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RESEARCH ARTICLE

Optimization of chemical fertilizer application for blueberry vegetative growth, fruit quality and soil condition

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ABSTRACT

Commercial cultivation of blueberry has rapidly expanded in China in recent years. However, suboptimal fertilization results in poor growth and management practices in blueberry orchards. The present study studied fertilization of southern highbush blueberry in southwest of China. We evaluated the effects of inorganic nitrogen, phosphorus, and potassium fertilizers at different doses. Plant vegetative growth, leaf photosynthesis parameters, fruit quality and soil nutrient contents were analyzed. Application of ammonium sulfate enhanced fruit weight, sweetness, and nutrient content, including vitamin C and anthocyanin contents. Comparison of P and K fertilizer treatments revealed that 30 g P/plant in combination with 30 g K/plant conferred superior plant growth and improved fruit sweetness and nutrient content. Using ammonium sulfate as the N source and monopotassium phosphate as the P and K source contributed to maintenance of soil acidity.

Keywords: Blueberry; Fertilizer; Fruit quality; Soil nutrient content; Vegetative growth

INTRODUCTION

Nitrogen (N), phosphorus (P) and potassium (K) together are three main elements acting as the essential plant nutrients for growth. Nitrogen is found in all plant cells, in plant proteins and hormones, and in chlorophyll. It promotes vegetative growth, and makes plant dark green and succulent (Gojon, 2017). Phosphorus helps to transfer energy from sunlight to plants and stimulates early root and plant growth, and hastens maturity. In practice, it promotes plant ripening, and improves the quality and yield of grain (Malhotra et al., 2018). Potassium increases vigor and disease resistance of plants. It helps to form and move starch, sugars and oils in plants, which is in favor of improvement of fruit quality (Çalişkan et al., 2017).

Blueberry plants prefer ammonium (NH_4^+) compared with nitrate (NO_3^-) as the N source. Accumulation of NH_4^+ renders the soil acidic (Alt et al., 2017), which is the favored soil pH for blueberry. Application of ammonium sulfate [$(NH_4)_2SO_4$] was recommended when the soil pH exceeds 5.0 (Hart et al., 2006). Highbush blueberry requires a N source at the rate of 25–100 $kg \cdot ha^{-1} \cdot year^{-1}$ for optimal growth and production (Chandler and Mason, 1942; Griggs and Rollins, 1947; Hanson, 2006; Hart et al., 2006). The plants absorb N most rapidly during the period from blooming to harvest (Throop and Hanson, 1997; Bañados, 2006). The application rate of N fertilizer affected biomass accumulation and allocation (Bañados et al., 2012). Nitrogen fertilizer significantly increased blueberry yields, while addition of P and K fertilizers had a quadratic effect on yield (Maqbool et al., 2016, 2017). A recommended P: K ratio of 1:1 (14 g P and 14 g K per plant) might lead to optimal plant growth, leaf physiological condition, and fruit yield and quality (Li et al., 2009).

Scientific research in China on blueberry was initiated in the early 1980s. In recent years, scale plating blueberry rapidly expanded in southwestern regions of China, and for now captured nearly 40 percent of all blueberry

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cultivating scale in China (Li et al, 2022). However, our personal investigation showed that management practices in blueberry cultivation require improvement. The urgent problem is suboptimal fertilization. For example, people usually tend to over use fertilizer and show a predilection for high nitrogen. These behaves prevented blueberry plant growth and more seriously was holding back blueberry industry development. Recently, a fertilization scheme on rabbiteye blueberry (*Vaccinium virgatum*), a hexaploidy, was reported (Guo et al., 2021), whereas the fertilization scheme on tetraploid highbush blueberry (*Vaccinium corymbosum*), the type most cultured in China, is scarce. For the purpose to promote blueberry-cultivating standard, especially for the cultivation in southwest of China, we studied the effects of different concentrations of inorganic fertilizers providing the three major plant macro-elements, i.e., N (ammonium sulfate), P (monopotassium phosphate), and K (monopotassium phosphate and potassium sulfate). The objective of the present study was to establish a referential fertilization scheme for blueberry orchards in southwestern China to promote stable and sustainable development of the blueberry industry.

