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Effect of phosphorus application on economic yield, quality and phosphorus utilisation efficiency of purple-fleshed sweetpotato

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Abstract: This study aims to explore the effect of phosphorus (P) application on the economic yield, quality, P accumulation, and P utilisation efficiency of purple-fleshed sweetpotato and to provide a basis for the P efficient utilisation and high crop yield. Field experiments were conducted in 2018–2019, and five P application rates (0, 10.9, 21.8, 32.7, and 43.6 kg P/ha, expressed as P0, P1, P2, P3, and P4, respectively) were set. The results showed that P application significantly increased the yield and commodity potato yield of purple-fleshed sweetpotato, and that of P3 treatment was the highest, followed by P2 treatment. P application also increased the starch content in the storage root and increased the reducing sugar and soluble sugar (except for P2 treatment). P fertiliser supply significantly increased P accumulation and dry matter production of purple-fleshed sweetpotato during the growth period of 90 to 120 days. When the P application rate was over 21.8 kg/ha, the fertiliser investment rate, apparent P utilisation efficiency and P agronomic efficiency decreased with the increase of the application rate. Considering all the indexes, the supply of 21.8 kg/ha P fertiliser can meet the demand for high economic yield and P efficient utilisation in purple-fleshed type sweetpotato under the condition of this experiment.

Keywords: food crops; macronutrient; fertiliser management; nutritional quality

Sweetpotato (*Ipomoea batatas* [L.] Lam.) is an important food, feed, and industrial raw material crop. According to statistics, the annual planting area of sweetpotato in China is about 2.4 million/ha, accounting for 30% of the world, and the total output is about 60% of the world (FAO 2019). Sweetpotato is rich in starch, dietary fibre, carotene, vitamins, and more than 10 kinds of trace elements. In addition to the nutrients of ordinary sweetpotato, purple-fleshed sweetpotato also contains high anthocyanins, which have obvious antioxidant properties, and play an important role in protecting the liver, reducing blood glucose and lipids, and inhibiting the production of carcinogenic substances (Steed and Truong 2010, Bakuradze et al. 2019). With the wide application of purple-fleshed sweetpotato as raw material in natural violet extraction, food, medicine, and the chemical industry, the demand for purple-fleshed sweetpotato is increasing rapidly (Yan et al. 2022).

Phosphorus (P) is a macronutrient element for the normal growth and development of sweetpotato. Appropriate P application can develop a root system, promote the synthesis, transportation, and storage of carbohydrates, increase the starch content of stor-

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age roots, and increase the yield (Boru et al. 2017). However, excessive application of phosphorus fertiliser leads to the reduction of phosphorus fertiliser utilisation rate and the increase of environmental load in the current season, which is not conducive to the increase of yield and even leads to its reduction of yield (MacDonald et al. 2011). Therefore, it is of great significance to explore the appropriate amount of P fertiliser to achieve the balance between sweetpotato yield and the utilisation rate of P fertiliser.

The commodity potato yield and nutrition quality are important indicators affecting the economic benefits of edible sweetpotato. It has been reported that applying more P fertiliser led to higher sweetpotato yield but lower commodity potato yield (Munda 2017). Another study showed that the application of P was beneficial to the accumulation of starch and protein but reduced the soluble sugar and reduced sugar in the storage root (Tang et al. 2011). However, there is a lack of studies on the effects of P fertiliser dosage on the economic yield, quality, and utilisation rate of P fertiliser of purple-fleshed sweetpotato.

Here, a purple-fleshed sweetpotato cultivar, Xuzishu 5, was taken as an example to compare the effects of different P fertiliser dosages on yield, commodity potato yield, economic profit, P uptake, and P utilisation efficiency. It will provide theoretical guidance for improving the economic benefit and P fertiliser utilisation efficiency of purple-fleshed sweetpotato.

MATERIAL AND METHODS

Plant materials and experimental design. The experiment was undertaken in the summer season of 2018–2019, and the experimental field was located at the Xuzhou Sweetpotato Research Center (34°27'N, 117°29'E), Jiangsu province, China. The experimental field was yellow flavour-aquic soil with a sandy texture. Before the experiment, chemical analysis showed that the soil layer of 0–20 cm had 110 mg/kg available K, 31.7 mg/kg available P, 125.46 mg/kg hydrolysable N, 1.04 g/kg total N, and 11.05 g/kg organic carbon, and the soil pH was 7.76. The experimental material was the purple sweetpotato cv. Xuzishu 5, which was selected and bred by Xuzhou Sweetpotato Research Center, Jiangsu province. It has good taste and is widely planted in the middle and lower reaches of the Yangtze river and the Huang-Huai-hai Plain.

