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# The Developing Blueberry Industry in China

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## Abstract

The present situation of blueberry industry in China was summarized. The six main blueberry cultivation areas in China were reviewed and practical suggestions were made. Reference and guidance for water management of rabbiteye blueberry in Yangtze river basin was provided, and water physiological characteristics and water requirement of blueberry were also clarified so as to provide scientific management of blueberry. Effects of vinegar residue on soil physical and chemical properties, enzymatic activities, growth of blueberry, nutrient uptake, and fruit quality were studied. The effect of vinegar residue on the growth of blueberry and the mechanism revealed from the perspective of soil amelioration were also discussed from the results.

**Keywords:** blueberry, China, cultivation, water management, vinegar residue

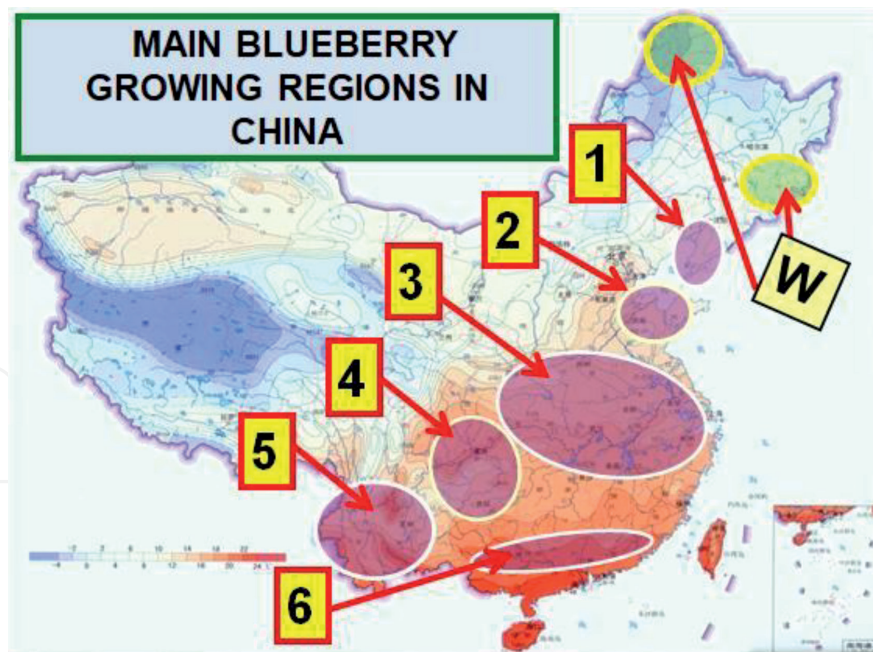
## 1. An overview of blueberry growing areas in China

There are 91 species, 24 subspecies of *Vaccinium* L., which distributed all over the country. Among them, *V. uliginosum* L. and *V. vitis-idaea* L. are used as raw materials for making jam and juice in Northeast China for a long history. The young leaves of another species, *V. bracteatum* Thunb., distributed widely in southern China, has been used as raw material for making “black rice,” a traditional health-care food, since Han dynasty about 2000 years ago. The cultivated blueberry industry in China, mainly soil cultivation, was established on the basis of introduced cultivars from abroad.

### 1.1 Current situation of blueberry cultivation in China

Blueberry varieties were first introduced from Northern America and Europe by Jilin Agricultural University and Institute of Botany, Jiangsu Province and Chinese Academy of Sciences in the middle of the 1980s, respectively. The expansion of commercial growing has been conducted since the beginning of the twenty-first century, and the growing areas have been developed rapidly, reaching 40,000 hm<sup>2</sup> so far. According to the characters of blueberry growing areas from north to south, six regions could be classified as follows (**Figure 1**):

1. Liaodong peninsula region, protected cultivation mainly
2. Shandong peninsula region, for fresh fruits mainly and processing as well



**Figure 1.** Main blueberry growing areas in China. W, wild blueberries mainly; 1, Liaodong peninsula region; 2, Shandong peninsula region; 3, Changjiang River basin region; 4, Guizhou and Sichuan region; 5, Yunnan region; 6, South China region.

3. Changjiang (Yangtze) river basin region, for both processing and fresh fruits
4. Guizhou and Sichuan region, for processing mainly and fresh fruits also
5. Yunnan region, for extremely early market and dual purpose fruits
6. South China region, the newly forming region for fresh fruits

It seems that there has greater potential in the latter four southern regions, especially the Changjiang river basin region. Accordingly, because of the different ecological characteristics of every region, the appropriate varieties were different.

#### 1.1.1 Liaodong peninsula region, Liaoning province

The climate of this region is temperate continental monsoon type, with many rainy days in summer, abundant sunshine, and frost free for 168–180 days. Slightly acidic and sandy loam is the main soil type, which is suitable for blueberry cultivation. The cultivation patterns include open field, cold shed, and greenhouse culture.

Varieties of open-field culture are “Blomidon,” “Bluecrop,” and “Duke.” Harvest time is from early July to late August, which is the latest ripening time in China. Both freezing damage and drought are the main ecological limiting factors in winter and spring. Plants must be put down and covered by soil to prevent cold and drought in winter. This measurement is barely feasible for young trees, and it is quite hard for adult plants to maintain high and stable yields. Sometimes fruit quality could be reduced by the continuous rainy days during the harvesting period.

Protected culture cannot only overcome those shortcomings of open-field culture but could also be used for forcing culture. As lower temperature usually comes early in autumn and sunshine is abundant in spring, forcing culture is a strategic choice for early harvest. But there would also be series of problems of culture techniques, facilities, and high management cost needed to be solved. Early maturing southern highbush varieties, such as “Misty,” are cultivated for pursuing high profit,

which could be harvested in mid-late March of the next year as the temperature in greenhouse could warm up in mid-November of the previous year. However, due to the development of early ripening fresh fruit in Yunnan and blueberry facility cultivation in Shandong, blueberry industry in this area has great competitive pressure.

### *1.1.2 Shandong peninsula region, Shandong province*

This region is typical of the warm monsoon climate with slightly acidic to neutral sandy loam soil. Light source is rich and there is large temperature difference between day and night. Shandong is a well-known horticultural province in China, with the unique ecological conditions which are suitable for many fruit trees and vegetables.

The annual rainfall in this area is 650–850 mm, 60% of which is concentrated in summer with rainstorm occurring sometimes, while the average annual evaporation is 1000–1200 mm, so the annual rainfall is insufficient for blueberry growing. Therefore, as for open-field blueberry cultivation, groundwater is the main water resource for irrigation. Both groundwater quality and supply are not desirable, and the air humidity is often so low; water shortage is the main limiting factor for open-field blueberry growing in this region. In addition, besides a few sites located in the coastal areas, blueberry production in this region is often threatened by hot and dry winds in late spring, as well as by freezing in winter and early spring. Therefore, culture model of greenhouse and cold shed cultivation become more popular, although open-field cultivation still exists in this area. The varieties cultivated in greenhouse have also changed from the original northern highbush varieties to much earlier maturing southern highbush varieties, which could be harvested in the mid-late March.