MATERIALS AND METHODS

Study site and plant materials

The experiment was conducted in the Sichuan Agricultural University's cooperative research blueberry orchard (Annex 1) on Nanbao Mountain (30°43' N, 103°22' E) at Qionglai, Chengdu city, Sichuan Province, China. The altitude of the site is 1350 m and the average temperature is 14.3 °C. The southern highbush blueberry (*Vaccinium corymbosum* cv. O'Neal) was used in the study. In 2020, the plants fruited for the fourth year. Plants were spaced 2 m × 1 m apart.

Experimental design and treatments

Two dependent experiments were performed: a N fertilizer test, and a P fertilizer plus K fertilizer (P × K) test. The experimental designs were explicated in Table 1 and 2. For each experiment, six biological repetitions were set up.

Indicators determination

Mature fruit were harvested on 16 July, 2020. Fruit quality indicators including anthocyanin content (Gündüz et al., 2014) were determined. Plant vegetative growth indicators were measured from the beginning of fertilizing treatment to fruit harvest. The photosynthetic capacity of leaves was analyzed using portable photosynthesis apparatuses (Li-6400x, LI-COR Inc., Lincoln, NE, USA). Soil samples (0–30 cm depth) were collected when fruits were harvested (16 July, 2020). Soil quality indicators were measured using Bao's methods (Bao, 2000).

Statistical analysis

One-way analysis of variance (ANOVA) and the Student–Newman–Keuls *q* test were performed at the 5% significance level with IBM SPSS Statistics 19.0 software (IBM Corporation, Armonk, NY, USA). Contrast analyses were used to separate the interactions.

RESULTS

Fruit quality

A trend for elevation in single fruit weight with increase in amount of N fertilizer applied was observed (Table 3). All N fertilizer treatments significantly increased TSS content compared with that of the control treatment ($P < 0.05$; Table 3), but for all N fertilizer treatments, the TSS content did not differ significantly. Treatment N2 resulted in higher WSS content (11.56 ± 0.09%) than those of the other N fertilizer treatments and CK(N) ($P < 0.05$; Table 3). The TA contents were similar among the N fertilizer treatments and CK(N) (Table 3). The lowest Vc content was observed in the CK(N), and the highest Vc contents were recorded in treatments N2 and N3. The lowest anthocyanin content was observed in the CK(N), and all N fertilizer treatments showed significantly higher anthocyanin contents than that of the CK(N) ($P < 0.05$; Table 3).

In the P × K fertilizer test, P1K3, P2K1, P2K2, and P2K3 treatments significantly promoted single fruit weight ($P < 0.05$; Table 3). The highest dose of P (i.e., P2K1, P2K2,

Table 1: The design of N fertilizer test.

Treatment code	N dose (g)
CK (N)	0
N1	7
N2	10
N3	13

Ammonium sulfate [$(NH_4)_2SO_4$, N ≥ 21%] was the nitrogen source, which was incorporated 2 weeks before bud burst (25 February, 2020). Sulfur-based compound fertilizer (15N–15P_2O_5–15K_2O) 100g was applied 20 d after flowering until fruiting (30 April, 2020), for three times.

Table 2: The design of P×K fertilizer test.

Treatment code	P dose (g)	K dose (g)
CK (PK)	0	0
P1K1	15	15
P1K2	15	30
P1K3	15	45
P2K1	30	15
P2K2	30	30
P2K3	30	45

Note: Monopotassium phosphate (KH_2PO_4, P_2O_5 ≥ 52%, K_2O ≥ 34%) was the phosphorus source. Potassium sulfate (K_2SO_4, K_2O ≥ 54%) was the potassium source. The six treatments were applied 20 d after flowering until fruiting (30 April, 2020), for three times. For nitrogen-balance, 70 g $(NH_4)_2SO_4$ was applied on the same data and 2 weeks before bud burst in both six treatments and the control.

Table 3: Fruit quality in in N and P×K fertilizer tests.

