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Original article

Customary fertilization rate decreases blueberry yields in southern China

Qilong Zeng[1], Jiguang Wei[1], Jiafeng Jiang[1], Chunfeng Ge[1], Gangqiang Dong[2], Yanqin Jiang[1], Hong Yu[1] and Liangliang Tian[1]

[1] Institute of Botany, Jiangsu Province and Chinese Academy of Sciences, Nanjing, China
[2] Amway (China) Botanical R&D Center, Wuxi, Jiangsu Province, China

Summary

Blueberry plantation area is expanding rapidly in China due to their high profits. However, there is a lack of knowledge on the fertilization for blueberry in China. In the study, a field experiment was executed in a commercial orchard of 6-year-old rabbiteye blueberry ('Brightwell') in 2017 and 2018, with four levels of compound fertilizer (N-P_2O_5-K_2O: 15-15-15): 0, 300, 450 or 600 g plant^{-1} year^{-1}. It was found that the yields in 2017 and 2018 were 14.8~17.4 kg plant^{-1} and 13.9~16.2 kg plant^{-1}, respectively. The lowest yield was obtained at 600 g treatment, whereas the yield of the 300 g treatment in 2017 and 2018 was the highest and increased by 17.6% and 16.5% compared to the 600 g treatment, respectively. No treatments had significant effect on fruit setting rate and single berry weight. In 2017 and 2018, titratable acid content of blueberry in 600 g treatment was the highest. Total soluble solid content of blueberry under the 300 g treatments was significant higher than other treatments in 2017, but there were no significant differences among treatments in 2018. Therefore, it was concluded that blueberry yield was highest by fertilizing with 300 g plant^{-1} year^{-1} without fruit quality decreasing, compared to the customary fertilization rate of 600 g plant^{-1} year^{-1}.

Keywords
fruit setting rate, nitrogen, nutrients, phosphorus, potassium, *Vaccinium ashei* Read.

Significance of this study

What is already known on this subject?

- China has become one of the major countries for blueberry production. However, growers apply fertilizers based on the experiences from other fruits; there is a lack of knowledge on the fertilization for blueberry in China.

What are the new findings?

- Customary fertilization rate (600 g plant^{-1} year^{-1} compound fertilizer) decreases blueberry yields and fruit quality; the optimal fertilization rate is suggested to be 300 g plant^{-1} year^{-1} compound fertilizer for mature rabbiteye blueberry plants in southern China.

What is the expected impact on horticulture?

- Findings of this study could enable commercial growers to decrease the fertilization rate and increase blueberry yields, which will reduce the costs of growers and increase their incomes, and, meanwhile, lower the risk of fertilizer loss.

Introduction

Blueberries (*Vaccinium* spp.) have been commercially grown for 18 years in China and the plantation area is expanding rapidly due to their health benefits and high profits (Yu et al., 2012; Li et al., 2017). Up to 2016, planting area and production of blueberries in China had reached 40,000 ha and 70,000 t, and accounted for 16.3% and 4% of the world, respectively (Brazelton et al., 2017). However, average yields in China were just one fifth of the average of top ten planting countries (Brazelton et al., 2017). The low average yields were mainly caused by the new fields being established recently, still without yields, inappropriate growing site, and grower's unfamiliarity with blueberry cultural practices (Yu et al., 2018). And improper application of fertilizer was also considered as one of the main reasons (Pang et al., 2012).

Blueberry is an oligotrophic plant according to the nutritional level of the whole plant; it has low nutrient requirements in comparison with many other fruit trees (Hanson and Hancock, 1996). However, the plant still needs regular application of fertilizers to maximize growth and fruit production (Bañados et al., 2012). Numbers of studies have been completed on the effect of fertilizer rate on the growth and yield of mature blueberry plants. It was found that blueberry requires 20–140 kg N ha^{-1} per season depending on the planting age, cultivars, location, soil type, and application method (Hanson, 2006; Bryla et al., 2010; Larco et al., 2013). And it was suggested to apply compound fertilizer (N-P_2O_5-K_2O: 10-10-10) when soil was not tested in Georgia, U.S.A. (Krewer and NeSmith, 1999). Excessive application of fertilizer has also been reported to prolong blueberry growth period, decrease yield, limit plant growth and even cause death (Krewer and NeSmith, 1999; Bryla et al., 2012). In China, there were few researches on managing blueberry nutrition (Li et al., 2009; Li et al., 2012; Jiao et al., 2017).