### *1.1.3 Changjiang (Yangtze) river basin region*

The range of this region is from the limitation of soil pH < 6.0 from north bank of Yangtze river to roughly along about 20°C annual isothermal line on the southern bank of Changjiang river. Annual rainfall is generally >1000 mm, and summer temperature is usually high. Strong acidic red soil and yellow soil (pH 4.5–5.5) are the main acidic soil types, that is, clay, poor fertility, low organic matter, and low total nitrogen content. Therefore, corresponding measures should be taken to improve soil permeability and increase soil organic matter content. How to use local resources to increase soil organic matter in Changjiang river basin is a long-term research topic. It is suggested that the laying of drainage pipeline under the planting site could be an effective measure to prevent the soil from being too wet.

The most adverse environmental factor in this region is high temperature in summer, and the extreme maximum temperature may reach above 40°C. The number of days with the highest daily temperature greater than or equal to 35°C in this region is also increasing with the tendency of global warming and reaching 20 days in most places and even up to 30 days in some sites. This region has not only heavy rain but also drought in summer and autumn due to monsoon climate. Therefore, soil moisture regulated by drainage and irrigation is one of the key measures of blueberry culture in this region. In addition, the harvest time of some varieties in this region coincides with the plum rain season, so rain shelter should be adopted to avoid this problem. Typhoon damage should also be prevented in offshore areas.

With appropriate cultural practice, most rabbiteye varieties were adaptable to high temperature in summer, and the yield of “Brightwell” could reach more than 22.5 t per hm<sup>2</sup>. As for southern highbush blueberries, only a few varieties with relatively strong wild traits could give high and stable yield.

### 1.1.4 Guizhou and Sichuan regions

The landform of Guizhou and Sichuan is complex, and blueberry is mainly planted in the low mountains and hills. The climate of Guizhou is warm and humid, belonging to the subtropical humid monsoon climate, relatively cooler in summer, and no severe cold in winter. Acid red soil is the main soil type. So, rainy weather and acid soil provide favorable environment for blueberry growing. It is practically proven that the yield of some rabbiteye varieties could reach 5–8 kg per plant. However, some weather factors, such as cloudy, foggy, and unstable spring temperature in plateau area, are the negative factors affecting the quality and yield.

Soil of the eastern Sichuan basin is mainly slightly acidic purple soil and paddy soil, which is relatively sticky and difficult to ameliorate. Other areas suitable for blueberry cultivation are mainly hilly gentle slopes, of which the soil is acid yellow brown soil and also heavy. Considering the poor local transportation, processing variety with more suitable adaptability should be adopted for the culture.

### 1.1.5 Yunnan region

As Yunnan is located in the low latitude plateau, the temperature varies greatly due to the influence of altitude and latitude. Except for a few places, the continuous growth season in most places lasts for more than 300 days every year. Blueberry has been introduced to Yunnan since 2004, and this region has become an early fresh blueberry producing region with a special reputation in China. Under applicable facilities, such as canopy and integration of water and fertilizer, supply of fresh fruit might last from January to August. With the cooler summer, large difference between day-night temperatures, and abundant sunshine, blueberry culture in this region could achieve high and stable yield, with qualified fruits of high sugar content; good coloring; solid, thick peel; and fragrance.

For open-field cultivation, sometimes yields would be affected by late frost in later spring and hail in spring and summer. What is more, fruit quality and harvesting of medium-maturity variety would be affected by rainy season from May to October.

### 1.1.6 South China region

This growing region has just been forming, including low mountains, hills, and river plains in Guangdong, Fujian and, Guangxi provinces, with the lowest latitude in all production regions in China. Annual average temperature is a little higher, and most acid soil is red soil with sticky texture and low content of soil organic matter. Considering the higher annual average temperature, some southern highbush varieties are suitable for this region; and planting areas would develop mainly around large or medium-sized cities so as to face the local consumer groups directly.

## 1.2 Prospects

In China, blueberry industry is a new, rising, and prospective business, but it could not be successful easily. Struggling hard and implementing hard are both needed seriously, and, among all, the key points are scientific research and practice for development.

### 1.2.1 Strengthening the basic construction of orchards, implementing fine cultural practice, and insuring high and stable yield with good quality

In an overall view, although the growing areas increased rapidly and qualified orchards had emerged with good yields, such as 22.5 t/hm<sup>2</sup>, approaching the

international high level, production on most plantations was low, usually only 3–4 t/ha, so the integrated level of blueberry industry was obviously lagging behind. There appeared a serious imbalance among different regions and orchards. Problems occurred during the early blind development stage, such as poor selection of orchard site, orchard infrastructure construction being not in place, and extensive management. It is helpful to be taught by all these historical experiences and to eliminate all these problems in order to improve orchard conditions to get successful and bright future.

### *1.2.2 Paying attention seriously to using suitable cultivars in various regions*

At the beginning of commercial development stage, especially affected by the fever of making profit by selling seedlings, a number of orchards were failed by a wrong selection on cultivars, e.g., in southern China, where the soil was very heavy, people were particularly interested in southern highbush cultivars but not rabbiteye cultivars, since most southern highbush cultivars were not adapted to the ecological conditions in southern China and orchards were falling down totally in a few years. Learning from practice experience, now, most orchards have known that “cultivars with good adoption to environment is the basic principle of a good cultivar.” Otherwise, no matter how nice it is, it is not a reasonable one. Even more, it has been realized that the most suitable cultivars in China should be eventually bred by Chinese breeding system in various regions.

### *1.2.3 Emphasizing harvesting, storing, and shipping in order to promote fruit quality*

As cooling line is, so far, not perfectly used in Chinese blueberry industry, there is a big room to promote the quality by fully using these techniques. Furthermore, processing to increase economic value is a preferable way to gain profit by enterprises of blueberry industry. Accordingly, it is important to have varieties especially for processing. Recently, a favorable selection “LM-1” was released, and it possesses better adaptability to clay soil and hot summer and bears smaller fruit of approximately 1 g per berry with rich nutrition and wild fruit flavor. Its yield could reach more than 15 t/hm<sup>2</sup>. It is one of the new representative varieties found in China.