Treatment code	Single fruit weight (g)	Total soluble solids (°Brix)	Water-soluble sugars (%)	Titratable acid (%)	Vitamin C (mg/g·FW)	Total anthocyanins (mg/g·FW)
CK (N)	2.03±0.06c	8.30±0.35c	3.36±0.09a	10.03±0.80a	0.34±0.02d	0.56±0.01c
N1	2.19±0.06b	9.77±0.15a	3.44±0.64a	11.57±1.52a	0.40±0.01c	0.74±0.06b
N2	2.38±0.09a	9.75±0.07a	4.25±0.09a	11.03±0.31a	0.54±0.01a	0.89±0.01a
N3	2.39±0.05a	9.45±0.07a	3.59±0.75a	12.13±3.88a	0.50±0.01b	0.79±0.03b
CK (PK)	2.11±0.07c	9.03±0.12d	4.29±0.82bc	6.95±0.35d	0.37±0.01c	0.71±0.04b
P1K1	2.11±0.16c	9.45±0.07c	5.90±0.79ab	7.40±0.57cd	0.41±0.02bc	0.79±0.01b
P1K2	2.21±0.12bc	9.47±0.12c	3.21±1.04c	8.23±0.32bc	0.39±0.01c	0.85±0.02b
P1K3	2.43±0.11ab	9.73±0.15c	4.06±0.62bc	8.75±0.35b	0.43±0.04bc	0.98±0.01b
P2K1	2.50±0.08a	10.50±0.14b	6.73±0.30a	10.6±0.14a	0.59±0.02a	1.01±0.08b
P2K2	2.46±0.10a	11.43±0.23a	4.49±0.27bc	11.35±0.49a	0.46±0.02b	1.30±0.18a
P2K3	2.38±0.01ab	10.33±0.15c	3.74±0.30bc	9.25±0.35b	0.37±0.02c	0.95±0.14b

CK (N): the control treatment in N fertilizer test. CK (PK): the control treatment in P×K fertilizer test. The treatment codes are indicated in Table 1 and 2.

and P2K3) increased the TSS content effectively compared with that of the lower P fertilizer dose (i.e., P1K1, P1K2, and P1K3). The WSS content in all other P × K fertilizer treatments was not significantly different from that of the CK(PK) (Table 3). All P × K fertilizer treatments increased TA content (Table 3). The highest dose of P fertilizer increased the TA content effectively compared with that of the lowest dose of P fertilizer. The highest dose of P fertilizer resulted in higher fruit anthocyanin content than that under the P1 fertilizer dose (Table 3).

Vegetative growth

All N fertilizer treatments resulted in greater plant height increment than that of the control CK(N). The greatest increment in plant height was observed in the treatment N2 (Table 4). The canopy width increment in the N2 and N3 treatments was greater than that of CK(N) plants (Table 4). Stem diameter increment in the N3 treatment (4.3 ± 2.5 mm) was significantly higher than that of all other N fertilizer treatments and the control ($P < 0.05$; Table 4).

All P × K fertilizer treatments promoted plant height increment compared with that of the control CK(PK) (Table 4). Treatments that incorporated the highest dose of P fertilizer (P2K1, P2K2, and P2K3) resulted in greater plant height increment than that with the lower P dose (P1K1, P1K2, and P1K3). Plants treated with P2K2 showed the best increased plant height. All P × K fertilizer treatments showed a remarkably increased canopy width compared with that of the CK(PK) (Table 4). Rapid increase in canopy width was observed in the treatment P2K2. Treatments that included the highest K dose (P1K3 and P2K3) stimulated greater growth in canopy width (Table 4). The stem diameter increment was greatest in the treatment P2K1 (Table 4).

Photosynthesis indices

Among the N fertilizer treatments, N3 stimulated the highest NPR, which was significantly higher than that of

Table 4: Vegetative growth in N and P×K fertilizer tests.

Treatment	Height increment (cm)	Canopy Width (cm)	Stem diameter increment (mm)
CK (N)	9.5±0.7b	28.0±1.4a	2.43±0.09b
N1	13.0±1.4ab	27.0±2.8a	1.69±0.16c
N2	17.5±2.1a	30.5±0.7a	1.25±0.14d
N3	14.5±2.1ab	32.0±1.4a	4.35±0.25a
CK (PK)	15.0±2.8c	12.5±2.1d	2.48±0.09ab
P1K1	15.7±2.1bc	25.0±5.6bc	2.70±0.41ab
P1K2	22.3±4.0abc	17.0±4.2cd	2.66±0.43ab
P1K3	22.0±1.4abc	29.5±0.7ab	2.22±0.12b
P2K1	25.0±1.4ab	21.5±0.7bcd	3.03±0.45a
P2K2	27.7±4.7a	37.0±2.8a	2.22±0.20b
P2K3	24.3±2.9abc	31.0±2.6ab	2.00±0.04b

CK (N): the control treatment in N fertilizer test. CK (PK): the control treatment in P×K fertilizer test. The treatment codes are indicated in Table 1 and 2.

the control CK(N) plants ($P < 0.05$; Table 5). All N fertilizer treatments increased SC above that of the CK(N) (Table 5). The leaf C_i in the N3 treatment was slightly lower than that of the control and other N fertilizer treatments (Table 5). The TR was increased in all N fertilizer treatments (Table 5).