Growers usually applied fertilizers based on the protocol of other fruits, which always required more fertilizer than blueberry (Bryla and Strik, 2015). The application of fertilizer without guidelines has resulted in vigorous vegetative growth of blueberry or salt damage in China, based on our investigations. Therefore, a field experiment was carried out with the growers in the south of China, the major blueberry planting area, aimed to evaluate the grower fertilization practice and find the proper amount of fertilizer.

Materials and methods

Study site

In 2017, a 0.13 ha field of rabbiteye blueberry (*Vaccinium ashei* Read. 'Brightwell') was chosen with uniform canopy (2.2 m high, 2×2.2 m wide (in row × between rows)) from a commercial blueberry orchard. The field was located in Dushan town, Huangmei County, Hubei province, China (30°2'24"N, 116°4'21"E, alt. 37 m). The annual average temperature is 16.8°C, and the annual precipitation is 1,270 mm. The field was established in 2011 and 22 m^3 grounded pine bark was incorporated in the soil prior to planting. Soil is silt loam, soil pH is 4.8, and total nitrogen (N), available phosphorus (P) and potassium (K) is 1.01 g kg^{-1}, 0.97 mg kg^{-1} and 57.96 mg kg^{-1}, respectively. Plants were spaced at 2 m in the row (North-South direction) with 3.0 m between rows (1,667 plants ha^{-1}). Approximately another 22 m^3 grounded pine bark was applied on top of the rows as mulch immediately after planting. After the fourth year of planting, 600–800 g compound fertilizer (N-P_2O_5-K_2O, 15-15-15) was divided into three or four applications and applied to each bush at the beginning of March, April, May or August. And at blooming, honeybee hives were introduced to the field to facilitate pollination. Weeds between the rows were controlled by post-emergency herbicides. In winter, plants were pruned according to the orchard's own standard practice.

Experimental design

Four fertilizer treatments were allocated in a randomized complete block design, with three blocks consisting of six adjacent rows. Two adjacent rows were divided to allow for four treatment plots. Each treatment plot consisted of five measurement plants with one guard plant on either end. A guard row was planted on the east and west perimeter. Treatments consisted of a no-fertilizer control (0 g), three levels of fertilizer applied at 50, 75 and 100% of the rate used by the growers; they were 300 g, 450 g and 600 g per plant, respectively. Compound fertilizer (N-P_2O_5-K_2O, 15-15-15) was used. According to the method of growers, fertilizer was spot applied in three equal applications at bud break (the beginning of March), blooming (the middle of April), and after harvest (the beginning of August). The fertilizer spot was about 50 cm long, 20 cm wide, 15 cm deep, located at two sides of the row, close to the edge of canopy. All treatments received the same management during the experiments (2017 and 2018).

Yield and fruit quality measurements

1. Fruit setting rate. When most flowers were at stage 5 to 6 of development (Spiers, 1983), two bushes were selected from each treatment plot. Above 300 flowers were counted on 2–3 tagged shoots at the similar position and direction of each bush. Fruit setting rate was assessed by counting the number of fruit on the tagged shoots eight weeks after flowering, and divided by the total number of flowers.

2. Yields and single blueberry weight. In 2017-2018, all the bushes were harvested from late June to early August. All the fully ripe blueberries were hand-picked every week and weighted. And at the second picking, 100 blueberries were weighted for average single blueberry weight and stored in the 4°C for quality determination.

3. Total soluble solids content (TSS) and titratable acidity (TA). Twenty g blueberry was homogenized by a food blender (Philip, Shanghai, China). TSS was analyzed by a hand refractometer (Atago Co., Japan) on juice obtained by squeezing homogenized blueberries. For the determination of TA, a 2.5 g sample of homogenized blueberries was diluted with 50 mL distilled water. The TA was determined by neutralizing 0.1 mol L^{-1} NaOH solution to an end-point of pH 8.1. The TA was expressed as the percentage citric acid (mass/mass) on a fresh weight basis.

Leaf measurement

Leaves were sampled at the beginning of August, just after the harvest. About ten mature leaves located in the mid-portion of current season's shoots were collected from each plant in each plot, pooled as a replicate, oven-dried at 70°C and ground. The grounded samples were then digested in concentrated H_2O_2 and H_2SO_4 (analytical reagent). The N concentrations in the digested solution were determined by the micro-Kjeldahl method, P concentrations by the molybdate-blue method, and K concentrations by flame photometry (Zhu et al., 2016).