## **2. Some ecophysiological response of blueberry grown under different water regimes**

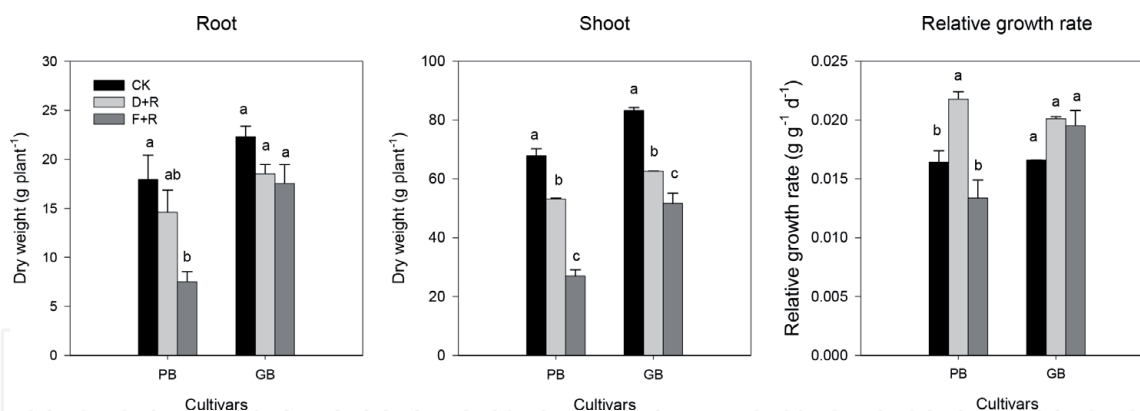
Blueberries (*Vaccinium* spp.) usually prefer well-drained, moist, acidic sandy loam soils with high organic content. It can tolerate moderate drought but is sensitive to soil waterlogging [1]. Inadequate or excessive soil water supply attenuates the growth and development of blueberry and makes a negative effect on both yield and fruit quality. Among the myriad of management measures for blueberry culture, scientific and reasonable water management is particularly critical [2]. Clarifying the water physiological characteristics and water requirement of blueberry is a precondition for development of water-saving and efficient irrigation schedule. Therefore, water physiology and water requirement of different types of blueberry at different growth stages under different soil and climatic conditions have been extensively studied [3–7]. Results from previous studies showed blueberry water requirements vary with plant age and cultivar, weather and soil conditions, and cultural practices [8–14]. Consequently, water demand of blueberry under different climate and soil conditions should be appropriately adjusted and revised according to local condition.

Soil types in Changjiang (Yangtze) river basin region are red soil and yellow-brown soil, which are heavy clay with poor drainage. Moreover, there are not only heavy rain days but also drought days in summer and autumn due to monsoon climate. Therefore, soil permeability improvement by soil amelioration and soil moisture regulation by precision irrigation are the key measures of blueberry cultivation in this region. Because of the different soil texture and climate conditions, it is necessary to study the water stress tolerance and water requirement of major blueberry cultivars based on local experiments in this region. It has been found that types of blueberries that best suited to grow in Yangtze river basin region are rabbiteye (*Vaccinium ashei*) and southern highbush (*V. corymbosum*). In this study, changes in growth indexes and photosynthetic characteristics of rabbiteye blueberry seedlings after drought or flooding stressed for 14 days and recovering normal water supplying were analyzed and compared. Effects of different irrigation regimes on seedling growth and water consumption pattern of “Brightwell” rabbiteye blueberry and “Misty” southern highbush blueberry were investigated. The relationship between actual water requirement of blueberry seedlings and water surface evaporation was studied, and the water requirement model based on water surface evaporation was established. Recommendations for optimum irrigation management of blueberry grown in southern China were drawn accordingly.

## 2.1 Studies on some ecophysiological responses of blueberry grown under different water regimes in Nanjing

### 2.1.1 Adaptability of blueberry to water stress

Drought and soil waterlogging were prone to occur due to the evident uneven distribution of rainfall in blueberry growing areas of the Yangtze river basin [15]. Therefore, it is urgent to carry out studies on adaptability of blueberry to water stress. Taking 2-year-old potted seedlings of cultivar “Powderblue” and “Gardenblue” of rabbiteye blueberry (*Vaccinium ashei* Reade) as research objects, changes in growth indexes of seedlings after drought or flooding stress for 14 days and recovering normal water supply for 60 days were examined and analyzed. The results showed that after drought or flooding stress for 14 days, growths of two cultivar seedlings are inhibited severely, and their root dry weight, shoot dry weight, and whole plant relative growth rate (RGR) are significantly lower than those of the control. After recovering under normal water supplying for 60 days, “Powderblue” and “Gardenblue” did not show significant differences in the root dry weight (81.4 and 83.1% of control values, respectively) between drought-stressed and control plants. Shoot dry weight of drought-stressed plants of two cultivars was still significantly lower than those of the control. RGR of drought-stressed “Powderblue” seedlings were significantly higher than that of the control, whereas “Gardenblue” did not show significant differences in RGR (75.2% of control values) between drought-stressed and control plants. Recovering under normal water supply for 60 days after flooding stress, root dry weight and shoot dry weight of the recovered “Powderblue” seedlings were significantly lower than those of the control (41.9 and 39.8% of control values, respectively), whereas recovered “Gardenblue” seedlings maintained root dry weight and shoot dry weight of 78.7 and 62.1%, respectively, of those of corresponding controls. RGR of recovered “Powderblue” seedlings were lower than that of the control, whereas RGR of “Gardenblue” was greater than that of the control seedlings (**Figure 2**). It is concluded that recovered rabbiteye blueberry seedlings preferentially partitioned assimilate to the roots during the recovery period. RGR of the recovered seedlings approached or exceeded



**Figure 2.**

Comparison on some growth indexes of “Powderblue” and “Gardenblue” of *Vaccinium ashei* after water stress for 14 days and recovering under normal water supply for 60 days. Different small letters indicate the significant difference ( $P \leq 0.05$ ) among different treatments of the same cultivar. CK, the control; D + R, recovering under normal water supply for 60 days after drought stress; and F + R, recovering under normal water supply for 60 days after flooding stress.

those of the control by the end of the experiment. “Powderblue” is more drought-resistant, whereas “Gardenblue” is more flood-resistant. Our study demonstrated that rabbiteye blueberry “Powderblue” and “Gardenblue” appear to be promising cultivars for commercial planting in Yangtze river basin region prone to drought or flooding of up to 2 weeks.

