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Effects of Potassium Application Rates on Leaf Growth and Soil Nutrients in Greenhouse Peaches

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Abstract [**Objectives**] To clarify the effects of varying potassium application rates on leaf growth and soil mineral nutrients of greenhouse peaches, and to identify the optimal potassium fertilizer dosage. [**Methods**] Using the greenhouse peach superior line C26-7-17 as the test material and maintaining a fixed ratio of nitrogen and phosphorus fertilizers, five potassium fertilizer treatment groups were established. The application rates of potassium sulfate were 0, 67, 135, 202, and 269 g/plant, respectively. The regulatory effects of varying potassium application rates were analyzed by measuring leaf area, chlorophyll content, and soil mineral element content. [**Results**] Applying nitrogen, phosphorus, and potassium fertilizers in specific proportions increased the leaf area of greenhouse peaches, enhanced chlorophyll content, and significantly improved the soil's nutritional status. Considering the overall optimization of soil nutrients, the recommended potassium fertilizer dosage under the experimental conditions was 202 g/plant. [**Conclusions**] This study offers theoretical insights that may enhance the quality and efficiency of greenhouse peaches, as well as inform nutrient management strategies.

Key words Greenhouse peach, Potassium application rate, Leaf growth, Soil mineral element, Fertilization recommendation

0 Introduction

Peach (*Prunus persica* L.), a member of the Rosaceae family and the genus *Prunus*[1], is characterized by its sweet and fragrant flavor, thick and juicy flesh, and high content of various vitamins and mineral elements. It is a traditional fruit that is widely cherished by the public in China. With advancements in agricultural science and technology, alongside increasing consumer demand, greenhouse cultivation techniques have been progressively adopted in the peach industry. Following years of development, greenhouse cultivation has become a significant sector in the peach industry. Potassium is an essential mineral element for plant growth and development, playing a crucial role in key physiological processes such as photosynthesis and transpiration. It acts both as a component and an activator of numerous enzymes[2], and functions as an osmotic regulator within cellular tissues. Additionally, potassium is a vital nutrient in fruits, contributing to osmotic regulation, maintaining cation-anion balance, and facilitating the transport of assimilates. Thus, it is recognized as a multifunctional nutrient and a "quality element"[3-5]. The appropriate application of potassium fertilizer, along with maintaining a balanced ratio of nitrogen, phosphorus, and potassium, constitutes essential strategies for increasing yield and improving quality. Consequently, standardizing the fertilization ratio for greenhouse peaches is of considerable practical significance in enhancing fruit quality.

This study employed the greenhouse peach superior line C26-7-17 to examine the effects of different potassium application rates on leaf growth and soil element content. The objective was to elucidate the variation patterns of soil element content in response to potassium application rate, thereby offering theoretical insights and practical guidance for the efficient cultivation and nutrient management of greenhouse peaches.

1 Materials and methods

1.1 Experimental design The experiment was carried out from March to September 2022 in No.2 Greenhouse at the Changli Institute of Pomology, Hebei Academy of Agricultural and Forestry Sciences. The experimental material consisted of the low-chilling-requirement superior line C26-7-17, which was developed by the Institute of Pomology at the Jiangsu Academy of Agricultural Sciences and was planted in the spring of 2019. Plants were spaced at 1 m × 1.5 m, with soil pH measured at 7.0 and organic matter content at 27.16 g/kg. Standard water and fertilizer management practices were implemented, alongside routine flower and fruit thinning, to maintain a consistent fruit load per tree.

The experiment consisted of five treatment groups. Nitrogen and phosphorus fertilizers were applied in a ratio of 2 : 1, whereas potassium fertilizer was administered at gradient ratios of 0, 0.5, 1, 1.5, and 2, corresponding to potassium sulfate application rates of 0, 67, 135, 202, and 269 g/plant, respectively. Isolation rows were established between each fertilization treatment. Fertilizers were applied via furrow application at a depth of 30 cm, one month after the stone hardening stage and prior to fruit maturity.

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1.2 Measurement indicators and methods Leaf area was quantified using a leaf area meter. Chlorophyll content was assessed through ethanol extraction followed by ultraviolet spectrophotometry. Soil nitrogen content was analyzed employing a Kjeldahl analyzer. Other mineral elements were determined via inductively coupled plasma emission spectroscopy subsequent to microwave digestion.