In the P × K fertilizer treatments, NPR was improved to a certain degree compared with that of the control CK(PK). The P2K1 treatment resulted in the highest NPR (Table 5). All P × K fertilizer treatments conferred greater SC compared with that of the control; the greatest SC was recorded in the treatment P1K3 (Table 5). The C_i in the P2K2 treatment was depressed compared with that of the control, but no significant differences in C_i were observed (Table 5). Distinct increment in the TR of all P × K fertilizer treatments compared with that of the control was observed (Table 5).

Soil nutrient contents

The soil pH values were depressed in all N fertilizer treatments compared with that of the control CK(N) (Table 6). The OM content was increased in treatment N3

Table 5: Photosynthesis indices in N and P×K fertilizer tests.

Treatment	Net photosynthesis rate (μmol·m⁻²/s)	Stomatal conductance (μmol·m⁻²/s)	Intercellular CO_2 concentration (μmol·m⁻²/s)	Transpiration rate (μmol·m⁻²/s)
CK (N)	9.36±0.97b	0.156±0.012a	240.71±48.69a	1.435±0.033a
N1	11.38±1.49ab	0.185±0.007a	241.30±42.60a	1.677±0.475a
N2	10.86±0.68ab	0.187±0.024a	249.60±47.87a	1.459±0.302a
N3	12.25±1.12a	0.184±0.028a	188.26±12.33a	1.533±0.054a
CK (PK)	9.62±0.98b	0.114±0.019d	242.51±28.04a	1.390±0.015b
P1K1	11.17±2.13ab	0.243±0.047ab	250.65±30.74a	1.632±0.359b
P1K2	9.90±1.43ab	0.191±0.049bc	254.24±26.12a	1.928±0.440ab
P1K3	12.52±1.14ab	0.281±0.054a	247.82±19.97a	2.355±0.303a
P2K1	13.23±0.27a	0.209±0.007bc	271.07±12.11a	1.836±0.225ab
P2K2	10.74±2.33ab	0.140±0.031cd	137.91±18.61a	1.717±0.081b
P2K3	11.75±0.95ab	0.171±0.013bcd	258.56±33.18a	1.996±0.419ab

CK (N): the control treatment in N fertilizer test. CK (PK): the control treatment in P×K fertilizer test. The treatment codes are indicated in Table 1 and 2.

Table 6: Soil nutrient contents in N and P×K fertilizer tests.

Treatment	pH	Organic matter content (g/kg)	Available nitrogen content (mg/kg)	Available phosphorus content (mg/kg)	Available potassium content (mg/kg)
CK (N)	4.511±0.803a	6.33±1.22b	31.44±5.17a	46.55±1.83a	221.49±17.97a
N1	4.279±0.075a	6.36±0.58b	28.63±1.70a	24.19±5.30b	307.43±89.33a
N2	4.277±0.426a	6.16±0.63b	29.42±7.16a	28.87±5.52b	317.34±40.33a
N3	4.306±0.524a	9.25±1.70a	20.91±1.73a	34.39±5.61b	239.67±28.18a
CK (PK)	4.505±0.969a	10.81±0.43a	16.05±2.29c	20.62±3.31a	56.23±4.12c
P1K1	4.501±0.252a	10.15±1.63a	16.36±3.33c	21.95±2.02a	128.90±9.96bc
P1K2	4.350±0.483a	10.96±1.63a	13.39±0.60c	20.48±1.17a	138.00±22.12bc
P1K3	4.116±0.417a	11.10±0.90a	13.30±2.35c	25.87±3.79a	118.20±11.39bc
P2K1	4.294±0.807a	6.79±0.63b	28.23±7.24ab	32.50±9.20a	193.40±39.17b
P2K2	4.282±0.792a	8.90±036a	23.59±2.24bc	26.28±2.92a	347.00±69.94a
P2K3	4.212±1.337a	5.84±0.75b	34.25±7.94a	30.20±6.57a	314.00±58.96a

CK (N): the control treatment in N fertilizer test. CK (PK): the control treatment in P×K fertilizer test. The treatment codes are indicated in Table 1 and 2.

after fruit harvest (Table 6). The soil available N contents in all N fertilizer treatments were less than those of the control; the lowest N content was observed in the treatment N3 (Table 6). Similarly, the soil available P content in all N fertilizer treatments was lower than that of the control (Table 6). The soil available K content in all N fertilizer treatments were higher than those of the control, and was significantly different in the N1 and N2 treatments (Table 6).