### 2.1.2 Study on photosynthetic physiology of rabbiteye blueberry under water stress

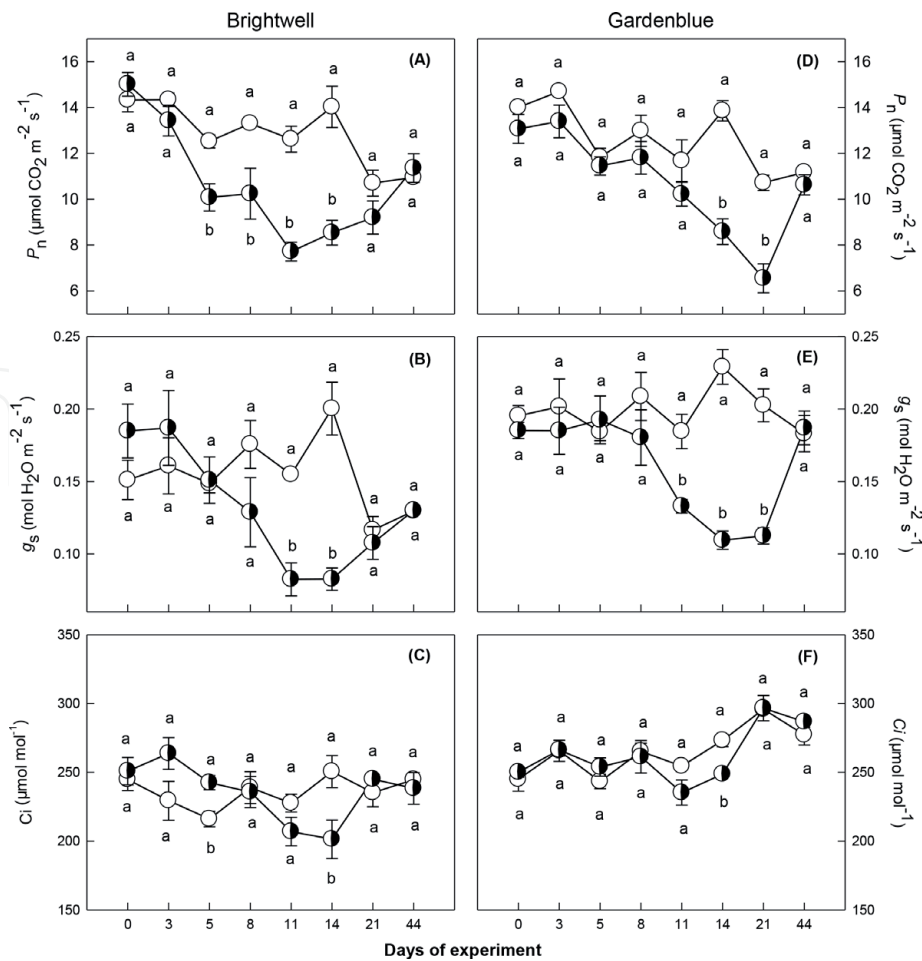
Study on photosynthetic response of rabbiteye blueberry to water stress was not only helpful to reveal photosynthetic adaptation to water stress in blueberry but also beneficial to selecting appropriate measures to improve the stress resistance of blueberry, creating favorable conditions for growth and yield formation of blueberry. In this study, potted, 1-year-old seedlings of rabbiteye blueberry “Brightwell” and “Gardenblue” were subjected to 14-day flooding stress, followed by a recovery for 30 days. The leaf net photosynthetic rate ( $P_n$ ), stomatal conductance ( $g_s$ ), and intercellular  $\text{CO}_2$  concentration ( $C_i$ ) were measured during stress, 7 days after recovery and 30 days after recovery.

Repeated measures ANOVA showed that flooding treatment and duration both had a significant effect on net photosynthesis rate ( $P_n$ ), stomatal conductance ( $g_s$ ), and intercellular  $\text{CO}_2$  concentration ( $C_i$ ) in both cultivars ( $P \leq 0.05$ ). There was also a significant interaction between flooding treatment and duration ( $P \leq 0.05$ ), indicated that the negative effects of flooding increased over time (Figure 3A–F).

The  $P_n$  in “Brightwell” decreased gradually after 3 days of flooding, and exhibited a significant drop by the 5th day. By day 11, the  $P_n$  of flooded plants in “Brightwell” dropped to the lowest values (–39% compared with that of control) and increased thereafter until the end of the experiment (Figure 3A). After 8 days of flooding, flooded plants in “Gardenblue” showed a significant reduction in  $P_n$  compared to control plants. The largest decline in  $P_n$  of flooded plants in “Gardenblue” was observed on days 21 (–39% compared with that of control) (Figure 3B). After the flooding was ended and plants were allowed to recover for 30 days, the  $P_n$  of both cultivars recovered to different degree (104 and 95% for “Brightwell” and “Gardenblue” with respect to control plants, respectively).

Flooding-induced decline in  $g_s$  in both cultivars were evident after 11 days of flooding (Figures 3C and 1D;  $P \leq 0.05$ ). The largest decline in  $g_s$  of flooded plants in both cultivars was observed on days 14 as compared to the control





**Figure 3.** Changes in the net photosynthesis rate ( $P_n$ ), stomatal conductance ( $g_s$ ), and intercellular  $\text{CO}_2$  concentration ( $C_i$ ) in the leaves of 1-year-old seedlings of “Brightwell” (A–C) and “Gardenblue” (D–F) under two soil conditions: Control (open circles) and flooding plus recovery (half-closed circles). Measurements were taken on days 0, 3, 5, 8, 11, and 14 (during the flooding); day 21 (7 days after flooding ended); and day 44 (30 days after flooding ended). Different lowercase letters indicate significant differences ( $P \leq 0.05$ ) among treatments. Values are mean  $\pm$  standard error.

(–59 and –52% for “Brightwell” and “Gardenblue,” respectively). When the flooding treatment ended,  $g_s$  in both cultivars recovered gradually and reached a level similar to that of the control (100 and 102% for “Brightwell” and “Gardenblue” with respect to control plants, respectively) by the end of the experiment.

The  $C_i$  in both cultivars decreased gradually after 5 days of flooding. Compared with the control, the  $C_i$  of “Brightwell” and “Gardenblue” under flooding significantly decreased by 19.6 and 9.0%, respectively, by the 14th day (Figures 3E and 1F;  $P \leq 0.05$ ). After the flooding was ended and plants were allowed to recover for 7 days, the  $C_i$  of both cultivars increased rapidly and was slightly higher than that of the control. By day 44 (30 days after flooding ended), the  $C_i$  in both cultivars increased to a level similar to that in the control (97.4 and 103.4% for BW and “Gardenblue” with respect to control plants, respectively).

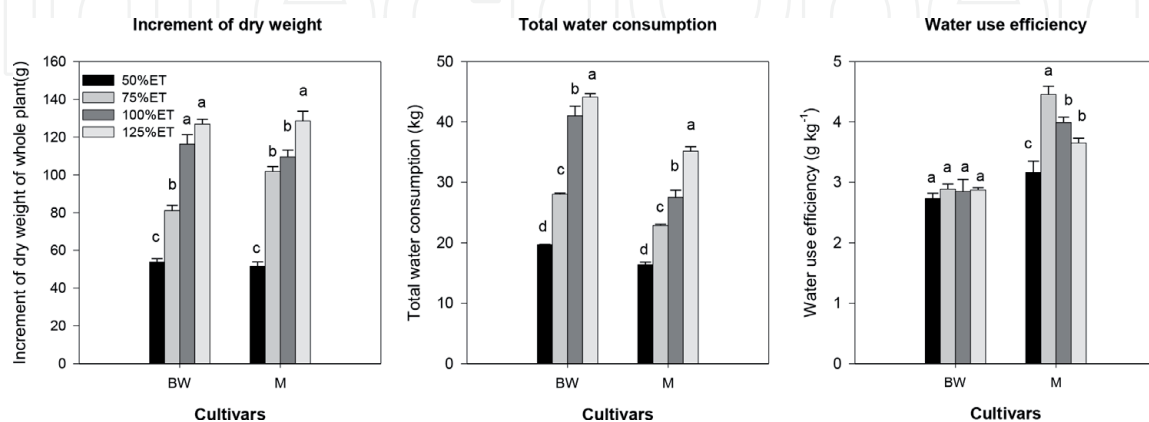
Decreases in carbon assimilation under the flooding condition have been demonstrated in many woody fruit species [3, 4, 16, 17]. In the present study, the leaf net photosynthetic rate ( $P_n$ ) of flooded plants in both cultivars was significantly less than those of unflooded controls after 14 days of flooding. Meanwhile, the stomatal conductance ( $g_s$ ) and intercellular  $\text{CO}_2$  concentration ( $C_i$ ) also decreased significantly, indicating that flooding reduced photosynthesis mainly via a decrease in stomatal conductance. Photosynthetic activity decreased during flooding in both cultivars but recovered rapidly following drainage, which indicates that decreased