2 Results and analysis

2.1 Effects of different potassium application rates on the leaf area and chlorophyll content of greenhouse peaches The application of potassium fertilizer had a significant effect on leaf area and chlorophyll content. As illustrated in Fig. 1, no statistically significant differences in leaf area were detected among the treatments. Nevertheless, the treatment with 269 g/plant potassium fertilizer produced the largest leaf area, measuring 28.59 cm^2. In the 67 g/plant potassium fertilizer treatment, the contents of chlorophyll a, chlorophyll b, and total chlorophyll (chlorophyll a+b) were all higher than those in the control group, with the content of chlorophyll a and total chlorophyll exhibiting statistically significant increases relative to the control. Conversely, the chlorophyll a content under the 269 g/plant potassium fertilizer treatment was significantly lower than that of the control. In summary, under the combined application of nitrogen, phosphorus, and potassium, the addition of potassium fertilizer did not result in a significant change in leaf area. However, when potassium fertilizer was applied at a rate of 67 g/plant, the contents of chlorophyll a, chlorophyll b, and total chlorophyll increased to varying extents. This significant enhancement in chlorophyll content facilitates the utilization and conversion of light energy, thereby improving the photosynthetic performance of the plants.

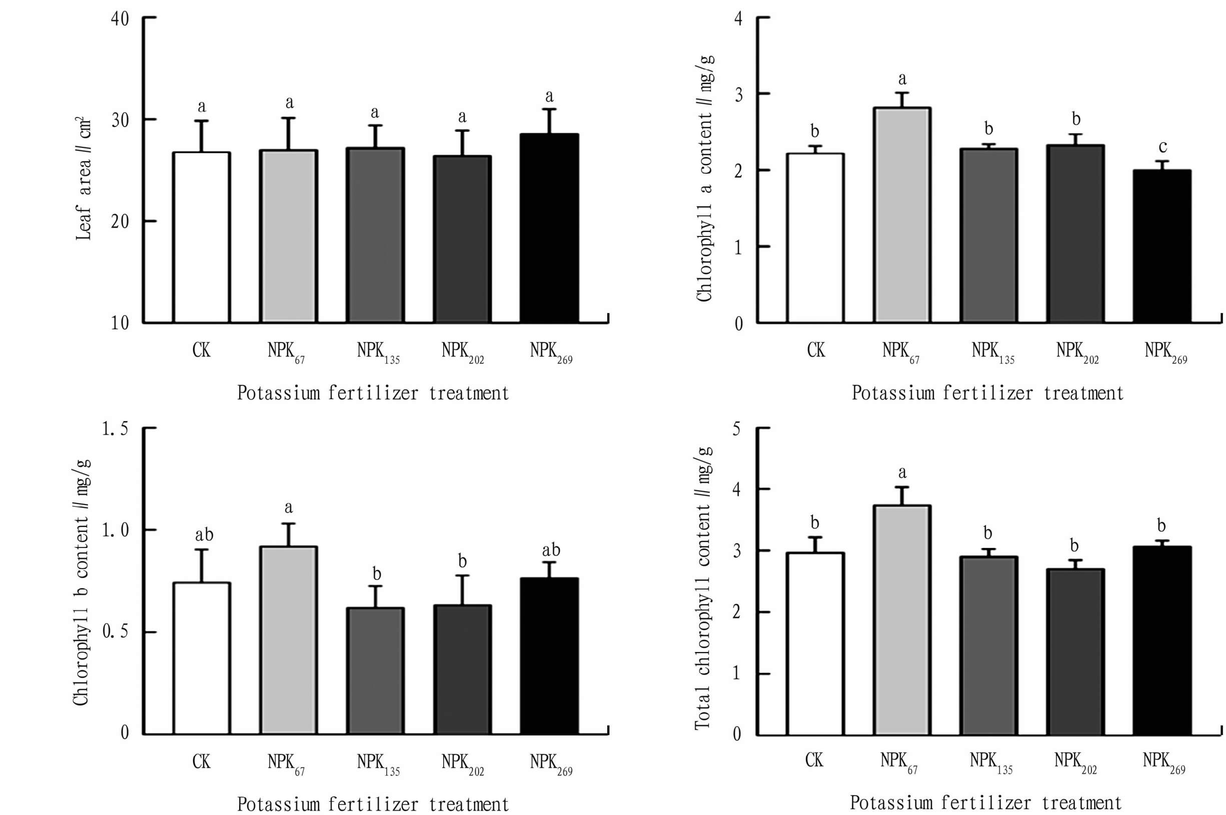

Fig. 1 Effects of different potassium application rates on the leaf area and chlorophyll content of greenhouse peaches