All P × K fertilizer treatments decreased the soil pH value compared with that of the control. The highest K fertilizer treatments, P1K3 and P2K3, conferred a lower soil pH. The OM content under treatment with the highest P fertilizer amount (P2K1, P2K2, and P2K3) was significantly lower than that of the lower P fertilizer dose (P1K1, P1K2, and P1K3) and the control (Table 6). In contrast, the soil available N content in treatments with the highest P fertilizer amount, regardless of the amount of K fertilizer applied, were significantly higher than that of the lower P fertilizer dose and the control (Table 6). All P × K fertilizer applications increased the available P and K contents in the soil after fruit harvest, and the highest P fertilizer dose induced higher available P and K contents in the soil (Table 6). The highest P fertilizer dose in combination with the highest K fertilizer dose, i.e., P2K2 and P2K3, resulted in higher soil available K content after fruit harvest (Table 6).

DISCUSSION

Application of ammonium sulfate as the N source significantly influenced the chemical composition of the substrate, nutrient content of leaves, vegetative growth, and fruit yield and quality of blueberry (Leitzke et al., 2015). In the present assessment of N fertilizer treatments, 25 g N/plant stimulated the greatest increase in plant height, and 28 g N/plant induced the greatest increment in stem diameter. In addition, the nutrient content of fruit from N fertilizer-treated plants, including Vc and anthocyanin contents, was higher than that of the control fruits. In the P × K fertilizers comparison, treatment with 30 g P/plant in combination with 30 g K/plant conferred optimal plant growth, e.g., greatest increments in plant height and canopy width. The greatest increment in stem diameter was achieved with application of 30 g P/plant in combination with 15 g K/plant. A P: K ratio of 2:1 or 2:2, i.e., 30 g P/plant in combination with 15 or 30 g K/plant, was beneficial to improve fruit sweetness and nutrient content.

In the present study the optimal photosynthesis parameters were observed in treatment N3 among the N fertilizer treatments. In the P × K fertilizer experiment, it was apparent that the treatment P: K ratio of 2:2 significantly increased the photosynthesis parameters. Plants subjected to 38 mmol/L N in hydroponic solution, which provides excessive N, showed the minimum values for photosynthesis parameters (Yanez-Mansilla et al., 2014). Thus, appropriate fertilizer application has positive effects on photosynthesis parameters with decreased risk of excessive soil electrical conductivity (Li et al., 2011; Messiga et al., 2018).

The present results showed that the soil pH was depressed in all ammonium sulfate N fertilizer treatments compared with that of the control, which was attributed to the positive effects of NH_4^+ accumulation on increasing H^+ concentration. Similar results were observed by previous report (Messiga et al., 2018). The soil N concentration at 0–30 cm soil depth after fruit harvest in the N fertilizer treatments was little depressed compared with that of the control soil in the present study. A possible explanation is that plant vegetative growth and fruit development caused vigorous consumption of N from both the primary soil and the fertilizer. Similar observations were reported previously (Bryla and Machado, 2011; Yan et al., 2018; Xiang et al., 2019). Phosphorus moves extremely slowly through the soil profile (Weil and Brady, 2017), which might be the reason, in the present research, for higher amounts of residual P in soil treated with P fertilizer than in the control soil, and the soil residual P content was increased in response to the highest dose of P fertilizer. With regard to blueberry, we therefore recommend applying the higher amount of monopotassium phosphate (58 g/plant) as a source of P and K.

CONCLUSIONS

The present study confirmed that ammonium sulfate was the effective N element to enhance fruit weight, sweetness, and nutrient content, including vitamin C and anthocyanin contents. The P element of 30 g/plant in combination with 30 g K/plant conferred superior plant growth and improved fruit sweetness and nutrient content. From the soil quality analysis, the present used sources of macro-elements, ammonium sulfate (N source) and monopotassium phosphate (P and K sources), were proved to maintain soil acidity. The present study provided a referable fertilizing programme for southern highbush blueberry cultivation.

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