly (Table 1). This result agrees with those observed by Qin *et al.* (2019), who demonstrated that the NO₃⁻-N contents in soil were decreased significantly when the N fertilizer reduction exceeded 40%.

The SPAD value of cotton leaves increased significantly when the N application rate was reduced by 16.67 and 33.33% and decreased significantly when reducing N use exceeded 33.33%. At the same time, the total N content of cotton plant decreased significantly with the increase of the proportion of N fertilizer reduced (from 16.67 to 33.33%, and 50 to 100%) (Tables 2 and 3). Previous studies have reported that N application reduction rate of 20% compared to the conventional N application (300 kg ha⁻¹) could increase

the N uptake of cotton stems and leaves, whereas the N uptake of cotton bolls decreased significantly (Qin *et al.* 2019). This indicates that excessive reducing N application would reduce the external source of N required for normal growth of cotton. This might result in yield loss, which makes it difficult to achieve both economic benefit and environmental safety (David *et al.* 2017; Martina *et al.* 2018; Abbas *et al.* 2020).

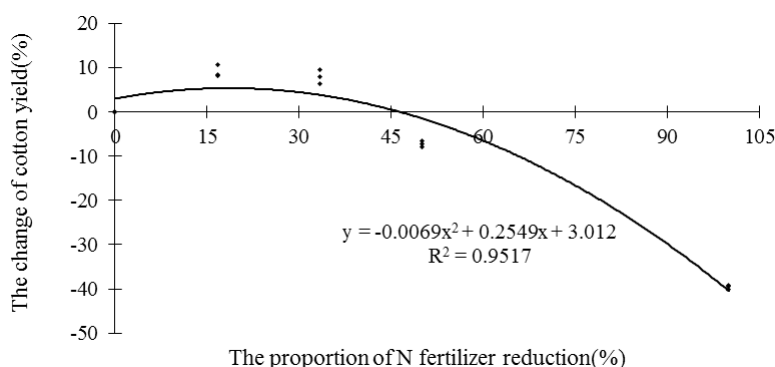
Previous studies have also shown that reducing N fertilizer application is beneficial to the growth of cotton at a later growth stage and promotes the dry matter accumulation of cotton at a later growth stage (Faiyad *et al.* 2019). Remy *et al.* (2009) reported that when the N application rate was reduced from the conventional 402.5 to 195.5 kg ha⁻¹, the boll number of cotton increased significantly and the yield of cotton was improved. Therefore, proper reduced N application was beneficial to coordinate the balance between vegetative growth and reproductive growth of cotton, improve the dry matter accumulation, and increase the boll number and yield of cotton. In this study, cotton yield increased by 9.2 and 7.9%, respectively, when the N application rate decreased from a conventional level of 476 to 395 and 317 kg ha⁻¹, respectively. However, cotton yield

Table 4: Effect of reduced doses of nitrogen application on seed cotton yield

Treatments	Seed cotton yield (kg ha ⁻¹)		
	2015	2016	2017
N100	6065.14 ± 32.01b	6087.95 ± 61.13c	6162.78 ± 52.34b
N-16.67	6563.51 ± 24.70a	6739.10 ± 29.27a	6688.66 ± 91.32a
N-33.33	6545.19 ± 41.09a	6665.54 ± 39.72b	6551.19 ± 45.84a
N-50	5672.49 ± 36.07c	5649.53 ± 43.54d	5677.44 ± 44.32c
N-100	3670.90 ± 17.03d	3708.46 ± 19.44e	3697.84 ± 37.25d

Mean ± standard deviations followed by different lowercase letters in the same column are significantly different from each other at $P \leq 0.05$

N100= 476 kg N ha⁻¹ (conventional N application); N-16.67= 395 kg N ha⁻¹ (16.67% reduced N rate); N-33.33= 317 kg N ha⁻¹ (33.33% reduced N rate); N-50= 238 kg N ha⁻¹ (50% reduced N rate); N-100= 0 kg N ha⁻¹ (100% reduced N rate)

**Fig. 1:** Relationship between N fertilizer reduction and cotton yield

decreased significantly when the N fertilizer reduction exceeded 50%.