2.2 Mineral nutrients in the soil

2.2.1 0–20 cm soil layer. As presented in Table 1, within the 0–20 cm soil layer, the nitrogen content generally increased with higher application rates of potassium fertilizer, except for the 135 g/plant potassium fertilizer treatment. The highest nitrogen content was observed at the 269 g/plant potassium fertilizer treatment, which was significantly greater than that of the control by 11.11%. Conversely, the phosphorus content was significantly reduced in all fertilized treatments compared to the control, with the 269 g/plant potassium fertilizer treatment showing the lowest phosphorus content, which was significantly lower than the control by 23.59%. The potassium content initially decreased and subsequently increased from the first fertilization treatment. The potassium levels in the 67 and 135 g/plant potassium fertilizer treatments were significantly lower than those in the control group, whereas the potassium levels in the final two potassium fertilizer treatments did not differ significantly from the control. These findings suggest that the application of nitrogen and phosphorus fertilizers in the first two treatments induced potassium deficiency in the plants, prompting increased potassium uptake from the soil and thereby reducing soil potassium content. With the subsequent increase in potassium fertilizer application, the contents of nitrogen, phosphorus, and potassium in the soil gradually stabilized, returning to levels comparable to those observed prior to fertilization. The calcium content was significantly lower than that of the control under 135 and 269 g/plant potassium fertilizer treatments. Conversely, the calcium content was higher than the control under 67 and 202 g/plant potassium fertilizer treatments, but these increases were not statistically significant. Both magnesium and copper contents were significantly lower than the control under the 135 g/plant potassium fertilizer treatment. The manganese content did not exhibit significant differences among the treatments. The zinc content was significantly reduced compared to the control following fertilization, demonstrating a decreasing trend. No significant differences were detected among the 135, 202, and 269 g/plant potassium fertilizer treatments, but the lowest zinc content was 34.79% lower than that of the control. The iron content began to decline at a potassium application rate of 135 g/plant and was significantly lower than the control. The minimum iron content was observed in the 269 g/plant potassium fertilizer treatment, representing a significant reduction of 25.62% relative to the control.

By comparing the effects of various potassium fertilizer treatments on mineral element content, the following conclusions were drawn. The application of 67 g/plant potassium fertilizer significantly decreased the contents of phosphorus, potassium, and zinc, while increasing nitrogen and calcium contents. At a dosage of 135 g/plant, all element contents except for nitrogen, calcium, and manganese were significantly reduced, with no observed increase in soil element content. The 202 g/plant potassium fertilizer treatment resulted in significant reductions in phosphorus, iron, and zinc contents, accompanied by increases in nitrogen and calcium contents. Finally, the 269 g/plant potassium fertilizer treatment significantly increased nitrogen content, whereas phosphorus, calcium, iron, and zinc contents were significantly decreased.

Table 1 Effects of different potassium application rates on the content of mineral elements in the 0 – 20 cm soil layer of greenhouse peaches