photosynthetic activity was temporary and that rabbiteye blueberry possessed rapid recovery ability after flood water was released. Our study demonstrated that rabbiteye blueberry could adapt to flooding stress by adjusting photosynthetic process and possess a certain extent of adaptation to flooded soil conditions.

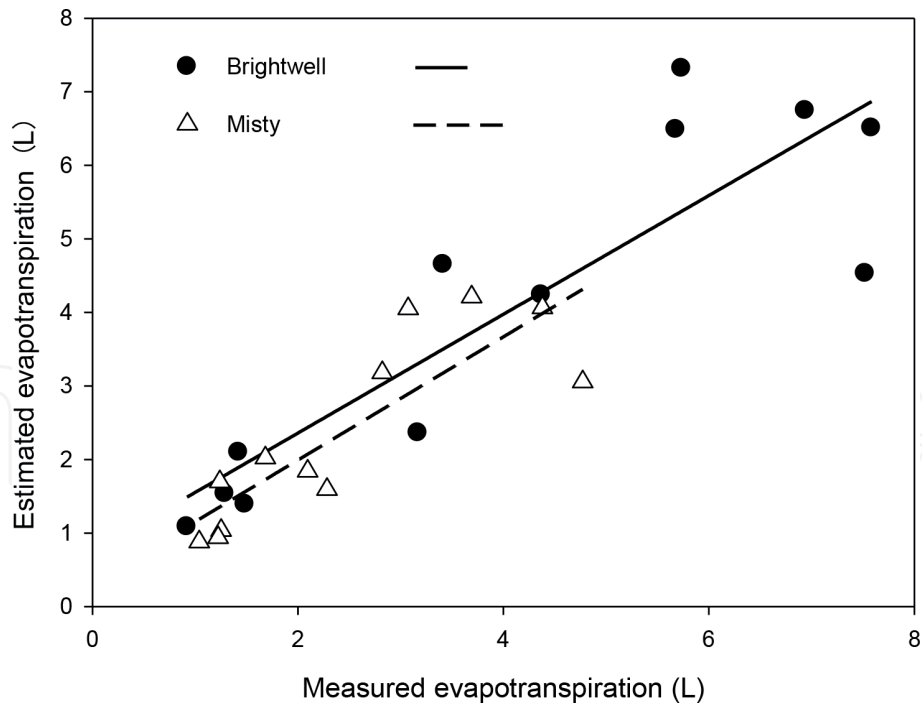
### 2.1.3 Study on water requirements of blueberry

Reasonable water management is the basic guarantee for the high fruit yield and quality of blueberry [18–20]. Clarifying the water requirement of blueberry is a precondition for scientific management of blueberry orchard. In this study, weighing lysimeters were used to determine actual evapotranspiration (ET) of young seedlings of “Brightwell” rabbiteye blueberry and “Misty” southern highbush blueberry under different irrigation regimes. Effects of different irrigation regimes on seedling growth, total water consumption, and water-use efficiency (WUE) were also investigated. The results show that net increment of dry weight (IDW) per plant and total water consumption (TWC) per plant of two cultivar seedlings both elevate with increasing amount of irrigation, while water-use efficiency is lowest under 50% ET condition and the highest under 75% ET condition. As for “Brightwell,” 125% ET treatments had similar values for IDW and WUE compared to 100% ET plants, whereas TWC was significantly higher than that of the control (100% ET). IDW and TWC in 50 and 75% ET treatments were significantly lower than that of the control, whereas no significant ( $P > 0.05$ ) differences in WUE were observed. As for “Misty,” IDW and TWC in 125% ET treatments were significantly higher than that of the control (100% ET), whereas WUE was not significantly different from that of the control (100% ET). IDW in 75% ET treatment was slightly lower than that of the control, and TWC was significantly lower than that of the control, whereas WUE was significantly higher than that of the control. IDW, TWC, and WUE in 50% ET treatment were all significantly lower than that of the control (**Figure 4**). It is concluded that the optimum irrigation treatment for “Brightwell” and “Misty” in southern China are 100 and 75% ET, respectively [21].

Water requirement estimation is one of the important aspects in crop water requirement research. Crop water requirement estimation by pan evaporation has been extensively used worldwide due to simplicity and low cost of the technique [22–24]. Pan evaporation method takes into account temperature, humidity, wind speed, solar radiation, and other meteorological factors, which are the same factors that affect crop



**Figure 4.** Effects of different irrigation treatments on net increment of dry weight per plant, total water consumption, and water-use efficiency of seedlings of *Vaccinium ashei* “Brightwell” and *V. corymbosum* “misty.” different lowercases in the same column indicate the significant difference ( $P \leq 0.05$ ) among different treatments of the same cultivar.



**Figure 5.**

The relationship between measured and estimated evapotranspiration for young seedlings of *Vaccinium ashei* “Brightwell” and *V. corymbosum* “misty.”

transpiration rate. In order to clarify the feasibility of water requirement estimation by water surface evaporation, actual water requirement of young seedlings of “Brightwell” rabbiteye blueberry (*Vaccinium ashei*) and “Misty” southern highbush blueberry (*V. corymbosum*) was measured by weighing lysimeter in this study. Simultaneously, water surface evaporation above the canopy was estimated using the standard 20 cm evaporation pan. The relationship between actual water requirement and water surface evaporation was studied, and the water requirement model based on water surface evaporation was established:  $Q = D^2 \times E_{p-20} \times k/1000$ , in which  $Q$  is the plant water use within a certain period,  $D$  is the diameter of the plant at drip line (cm),  $E_{p-20}$  is the measured evaporation from the standard 20 cm evaporation pan (cm), and  $k$  is the pan coefficient. The regression analysis results showed that estimation model for water requirement of “Brightwell” was  $Q = D^2 \times E_{p-20} \times 0.282/1000$ , and estimation model for water requirement of “Misty” was  $Q = D^2 \times E_{p-20} \times 0.291/1000$ . According to the water requirement estimation model, the fitting value of evapotranspiration was obtained, and regression analysis was conducted for the relevance between estimated and measured evapotranspiration. As illustrated in **Figure 5** there were significant positive correlations between the measured and estimated evapotranspiration ( $P < 0.01$ ) in both cultivars, indicating that actual water requirement estimation by water surface evaporation above the canopy is feasible and effective. Our results provide reference and guidance for water management of rabbiteye blueberry under the similar climatic and geographical conditions.