The study of Chapepa *et al.* (2020) showed that N application rate reduction decreased the dry matter weight of cotton stems and leaves but increased the dry matter weight of cotton bolls. When the N application rate was reduced by 20%, cotton yield and N use efficiency was 24.5 and 8.9% higher than those of farmers' conventional fertilization treatment, respectively. In this study, the results of the functional relationship between N fertilizer reduction and cotton yield showed that the cotton yield reached its highest value when the N application rate was reduced by 18.47%, which consistent with the observation made by Chapepa *et al.* (2020). In this study, the N use efficiency of cotton under different N application reduction regimes was not involved. Therefore, it is not clear whether the N use efficiency can be improved by proper N application rate reduction. This aspect needs further investigation.

Conclusion

The results of three consecutive years of the experiment showed that reducing N application decreased the soil NO₃⁻-N content and the total N content of the cotton plant, while proper reduced N application increased the SPAD value of cotton leaves and seed cotton yield. Generally, when N application rate was reduced by 16.67 and 33.33%, the contents of NO₃⁻-N in soil and plant total N were decreased slightly, and leaf SPAD value and yield of cotton were increased significantly. The relationship between the N fertilizer reduction rate and cotton yield suggested that the N

application rate can be reduced by 18.47–45.50% without compromising the cotton yield in South Xinjiang of China.

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Author Contributions

TY and ZH planned the experiments, XW and HM interpreted the results, TY, ZH and XW made the write up and SP statistically analyzed the data and made illustrations.

References

- Abbas G, Z Fatima, M Hussain, S Hussain, Atique-ur-Rehman, N Sarwar, M Ahmed, S Ahmad (2020). Nitrogen rate and hybrid selection matters productivity of maize–maize cropping system under irrigated arid environment of southern Punjab, Pakistan. *Intl J Plant Prod* 14:309–320
- Ahmed SE, S Raza, AI Abdo, ZJ Liu, ZJ Chen, JB Zhou (2019). Budgeting nitrogen flows and the food nitrogen footprint of Egypt during the past half century: Challenges and opportunities. *Environ Intl* 130:1–11
- Babar A, KK Zilati, BM Zakaria, B Abdul, HT Trinh (2014). Review on materials & methods to produce controlled release coated urea fertilizer. *J Cont Rel* 181:11–21
- Benjamin D, M Cuntz, M Vohland, E Schulz, D Doktor (2017). Estimation of photosynthesis traits from leaf reflectance spectra: Correlation to nitrogen content as the dominant mechanism. *Remot Sens Environ* 196:279–292
- Chapepa B, N Mudada, R Mapuranga (2020). The impact of plant density and spatial arrangement on light interception on cotton crop and seed cotton yield an overview. *J Cotton Res* 3; Article 18