Soil measurement

Soil samples were taken from the top 30 cm of the row (mulch was removed) under each plant at the beginning of August. Each soil sample was combined by five soil cores from different locations, which were evenly distributed between the two fertilizer application sites. Then the samples in each treatment plot were pooled together, and air-dried in the house for 1–2 weeks. Then soil samples were passed through 2-mm and 0.25-mm mesh for available P, K and total N analysis, respectively. Total soil N was determined by the Kjeldahl method (Bremmer and Mulvaney, 1982). Soil available P and K were extracted according to Bray II and Mehlich 3 method (Larco et al., 2013), and determined by molybdate-blue method and flame photometry, respectively (Zhu et al., 2016).

Statistical analysis

All analyses were performed using SPSS 18.0. Any difference among the treatments was tested using one way analysis of variance (ANOVA) at $p<0.05$. A multiple correlation test was also performed to find out if there were significant correlations ($p<0.05$).

Results

The harvest season lasted for 7 and 6 weeks in 2017 and 2018, respectively (Figure 1). The yield per bush per week ranged from 0.54 kg to 4.03 kg in 2017 and from 0.47 kg to 2.57 kg in 2018, which peaked in the second and third picking week of 2017 and 2018, respectively. Total blueberry yield was not significantly influenced by fertilizer treatments in 2017 and 2018; the yields in 2017 and 2018 were 14.8~17.4 kg $bush^{-1}$ and 13.9~16.2 kg $bush^{-1}$, respectively (Figure 2). The lowest yield was obtained at the 600 g treatment, whereas the yield of the 300 g treatment in 2017 and 2018 was the highest, and increased by 17.6% and 16.5%, respectively, compared to the 600 g treatment. Meanwhile, the treatments had no significant effects on fruit setting rate and single berry weight in 2017 and 2018.

Single berry weight was 2.19~2.30 g in 2017 and 2.02~2.10 g in 2018. Fruit setting rate ranged from 58.7%~69.4% in 2017 and 45.4%~52.2% in 2018. Besides, there were no significant relationships between yields and fruit setting rate, yields and single berry weight in both years (Figure 3).

TSS was not significantly influenced by fertilizer treatments, ranged from 10.8 to 12 and 14.6 to 15.6 in 2017 and 2018, respectively (Figure 4). TA ranged from 0.33% to 40%

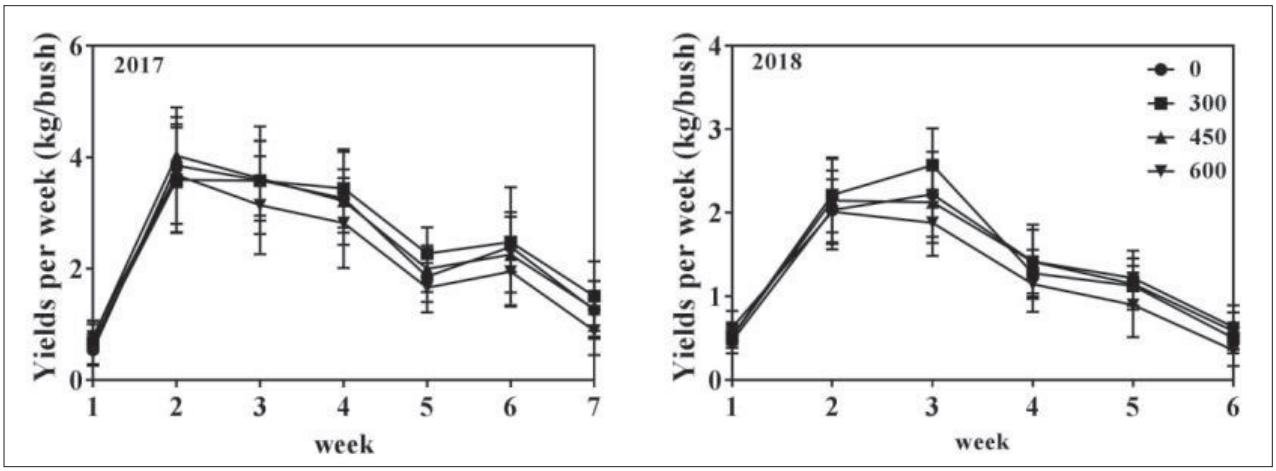


Figure 1. The yields of rabitteye blueberry 'Brightwell' receiving fertilizer rates in 0, 300, 450, 600 g plant^{-1} year^{-1} at each picking week in 2017 and 2018. Each point in the graph shows the mean ± standard deviation.

in 2017 and from 0.33% to 0.37% in 2018, which was significant higher in the 600 g treatment compared to other treatments in 2017, while no significant difference was observed in 2018. Similarly, TSS/TA ratio was not affected by the treatments in 2018, but TSS/TA ratio was significant lower in the 600 g treatment compared to other treatments in 2017.