Treatment	Nitrogen mg/g	Phosphorus mg/g	Potassium mg/g	Calcium mg/g	Magnesium mg/g	Iron mg/g	Manganese mg/kg	Zinc mg/kg	Copper mg/kg
NPK_0	2.33 ±0.02 c	1.74 ±0.03 a	4.08 ±0.11 a	4.07 ±0.5 ab	3.90 ±0.48 a	18.48 ±1.39 a	371.61 ±53.02 a	171.66 ±3.15 a	21.16 ±1.16 a
NPK_{67}	2.43 ±0.02 b	1.65 ±0.02 b	2.52 ±0.25 c	4.54 ±0.72 a	3.93 ±0.64 a	19.49 ±0.5 a	333.68 ±76.79 a	141.56 ±13.9 b	18.52 ±0.5 ab
NPK_{135}	2.27 ±0.04 c	1.35 ±0.06 c	3.38 ±0.28 b	3.40 ±0.28 bc	3.04 ±0.1 b	14.01 ±0.5 b	286.33 ±12.54 a	111.94 ±8.33 c	15.79 ±1.73 b
NPK_{202}	2.56 ±0.05 a	1.6 ±0.07 b	4.28 ±0.19 a	4.33 ±0.12 a	3.39 ±0.07 ab	15.06 ±0.53 b	348.84 ±65.11 a	117.09 ±3.76 c	19.28 ±0.42 a
NPK_{269}	2.59 ±0.03 a	1.33 ±0.04 c	3.89 ±0.21 a	3.03 ±0.01 c	3.45 ±0.35 ab	13.74 ±1.13 b	289.00 ±10.37 a	116.24 ±5.89 c	20.66 ±2.6 a

NOTE Different lowercase letters in the same column indicate statistically significant differences at the 0.05 level. The same below.

2.2.2 20 – 40 cm soil layer. The changes in mineral element content in the 20 – 40 cm soil layer are presented in Table 2. Following the application of potassium fertilizer, the contents of zinc and copper significantly decreased, whereas those of calcium and manganese significantly increased. As the application rate of potassium fertilizer increased, the nitrogen content initially rose, reaching a peak at the 202 g/plant potassium fertilizer treatment, which was significantly higher than the control by 18.84%, and began to decline at the 269 g/plant potassium fertilizer treatment. The phosphorus content was significantly reduced in the 135 and 269 g/plant potassium fertilizer treatments compared to the control, with the 269 g/plant potassium fertilizer treatment exhibiting the lowest value, which was 12.13% lower than that of the control. Conversely, the potassium content under the 202 g/plant potassium fertilizer treatment was significantly higher than the control by 8.4%. The calcium content was significantly elevated relative to the control across all fertilization treatments, displaying an initial increase followed by a subsequent decrease. The highest calcium content was recorded under the 202 g/plant potassium fertilizer treatment, surpassing the control by 41.62%. The magnesium content demonstrated an initial increase followed by a subsequent decrease, attaining its maximum value under the 67 g/plant potassium fertilizer treatment. The iron content exhibited a declining trend, with the content significantly lower than the control under the 269 g/plant potassium fertilizer treatment. The manganese content was significantly elevated compared to the control across all fertilization treatments, displaying a pattern of initial increase followed by a decrease, and peaking at the 67 g/plant potassium fertilizer treatment where it surpassed the control by 7.98%. The zinc content significantly decreased following fertilization, showing a gradual downward trend and reaching its minimum at the 269 g/plant potassium fertilizer treatment, which was 27.65% lower than the control. The copper content was significantly reduced relative to the control after fertilization, but no clear trend was discernible.

A comparative analysis demonstrated that the application rates of 67 and 135 g/plant potassium fertilizer significantly enhanced the content of nitrogen, calcium, magnesium, and manganese. The application rate of 202 g/plant potassium fertilizer significantly increased the contents of nitrogen, potassium, calcium, and manganese. In contrast, the 269 g/plant potassium fertilizer treatment significantly elevated calcium and manganese content but resulted in a significant reduction in phosphorus and iron content.

The changes in mineral element content across two soil layers were statistically analyzed to determine the number of elements that significantly increased or decreased under each fertilization treatment. Treatments NPK_{135} and NPK_{269} exhibited relatively less favorable effects, whereas treatments NPK_{67} and NPK_{202} showed more positive outcomes. Notably, the NPK_{202} treatment resulted in elevated potassium content in both soil layers, which is advantageous for enhancing fruit quality. Consequently, under the conditions of this experiment, a potassium application rate of 202 g/plant is recommended.