## 2.2 Future challenges

Water management is the key factor for the success of blueberry growth. The water ecophysiology of blueberry should be further studied from the following aspects:

- I. Study on blueberry water ecophysiology in the context of global climate change. Global climate change will increase the frequency and intensity of extreme weather events, which makes the blueberry growth face serious environmental challenges. Research on the ecophysiological response

mechanism of water, under the global environmental change scenario, could provide the scientific evidence for developing cultural and breeding strategy to cope with global climate change.

- II. Study on reliable and efficient evaluation and screening system for blueberry drought and waterlogging resistance. Plant stress resistance is a complex and comprehensive trait affected by many factors. At present, there is no widely accepted evaluation method, and the resistance evaluation screening system needs to be further improved.
- III. Study on the water requirement of blueberry under open-field and protected cultivation conditions. Systematic studies should be carried out on the dynamic of water requirement of different blueberry varieties at different growth stages, so as to provide theoretical basis and technical support for resource-saving and energy-efficient water management system of blueberry orchards.
- IV. Estimation of water consumption of blueberry orchard at regional scale. Along with the increase in blueberry growing areas, blueberry orchards have gradually become an important vegetation type. It is of great significance to research the water consumption of blueberry orchards at regional scale for the design of irrigation system and rational allocation of water resources.

### **3. Effect of vinegar residue on soil properties and blueberry growth**

Blueberry grows in acidic soil with high organic content [25]. Generally it is necessary to add a large number of organic materials for soil amelioration [26] due to its low content of soil organic matter and other factors in commercial cultivation in China. Therefore, exploring suitable acidic organic materials has become one of the basic factors to ensure the sustainable development of blueberry cultivation in China.

Vinegar residue, a unique organic material, is a by-product of traditional vinegar-making industry in China. Resource of vinegar residue is abundant, as there is 2.6 million tons of vinegar residue produced annually by just one enterprise, Jiangsu Zhenjiang Hengshun Sauce and Vinegar Co., Ltd. [27]. Vinegar residue has high crude fiber content, strong acidity, and high moisture content, which makes it difficult to be disposed [28]. It is reported that vinegar residue could ameliorate soil structure and increase soil organic matter content by its large amount of grain husks [29]. Besides, it contains high organic matter, protein, as well as N, P, and K nutrients, making it to possess potential in agricultural resource business, especially in blueberry cultivation, that prefers acidic organic matter.

Therefore, the effect of vinegar residue on soil physical and chemical properties, enzymatic activities, growth of blueberry, nutrient uptake, and fruit quality should be studied. And the effect of vinegar residue on the composition and diversity of rhizosphere microbial community of blueberry should further be analyzed. By this research we would clarify the effect of vinegar residue on the growth of blueberry and the mechanism revealed from the perspective of soil amelioration, in order to provide scientific basis for the application of vinegar residue on blueberry cultivation.

#### **3.1 Experiment setup**

The pot experiment was carried out in the blueberry nursery of the Institute of Botany, Chinese Academy of Sciences, Jiangsu province, in March 2016. And three treatments were set up as CK was pure soil; VR1 was V (vinegar residue),

V (soil) = 25:75; and VR2 was V (vinegar residue), V (soil) = 50:50. At harvest time in July 2017, soil and plant samples were collected, and soil physical and chemical properties (pH, conductivity, bulk density, total N content, total P content, and organic matter content), enzymatic activities (urease activity and acid phosphatase activity), growth of blueberry (plant height, basal diameter, average single fruit weight, fruit shape index, aboveground dry weight, root dry weight and root-shoot ratio), nutrient uptake (leaf N content, leaf P content and root N content, root P content) and fruit quality (total phenol and total ketone), and composition and diversity of rhizosphere microbial community of blueberry were examined.

### **3.2 Effect of vinegar residue on blueberry growth and fruit quality**

#### *3.2.1 Effect of vinegar residue on blueberry growth*

There showed no significant differences in plant height, basal stem, single fruit weight, and fruit shape index among treatments (**Table 1**), but the aboveground dry weight of blueberry was improved significantly by vinegar residue. And the aboveground dry weight of VR1 increased 23.82% compared with CK. Root dry weight of VR1 and VR2 increased by 85.47 and 83.94%, respectively, and there was no significant difference in root dry weight between VR1 and VR2 treatments. The root-shoot ratio of plants treated with VR2 was the highest, 72.00% higher than CK, indicating that the application of vinegar residue significantly promoted the growth of blueberry roots. And 50% vinegar residue amount had the best effect on promoting blueberry growth.

#### *3.2.2 Effect of vinegar residue on blueberry nutrient uptake*

The application of vinegar residue had no significant effect on the absorption of phosphorus in blueberry leaves, roots, and fruits (**Table 2**), and there was also no significant effect on the absorption of nitrogen in blueberry leaves and fruits (**Table 2**). In terms of total nitrogen content in roots, vinegar residue significantly promoted the total nitrogen content in roots. Total nitrogen in roots of VR1 and VR2 treatment increased by 18.86 and 24.06%, respectively, compared with CK.

#### *3.2.3 Effect of vinegar residue on blueberry fruit quality*

The reducing sugar of fruits of VR1 and VR2 increased by 8.12 and 9.65% (**Table 3**) with the application of vinegar residue, and the titratable acidity content decreased by 14.28 and 7.14% compared with the control. At the same time, the soluble solid content of fruits increased significantly as soluble solid content of fruits of VR2 increased by 11.60% compared with the control. The accumulation of total phenols and ketones in blueberry fruits was significantly promoted by the application of vinegar residue (**Table 3**), and the content of total phenols and total flavonoids of VR2 increased by 71.42 and 100.00%, respectively, compared with the control. The results showed that the application of vinegar residue could significantly improve the quality of blueberry fruits.