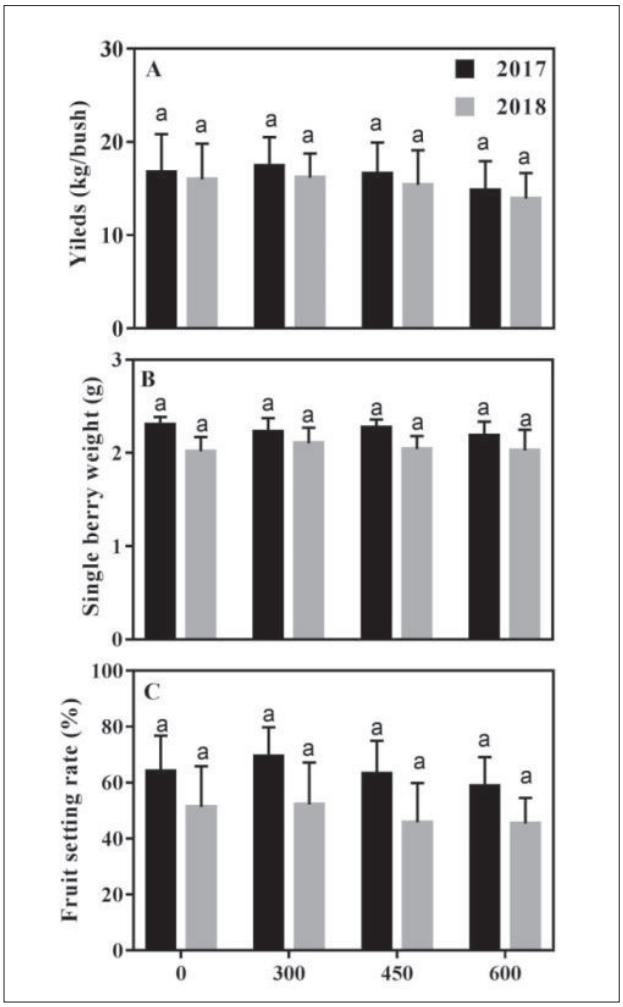


Figure 2. Effects of fertilizer rates on total yields (A), single berry weight (B) and fruit setting rate (C) of rabitteye blueberry 'Brightwell' in 2017 and 2018. Vertical bars indicate standard deviations. Different letters above the columns indicated the significant differences at $p < 0.05$.

Leaf N concentration ranged between 11.5~12.5 g kg^{-1} and 9.8~11.6 g kg^{-1} in 2017 and 2018, respectively (Figure 5). Leaf N concentration was significantly increased by fertilization in both years; however, it was not affected by fertilizer application rate. Leaf P concentration ranged between 1.36~1.56 g kg^{-1} and 1.49~1.52 g kg^{-1} in 2017 and 2018, respectively, which was not affected by the treatments. Leaf K concentration ranged between 4.35~4.70 and 3.60~4.43 g kg^{-1} in 2017 and 2018, respectively, which was also not affected by the treatments. Total N concentration in soils ranged between 1.68~1.94 g kg^{-1} and 1.75~2.56 g kg^{-1} in 2017 and 2018, respectively. Soil N was not affected by the treatments in 2017, while it was significant lower in the 450 g treatment compared to the 600 g treatment in 2018. Available P in soils ranged between 2.78~11.0 mg kg^{-1} and 3.88~6.93 mg kg^{-1} in 2017 and 2018, respectively. Soil available P in the 300 g and the 600 g treatment was higher than other treatments in 2017, while the highest available P was 300 g treatment in 2018. Soil available K ranged between 30.5~49.5 mg kg^{-1} and 30.9~69.3 mg kg^{-1} in 2017 and 2018, respectively. Soil available K was higher in the 600 g treatment compared to the 0 and the 450 g treatments in 2017, while it was higher in the 300 g treatment compared to other treatments in 2018.

There was no significant correlation between leaf N concentration and total N concentration in soil (Figure 6). Besides, Leaf P concentration was also not significantly correlated with available P in soil. Leaf K concentration was significantly negatively correlated with available K in soil.