Table 2 Effects of different potassium application rates on the content of mineral elements in the 20 – 40 cm soil layer of greenhouse peaches

Treatment	Nitrogen mg/g	Phosphorus mg/g	Potassium mg/g	Calcium mg/g	Magnesium mg/g	Iron mg/g	Manganese mg/kg	Zinc mg/kg	Copper mg/kg
NPK_0	1.38 ±0.07 d	0.99 ±0.02 a	3.45 ±0.13 b	3.34 ±0.06 c	4.6 ±0.09 c	22.73 ±0.27 a	389.76 ±1.26 c	145.07 ±6.75 a	63.48 ±0.45 a
NPK_{67}	1.49 ±0.08 bc	0.97 ±0.04 ab	3.60 ±0.08 ab	4.18 ±0.18 b	5.02 ±0.13 a	22.79 ±0.49 a	420.85 ±9.97 a	125.94 ±1.02 b	53.58 ±1.19 c
NPK_{135}	1.57 ±0 ab	0.93 ±0.01 b	3.50 ±0.03 b	4.29 ±0.05 b	4.80 ±0.03 b	22.52 ±0.1 ab	413.04 ±5.02 ab	120.23 ±3.06 b	56.22 ±1.04 b
NPK_{202}	1.64 ±0.06 a	1.00 ±0.01 a	3.74 ±0.05 a	4.73 ±0.09 a	4.75 ±0.04 bc	22.47 ±0.2 ab	407.35 ±2.58 b	118.43 ±4.64 b	56.60 ±0.80 b
NPK_{269}	1.41 ±0.04 cd	0.86 ±0.02 c	3.59 ±0.08 ab	4.30 ±0.08 b	4.61 ±0.06 c	22.04 ±0.26 b	403.61 ±3.2 b	104.96 ±3.86 c	52.84 ±0.41 c

3 Discussion

The results demonstrated that potassium application led to an increase in leaf area, but this effect was not statistically significant. In contrast, an increase in chlorophyll content was associated with enhanced photosynthetic performance of the leaves. Chlorophyll content showed consistent trends across varying potassium fertilizer rates, with a significant increase observed at the 67 g/plant potassium fertilizer treatment. This effect is likely attributable to potassium's role in improving nitrogen uptake and utilization, thereby facilitating accelerated chlorophyll synthesis. These findings are consistent with those reported by Ma Yehui *et al.* [6] in their study on potassium fertilizer application in tomatoes.

Research indicates that the element content varies significantly among different plant organs, reflecting differences in their transport capacity, absorption, and distribution characteristics. During the fruit enlargement stage, the fruit serves as the primary growth center, with the majority of elements being transported toward it[7]. Concurrently, complex interactions among elements occur, manifesting as either antagonism or mutual promotion[8]. Varying potassium application rates exert differential effects on mineral elements across plant organs, resulting in variable element uptake by plants. The trends of certain elements in the soil do not exhibit clear patterns but instead display irregular fluctuations.

Soil functions as the foundational medium from which root systems absorb nutrients. Soil pH plays a critical role in regulating nitrification processes and the transformation of soil constituents[9]. The mineral element content within the soil is the principal nutrient source for plant growth and fruit development. Studies have demonstrated that mineral element contents in plant leaves, petioles, and fruits are significantly or highly significantly correlated with those in the soil[10]. Adequate mineral nutrition improves fruit quality and enhances plant resistance. In this study, the potassium content in the 0 – 20 cm soil layer initially decreased and subsequently increased. This pattern may be attributed to the application of nitrogen and phosphorus fertilizers at the first two potassium fertilizer concentrations, which likely induced potassium deficiency in plants. As a result, plants absorbed substantial amounts of potassium from the soil, leading to a reduction in soil potassium levels. Thereafter, with increasing application rate of potassium fertilizer, the levels of nitrogen, phosphorus, and potassium in the soil gradually stabilized, returning to pre-fertilization conditions. Additionally, the experimental results demonstrated that potassium fertilization significantly enhanced nitrogen content in both soil layers while concurrently decreasing zinc content. Compared to the 0 – 20 cm layer, the 20 – 40 cm layer showed a greater variety of mineral elements with increased content. This phenomenon may be attributed to the comparatively weaker tree vigor and shallower root systems of greenhouse peaches relative to those cultivated in open fields. Despite the observed increase in mineral nutrients within the 20 – 40 cm layer following fertilization, their utilization efficiency remained relatively low.

In summary, the application of nitrogen, phosphorus, and potassium fertilizers in a specific ratio enhances the leaf area of greenhouse peaches and increases chlorophyll content, while markedly improving soil nutrient status. Based on soil nutrient considerations under the experimental conditions, the recommended potassium application rate is 202 g/plant.

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