### **3.3 Effect of vinegar residue on soil properties**

#### *3.3.1 Effect of vinegar residue on soil structure*

Soil pH dropped by 0.27 units by the application of vinegar residue (**Table 4**), but there showed no significant difference with the control. The soil electrical conductivity increased significantly with the application of vinegar residue, and the soil electrical

	Plant height/cm	Basal stem/cm	Single fruit weight/g	Fruit shape index	Aboveground dry weight/g	Root dry weight/g	Root-shoot ratio
CK	82.58 ± 16.15a	1.62 ± 0.14a	1.55 ± 0.29a	0.87 ± 0.06a	112.80 ± 18.87a	28.83 ± 10.48a	0.25 ± 0.06a
VR1	69.36 ± 16.86a	1.43 ± 0.09a	1.55 ± 0.32a	0.88 ± 0.06a	139.67 ± 27.02ab	53.47 ± 19.14b	0.38 ± 0.07bc
VR2	71.48 ± 7.75a	1.39 ± 0.15a	1.56 ± 0.29a	0.88 ± 0.06a	121.03 ± 21.25a	53.03 ± 11.22b	0.43 ± 0.03c

*Different lowercases in the same column indicate the significant difference at 0.05 level (P < 0.05).*

**Table 1.**  
*Effect of vinegar residue on blueberry growth.*

	Leave nitrogen/mg·kg <sup>-1</sup>	Root nitrogen/mg·kg <sup>-1</sup>	Fruit nitrogen/mg·kg <sup>-1</sup>	Leave phosphorus/mg·kg <sup>-1</sup>	Root phosphorus/mg·kg <sup>-1</sup>	Fruit phosphorus/mg·kg <sup>-1</sup>
CK	705.03 ± 28.89a	615.88 ± 83.02a	240.40 ± 15.86a	109.10 ± 23.29a	164.60 ± 21.29a	142.89 ± 28.47a
VR1	699.35 ± 19.57a	731.83 ± 33.95b	276.03 ± 22.99a	109.10 ± 8.22a	184.10 ± 33.04a	148.49 ± 27.24a
VR2	707.68 ± 30.39a	763.03 ± 63.31b	275.40 ± 33.01a	90.15 ± 6.34a	229.85 ± 79.10a	159.67 ± 28.68a

*Different lowercases in the same column indicate the significant difference at 0.05 level (P < 0.05).*

**Table 2.**  
*Effect of vinegar residue on blueberry nutrient uptake.*

	Soluble solid/%	Reducing sugar/ mg·g <sup>-1</sup>	Titratable acidity/%	Total phenols/ mg·g <sup>-1</sup>	Total flavonoids/ mg·g <sup>-1</sup>
CK	10.17 ± 0.70a	71.78 ± 7.12a	0.42 ± 0.07a	0.56 ± 0.13a	0.71 ± 0.11a
VR1	11.03 ± 1.81ab	77.61 ± 6.57a	0.36 ± 0.02a	0.85 ± 0.23ab	1.21 ± 0.29bc
VR2	11.35 ± 1.12b	78.71 ± 11.52a	0.39 ± 0.02a	0.96 ± 0.15b	1.42 ± 0.24c

*Different lowercases in the same column indicate the significant difference at 0.05 level (P < 0.05).*

**Table 3.**  
 Effect of vinegar residue on blueberry fruit quality.

	pH	Electrical conductivity/ $\mu\text{S}\cdot\text{cm}^{-1}$	Bulk density/ $\text{g}\cdot\text{cm}^{-3}$
CK	4.90 ± 0.10a	110.90 ± 9.51a	0.85 ± 0.02c
VR1	4.63 ± 0.24a	138.65 ± 12.75a	0.84 ± 0.03c
VR2	4.67 ± 0.11a	224.80 ± 49.56b	0.72 ± 0.02a

*Different lowercases in the same column indicate the significant difference at 0.05 level (P < 0.05).*

**Table 4.**  
 Effect of vinegar residue on soil structure.

	Soil nitrogen/ $\text{mg}\cdot\text{kg}^{-1}$	Soil phosphorus/ $\text{mg}\cdot\text{kg}^{-1}$	Soil organic matter/ $\text{g}\cdot\text{kg}^{-1}$
CK	11.15 ± 1.84a	13.30 ± 2.78a	8.24 ± 1.11a
VR1	22.30 ± 2.44b	18.83 ± 1.11ab	29.79 ± 2.82c
VR2	37.80 ± 6.26c	25.65 ± 3.18bc	51.84 ± 1.18d

*Different lowercases in the same column indicate the significant difference at 0.05 level (P < 0.05).*

**Table 5.**  
 Effect of vinegar residue on soil nutrient.

conductivity of VR2 224.80  $\mu\text{S}\cdot\text{cm}^{-1}$ , which was still in the range of the electrical conductivity suitable for the growth of blueberry. Soil bulk density of VR2 was 15.29% lower than the CK. The decrease of soil pH and bulk density was beneficial for the growth of blueberry after the application of vinegar residue.

### 3.3.2 Effect of vinegar residue on soil nutrient

The total nitrogen and total phosphorus contents of soil increased significantly with the application of vinegar residue (**Table 5**). The total nitrogen contents of VR1 and VR2 treatments were 22.30 and 37.80  $\text{mg}\cdot\text{kg}^{-1}$ , which were 100.00 and 239.01% higher than those of the control, and the total phosphorus contents were 18.83 and 25.65  $\text{mg}\cdot\text{kg}^{-1}$ , respectively, which were 41.58 and 92.86% higher than those of the control. The content of soil organic matter increased significantly with the increase of vinegar residue. Content of soil organic matter of VR2 was 51.84  $\text{g}\cdot\text{kg}^{-1}$ , 5.29 times higher than that of the control.

### 3.3.3 Effect of vinegar residue on soil enzymes

Soil urease and acid phosphatase activities increased significantly with the application of vinegar residue (**Table 6**). Soil urease activities of VR1 and VR2 treatments were 11.67 and 26.60  $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ , which increased by 177.86 and 533.33%, respectively, compared with the control. And acid phosphatase activities



	Urease activity/mg·kg <sup>-1</sup> h <sup>-1</sup>	Acid phosphatase activity/g·kg <sup>-1</sup> h <sup>-1</sup>
CK	4.20 ± 1.40a	11.70 ± 1.76ab
VR1	11.67 ± 1.62b	14.54 ± 7.08b
VR2	26.60 ± 2.80d	22.87 ± 5.00c

*Different lowercases in the same column indicate the significant difference at 0.05 level (P < 0.05).*