Discussion

Fertilizer consumption by horticultural crops in China has grown strongly in the last decade (Chen et al., 2018). Fertilization has played a key role in improving the yields, while the agriculturally diffused pollution and the down grade of agro-products resulted from the over-use of fertilizers has become one of the top agricultural concerns in China (Xin et al., 2012). Numbers of studies have been carried out to reduce fertilizer application rate in fruits field (Wang et al., 2016; Lu et al., 2018; Li et al., 2019).

Blueberry is a new crop introduced to China in the 1980s, and there are still few fertilization guidelines based on trial to recommend for the growers. Compared to the recommended fertilizer rate on rabbiteye blueberry in Georgia (Krewer and NeSmith, 1999), the rates applied to rabbiteye blueberry by the growers was doubled or even higher according to our investigation. However, high rates of fertilizer

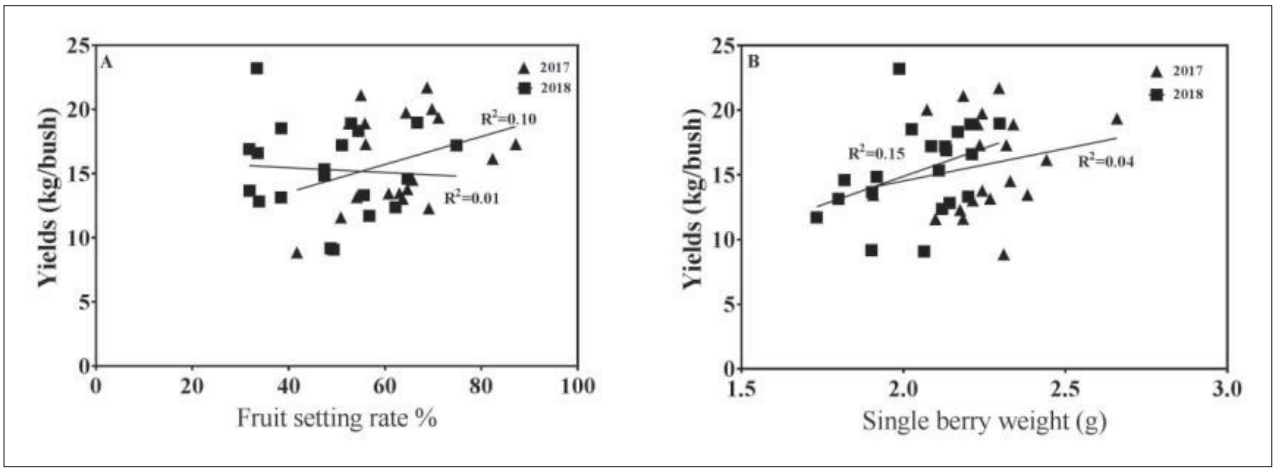


Figure 3. The relationship between yields and fruit setting rate (A), and single berry weight (B) of rabitteye blueberry 'Brightwell' in 2017 and 2018.