- David W, K Kirkman, N Hagenah, Z Tsvuura (2017). Soil respiration declines with increasing nitrogen fertilization and is not related to productivity in long-term grassland experiments. *Soil Biol Biochem* 115:415–422
- Faiyad RM, AG Bador, RE Mahdy (2019). Maximizing utilization of some organic fertilizers to produce the highest yield of cowpea. *Eur J Soil Sci* 59:53–66
- Li H (2000). *Principles and Techniques for Plant Physiology and Biochemistry Experiment*, Beijing Higher Education Press, Beijing, China (In Chinese)
- Li P, XB Qi, C Hu, ZJ Zhao, T Fan, XY Fan (2018). Influence of rhizosphere soil nitrogen supplying capacity of greenhouse tomato under different nitrogen rate with reclaimed water. *J Soil Water Conserv* 26:67–71 (In Chinese)
- Marenco R A, SA Antezana, HC Nascimento (2009). Relationship between specific leaf area, leaf thickness, leaf water content and SPAD-502 readings in six Amazonian tree species. *Photosynthetica* 47:184–190
- Martina M, C Luciano, M Alja, G Sorrenti, C Ciavatta, C Marzadori (2018). Changes in soil phenol oxidase activities due to long term application of compost and mineral N in a walnut orchard. *Geoderma* 316:70–77
- Minhas WA, M Hussain, N Mehboob, A Nawaz, S Ul-Allah, MS Rizwan, Z Hassan (2020). Synergetic use of biochar and synthetic nitrogen and phosphorus fertilizers to improves maize productivity and nutrient retention in loamy soil. *J Plant Nutr* 43:1356–1368
- Nan H, T Feike, H Back, HF Xiao, B Enno (2015). The effect of simple nitrogen fertilizer recommendation strategies on product carbon footprint and gross margin of wheat and maize production in the north China plain. *J Environ Manage* 163:146–154
- NBSPRC. 2019. China national statistical yearbook 2019. <http://www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm>
- Pilar MP, AMM Therese, AC Pablo, VSRG Vadakattu (2020). Combined nitrogen input from legume residues and fertilizer improves early nitrogen supply and uptake by wheat. *J Plant Nutr Soil Sci* 83:3–9
- Qian Y, L Alicia, C Kun, A Fabrizio, L Ulrike, BS Tek, B Frank, MS Clare, S Pete, JF Sun, GX Pen, H Jonathan (2018). Re-assessing nitrous oxide emissions from croplands across Mainland China. *Agric Ecosyst Environ* 268:70–78
- Qin YK, PC Li, CS Zheng, M Sun, S Liu, HL Dong, WX Xu (2019). Effects of nitrogen application rates on soil nitrogen content, nutrient uptake and utilization of cotton in low fertility fields. *Cotton Sci* 31:242–253 (In Chinese)
- Remy M, A Pacholski, C Frühauf, HJ Weigel (2009). Effects of free air carbon dioxide enrichment and nitrogen supply on growth and yield of winter barley cultivated in a crop rotation. *Field Crops Res* 110:185–196
- Resham T, C Amitava, A Rakesh, AM Devan, D Aaron (2016). Effect of enhanced efficiency fertilizers on nitrous oxide emissions and crop yields: A meta-analysis. *Soil Sci Soc Amer J* 80:1121–1134
- Ruth MHL, Q Ruijun, R Walter, S Peter, S Bernhard, MH Juan, N Christos (2020). Small-scale variation in nitrogen use efficiency parameters in winter wheat as affected by N fertilization and tillage intensity. *Sustainability* 12; Article 3621
- Seyed MRT, M Hamid, H Hossein, N Ghorban, D Farrokh (2020). Effect of chemical and compost fertilizers on yield and oil fatty composition of maize (*Zea mays* L) in delay planting date. *Commun Soil Sci Plant Anal* 51:15–20
- Solomon K, NK Karanja, FO Ayuke, J Lehmann (2019). Short-term influence of biochar and fertilizer-biochar blends on soil nutrients, fauna and maize growth. *Biol Fert Soils* 55:661–673
- Stuarta D, RL Scheweb, M McDermottc (2014). Reducing nitrogen fertilizer application as a climate change mitigation strategy: Understanding farmer decision-making and potential barriers to change in the US. *Land Use Pol* 36:210–218
- Suo JY, XW Ma, SF Gong, T Yang, XX Niu; BY Chen (2017). Variation characteristics of soil nitrogen and proper nitrogen rate in cotton field under mulch-drip irrigation. *Acta Agric Bor-Occident Sin* 26:738–744 (In Chinese)
- The National Bureau of Statistics of the People's Republic of China (NBSPRC) (2019). China statistical yearbook. China Statistics Press. Beijing, China (in Chinese)
- Uchino H, T Watanabe, K Ramu, KL Sahrawat, S Marimuthu, SP Wani, O Olto (2013). Calibrating chlorophyll meter (spad-502) reading by specific leaf area for estimating leaf nitrogen concentration in sweet sorghum. *J Plant Nutr* 36:1640–1646