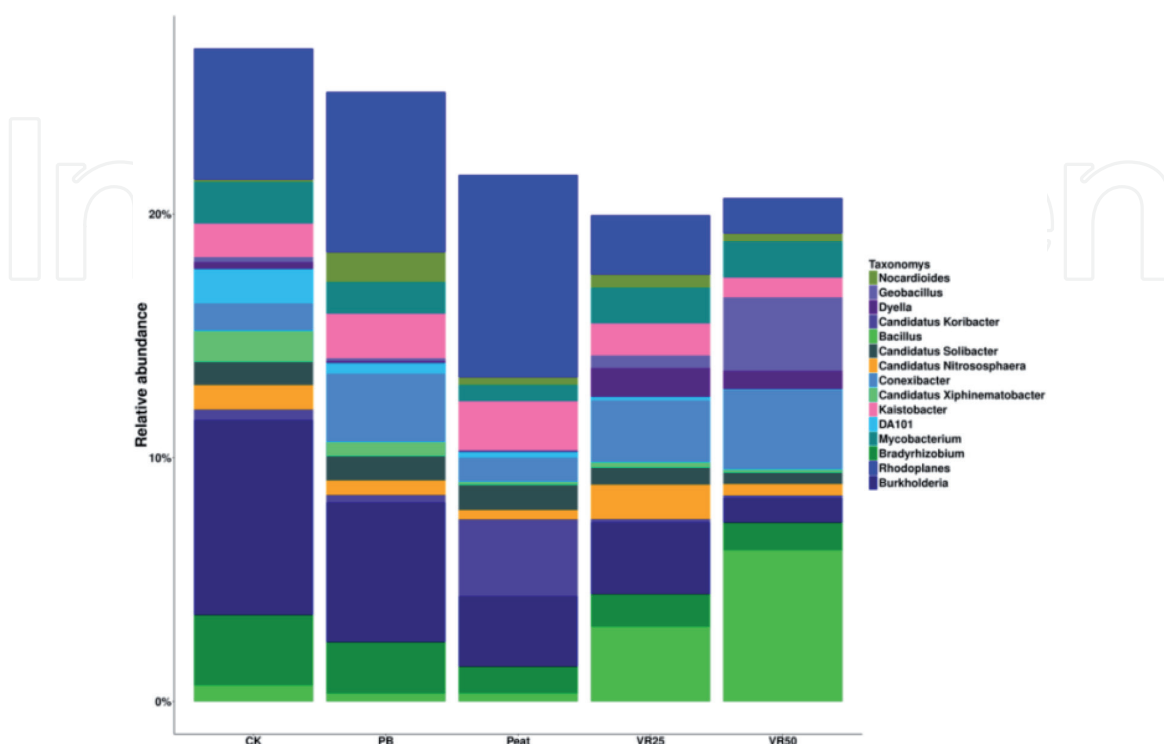
**Table 6.**  
Effect of vinegar residue on soil enzyme.

of VR2 treatments were 22.87 mg·kg<sup>-1</sup> h<sup>-1</sup>, which was significantly 95.47% higher than the control.

### 3.3.4 Effect of vinegar residue on the composition and diversity of rhizosphere microbial community

There were 12 genera of microorganisms with relative abundance of more than 1% in each treatment, and there were *Nocardioides*, *Geobacillus*, *Dyella*, *Candidatus koribacter*, *Bacillus*, *Candidatus solibacter*, *Candidatus nitrososphaera*, *Conexibacter*, *Candidatus xiphinematobacter*, *Kaistobacter*, DA101, *Mycobacterium*, *Bradyrhizobium*, *Rhodoplanes*, and *Burkholderia* (Figure 6). And its abundance was accounted for 20–25% of the total microbial biomass of blueberries.

The abundance of *Bacillus*, *Burkholderia*, and *Rhodoplanes* varied significantly among all treatments (Figure 7). The growth of *Burkholderia* and *Rhodoplanes* was inhibited by the application of vinegar residue. As *Bacillus* was an important growth-promoting bacterium in plant rhizosphere, which played an important role in plant root growth and nutrient uptake, the abundance of *Bacillus* increased to 3.5–6% with the application of vinegar residue, while it was quite low in CK.



**Figure 6.**  
Relative abundance of rhizosphere microbial community at genus level.



**Figure 7.**  
 Comparison of relative abundance of microorganisms at genus level.

	Chao1	Observed species	Shannon	Simpson
CK	2339 ± 159b	1407 ± 74c	7.83 ± 0.38ab	0.980 ± 0.014a
VR25	2300 ± 106b	1379 ± 61b	8.03 ± 0.14b	0.987 ± 0.003a
VR50	2108 ± 165a	1221 ± 119a	7.50 ± 0.48a	0.973 ± 0.014a

Different lowercases in the same column indicate the significant difference at 0.05 level ( $P < 0.05$ ).

**Table 7.**  
 Effect of vinegar residue on the rhizosphere microbial diversity of blueberry.

From the observed species, Shannon and Simpson index decreased significantly in VR2 (Table 7), indicating that rhizosphere microbial diversity of blueberry decreased by the application of 50% vinegar residue.

#### 4. Discussion and conclusion

Du et al. [30] found that vinegar residue compost amendment could promote the growth of cucumber and could be applied as a method for biological control of cucumber *Fusarium* wilt. Our results showed that vinegar residue could promote the growth of blueberry and increase the biomass accumulation of shoot and root, and root dry weight of blueberry under VR2 increased by 83.94% compared with CK. Previous studies have found that the application of organic materials could increase the reducing sugar content and reduce the titratable acidity content of fragrant pear fruit [31] and increase the content of Vitamin C (VC) and soluble solids in tomato fruit [32]. This research showed that the application of vinegar residue could significantly increase the soluble solid content of blueberry fruits. In addition, the total phenol and flavonoid content of the fruits of VR2 increased by 71.42 and 100.00%, respectively, compared with CK, indicating that the application of 50% vinegar residue had the best effect on promoting the quality of blueberry fruits.

Blueberry is suitable to grow in soil with abundant organic matter and pH under 5 (below 5.5) [1]. Soil pH of VR2 is 4.62, which is quite suitable for the growth of rabbiteye blueberry. Soil conductivity reflects the water soluble salt content. And soil conductivity of VR2 was  $224.80 \mu\text{S}\cdot\text{cm}^{-1}$ , which was 102.71% higher than CK, but did not exceed the suitable range of soil conductivity for blueberry growth [33]. The exchangeability of soil salt ions and nutrient separators was higher with the increase of soil conductivity at a certain range, which is more conducive to nutrient absorption of blueberry. In addition, soil bulk density was decreased in VR2, which indicated that the application of vinegar residue could increase soil porosity. And soil pH, electrical conductivity, and bulk density were the key factors to promote the growth of blueberries by applying vinegar residue. The results showed that VR2 treatment significantly increased root-shoot rate by 72.00% and root nitrogen by 23.89% compared with the control, suggesting that vinegar residue could significantly promote root growth.

Previous studies reported that adding organic materials can significantly increase soil nutrient content and enhance soil biological activity [34]. Our results showed that the application of vinegar residue could significantly increase the content of total nitrogen, total phosphorus, and organic matter in soil. Soil nitrogen content of VR2 increased by 239.01% compared with CK, and soil organic matter content increased by 43.6 g/kg with the application of 50% vinegar residue. Improvement of soil organic matter could ameliorate soil structure and serve as resource of organic nitrogen and phosphorus. What is more, it could also enhance the activity of soil microbial. Soil urease and acid phosphatase are important enzymes for the transformation of soil nitrogen and phosphorus. Goyal et al. [35] found that the application of exogenous organic materials could improve the activity of soil urease and phosphatase and thus improve soil fertility. This study found that activities of urease and acid phosphatase were highest in VR2, with 26.60 and  $22.87 \text{ g}\cdot\text{kg}^{-1} \text{ h}^{-1}$ , respectively, 533.33 and 95.47% more than the control. The results showed that the application of vinegar residue increased the activity of soil urease and acid phosphatase, thus increased the transformation of soil nitrogen and phosphorus, and then promoted the growth of blueberry [36, 37].


In conclusion, the application of vinegar residue could improve soil structure and increase soil nutrient and organic matter content, thus promoting the growth and fruit quality of blueberry. In the meantime, the application of 50% vinegar residue appeared to have the best effect on promoting blueberry growth.

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