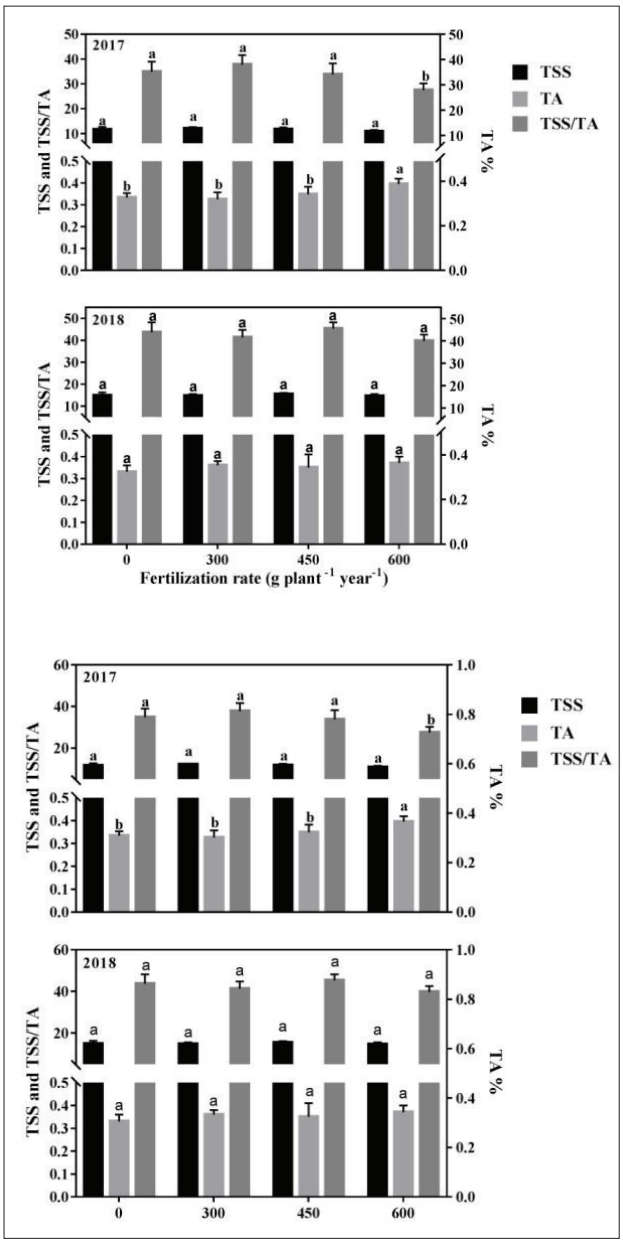


Figure 4. Effects of fertilizer rate on TSS, TA and TSS/TA of rabitteye blueberry 'Brightwell' in 2017 and 2018. Vertical bars indicate standard deviations. Different letters above the columns indicated the significant differences at $p < 0.05$.

did not increase blueberry yields, grower's fertilization rate tended to give the lowest yield (not significant) among the treatments in both years (Figure 2). The difference in yields were not significant clearly indicated that there was no benefit using the high fertilization rates. On the contrary, the 300 g treatment, half of the grower's fertilization rate, resulted in the highest yield during the experiments, although there were no significant differences. The results were similar to those of other researchers (Cumming, 1978; Bañados et al., 2012). It was reported that 3-years-old plants fertilized with high N rates (55.8 g) showed a lower biomass accumulation compared to the low N rates (Bañados et al., 2012). Clark et al. found that application of 67~134 kg N ha^{-1} reduced blueberry yield compared to the 22 kg N ha^{-1} treatment over two years (Clark et al., 1988). Bryla and Machado (2011) suggested that over-applied fertilizer resulted in high electrical conductivity (EC) in soil solution, which was detrimental to blueberry and reduced the yields. In our study the EC in the soils fertilized with 600 g were below 0.5 ds m^{-1} (data not shown), and plants fertilized with 600 g did not show any symptoms of salt stress. The lower yields in the 600 g treatment might be ascribed to the vigorous vegetative growth, which suppressed the development of flower buds (Hart et al., 2006). As there was no difference on fruit setting rates and fruit size among the treatments (Figure 2), the increase of yields in low fertilizer rate treatments were not a result of improved-fruit setting rates or fruit size (Figure 3).

In this study, the yield of no-fertilizer treatment was also higher than the 600 g fertilizer treatment. The result may be ascribed to sufficient nutrients in soil, since plants were applied too much fertilizer before the study. It was reported that mature blueberry just recovered only 32% of applied N in Michigan (Retamales and Hanson, 1989) and 22–43% in Oregon (Bañados et al., 2006). Some of the remaining N was still in the root zone (Retamales and Hanson, 1989). In fact, soil nutrients without fertilizer treatments were still relatively higher than some treatments (Figure 5). However, leaf N concentration of blueberry without fertilizer treatment was significant lower compared to fertilizer application treatments (Figure 5).

In this study, leaf N concentration was not increased with the fertilization rates, which was unlike other reports (Spiers, 1983; Bryla et al., 2012; Ehret et al., 2014). And leaf N concentration of most treatments in 2017 and all treatments in 2018 was below the limit of the recommended range (1.2~1.7%) in U.S.A. established by Krewer and NeSmith

(1999), while Leaf P and K concentrations were within the range each year, no matter the fertilization rates. Nutrients standards have been developed using results from research experiments and estimates from large databases that related tissue nutrients levels to high-yielding fields (Bryla and Strik, 2015). It was affected by the cultivars and growing locations (Hart et al., 2006). In fact, plants in this study showed a vigorous growth without any N deficiency symptoms in the

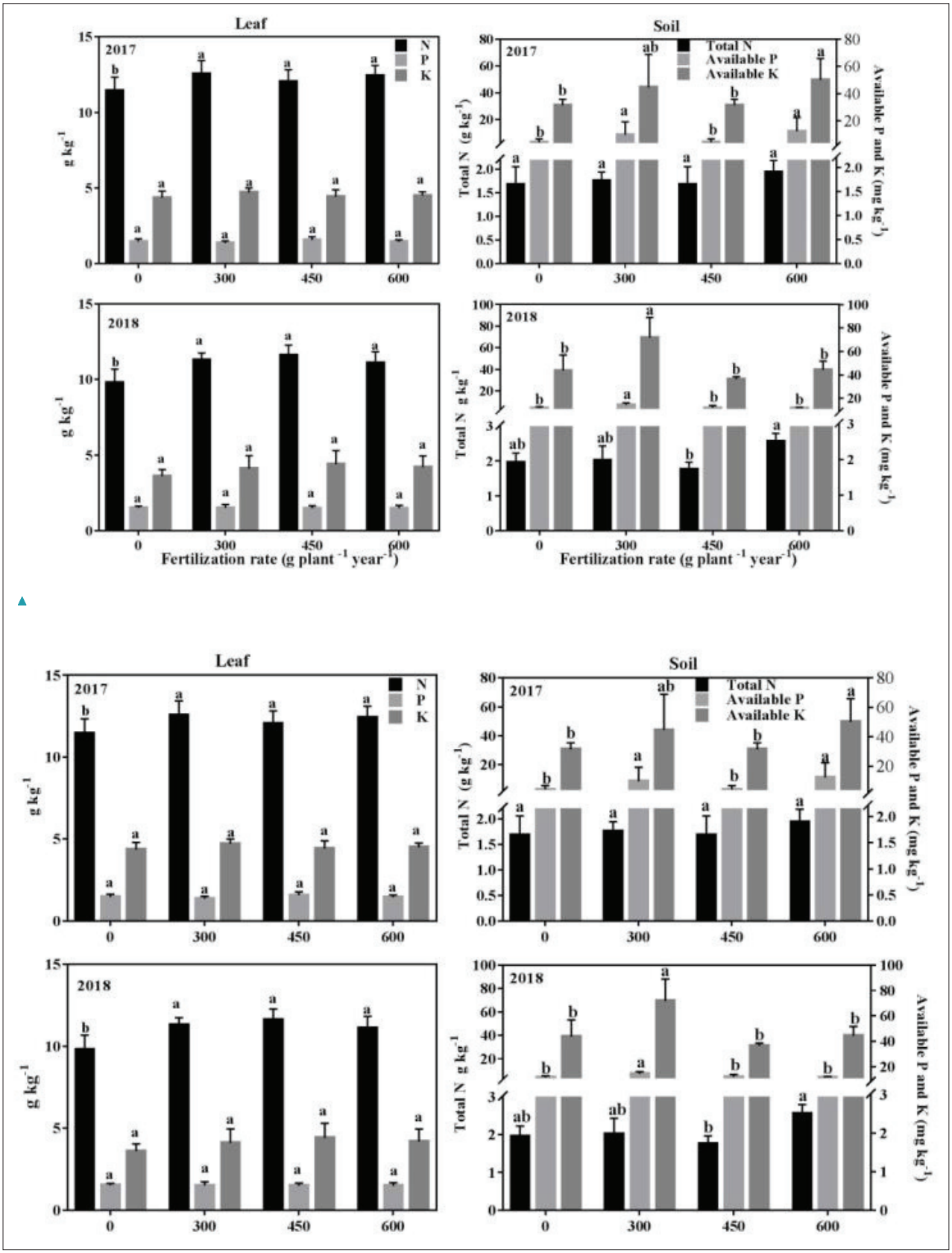


Figure 5. Effects of fertilizer rate on leaf N, P and K concentration of rabitteye blueberry 'Brightwell' and total N, available P and K of soil in 2017 and 2018. Vertical bars indicate standard deviations. Different letters above the columns indicated the significant differences at $p < 0.05$.

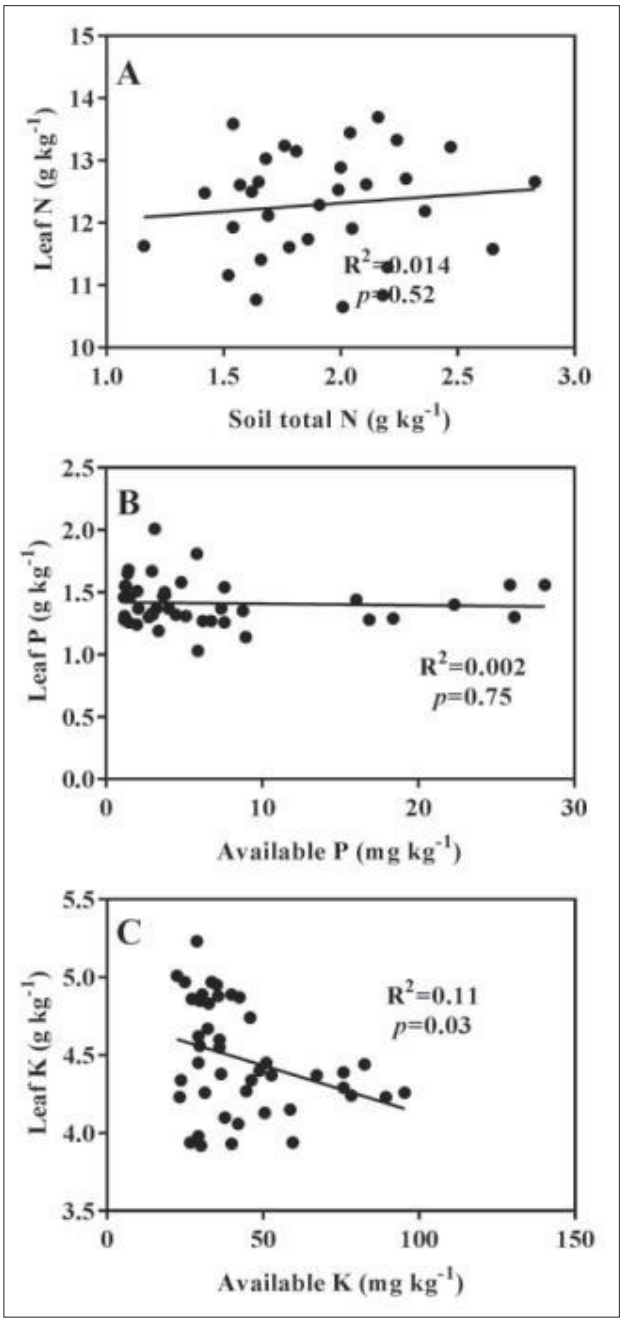


Figure 6. The relationship between leaf N and soil total N (A), leaf P and soil available P (B), leaf K, and soil available K (C).

field. Besides, the yields of all bushes were very high compared to other reports (Austin and Bondari, 1992; Lyrene, 2002). Therefore, the low N concentration of leaf in the study did not give N deficiency problems of blueberry, which was not adapted to the standard range of blueberry leaf nutrient levels of the U.S.A.

Messiga et al. (2018) reported that soil mineral nutrients were significantly increased by fertilizer rates in blueberry field. In this study, soil nutrients differed among the treatments, however, did not increase linearly with fertilization rates (Figure 5). The reason may be the fertilizer application method, since fertilizers were spot applied under the edge of the canopy. The application method concentrated nutrients, while soil sampling cores were evenly distributed under the canopy. Hart et al. (2006) found fertilizer concentrated application method complicated soil sampling and the interpretation of analysis results. Soil analysis results in blueberry could not always represent the accurate nutrients situations, soil and leaf samples will not have perfectly matching results (Pavlis, 2006). Similarly, leaf N and P concentration were not correlated with soil N and P concentrations in this study (Figure 6). It suggested that soil nutrients analysis was difficult to indicate nutrients situation of blueberry and recommend fertilizer application for growers in the application method.

TSS and TA play an important role in fruit quality. It has been reported blueberry TSS was affected by years, fertilizers and cultivars (Strik et al., 2017). Ehret et al. (2014) found that TSS and TA of blueberry were not affected by fertilization rates and application method. However, Jiao et al. (2017) reported that TSS was significantly increased by fertilizations, while there was no significant difference among the fertilization rates. In this study, TSS and TA were also not affected by the fertilization rates in both years, except the 600 g treatment increasing blueberry TA in 2017. It was suggested that low fertilization rate did not negatively impact blueberry qualities.

Conclusion

From results of the study could be concluded that the fertilizer rate used by growers was too high for blueberry production. Half of the growers' fertilization rate could increase the blueberry yields by 16.5~17.6% without fruit quality decreasing, which was also helpful to reduce planting costs and lower risks of fertilizer loss.

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Addresses of authors:
Qilong Zeng[1], Jiguang Wei[1], Jiafeng Jiang[1], Chunfeng Ge[1], Gangqiang Dong[2], Yanqin Jiang[1], Hong Yu[1] and Liangliang Tian[1,*]

[1] Institute of Botany, Jiangsu Province and Chinese Academy of Sciences, P.O. Box 1435, Nanjing 210014, China
[2] Amway (China) Botanical R&D Center, Wuxi, Jiangsu Province, 214115, China
* Corresponding author; E-mail: tl6132000@163.com
Tel.: 86-02584347048