In 2018, four P fertiliser treatments (superphosphate) were set, 0 kg P/ha (P0), 10.9 kg P/ha (P1), 21.8 kg P/ha (P2) and 43.6 kg P/ha (P4). Each plot had an area of 48 m^2 and four ridges, with 45 cm in width and 35 cm in height. Except for phosphate fertiliser, each treatment used the same nitrogen fertiliser (50.0 kg N/ha, urea) and potassium fertiliser (82.7 kg K/ha, potassium sulphate), and all fertilisers were applied as a base fertiliser before ridging. From the test results in 2018, we found that the highest commodity potato yield was under P2 treatment, but the highest commodity potato rate was under P4 treatment. There may be a dosage between P2 and P4 that can simultaneously obtain higher storage yield and commodity potato yield. Therefore, the test was repeated in the same plots in 2019, and treatment of P3 (32.7 kg P/ha) was added in the same field. Three repetitions were set for each treatment. The sweetpotato seedlings were planted in mid-June at a density of about 49 000 plants/ha. Other crop management practices, such as irrigation, weeding, and pesticide application, were consistent across treatments.

Measurement of available nutrients in the soil. Total N was analysed by Micro-Kjeldahl methods. Hydrolysable N content was extracted by the alkaline hydrolysis diffusion method. Available P concentration was determined by the Olsen-P method. Available K was extracted by 1 mol/L NH_4Ac solution and detected through flame ignition, and the concentrations of soil organic carbon (SOC) were determined by the K_2CrO_7-oxidation method. Soil pH was measured in a soil : water ratio of 1 : 2.5 and measured by a laboratory pH meter (Mettler Toledo, Shanghai, China).

Measurement of biomass productivity and yield. In each treatment, three plants were dug out continuously at 60 and 90 days, and the above-ground part and the storage root were separately weighed. Three to five storage roots with uniform size were cleaned and cut into fine filament, and they were dried in an oven at 80 °C together with the above-ground parts for 72 h. The dry weight of the above-ground parts and the roots were weighed, and then they were ground into fine powder to determine the P content; the measurement method was according to Bao (2000). At 120 days, all crops were harvested, and the same indexes were measured; the final shoot and root yields and the root-top (R/T) ratio were also calculated at the same time. The weight of commodity potato (100–250 g for individual potato) was investigated, and the commodity potato rate was calculated.

Measurement of nutritional quality sweetpotato. The fine powder of sweetpotato storage roots harvested at 120 days was also used to determine

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nutritional quality. The contents of starch, reducing sugar, soluble sugar, and protein were determined by Vector22/N-type Fourier to transform near-infrared reflectance spectroscopy (Bruker Optics, Ettlingen, Germany) (Ma et al. 2009). The sweetpotato powder was transferred into a rotating sample container with a diameter of 50 mm and scanned at a wavelength range of 4 000–10 000/cm, with a resolution of 4/cm. Each sample was scanned 3 times. The calibration of the software was adopted to calculate the results of the samples.

Statistical analysis. The calculation formula of P accumulation and P utilisation efficiency (in 2019) was as follows Eq. 1, (Srivastava et al. 2014) (Eq. 2) and (Chuan et al. 2013) (Eq. 3):

$$\text{PA (kg/ha)} = \text{PC} \times \text{DW} \quad (1)$$

$$\text{APU (\%)} = (\text{PAA} - \text{PAF}) / \text{P fertiliser dosage} \times 100\% \quad (2)$$

$$\text{PAE (kg/kg)} = (\text{yield in PAA} - \text{yield in PAF}) / \text{P fertiliser dosage} \quad (3)$$

Where: PA – P accumulation; PC – P content; DW – dry weight; APUE – apparent P utilisation efficiency; PAE – P agronomic efficiency; PAA – P accumulation in P application area; PAF – P accumulation in P free area.

Statistical processing of the results was performed using SPSS 20.0 program (SPSS Inc., Chicago, USA). Data were presented as mean ± standard deviation ($n = 3$). One-way ANOVA followed by Duncan's multiple range test ($P < 0.05$) was used to identify significant differences between treatments. The figures and tables were created using Microsoft Office 2016 (Beijing, China).

RESULTS

Effects of P application on yield and commodity potato yield of purple-fleshed sweetpotato. The yield characteristics of purple-fleshed sweetpotato varied between years (Table 1). The shoot yield in 2018 was significantly higher than that in 2019, but the R/T ratio, commodity potato yield, and commodity potato rate were significantly lower than those in 2019. However, there was no significant difference in storage yield between the two years.

The yield characteristics of purple-fleshed sweetpotato under different P treatments were significantly different. In 2018, compared with other treatments, the P2 treatment had the highest storage root yield, R/T ratio, and commodity potato yield, which were significantly increased by 21.1, 39.4, and 40.6% compared with P0, respectively (Table 1). The shoot yield and commodity potato rate under the P4 treatment were the highest, which were significantly increased by 19.8% and 26.0% compared with the P0 treatment, respectively. However, the storage root yield, R/T ratio, and commodity potato yield under the P4 treatment were significantly lower than those under the P2 treatment. In 2019, with the increase in P application rate, the storage roots yield, R/T ratio, commodity potato yield and commodity potato rate all showed a trend of first increasing and then decreasing, and they were the highest under the P3 treatment, which was significantly increased by 31.9, 17.7, 41.2, and 7.19% compared with P0 treatment, respectively. However, there was no significant difference between the P2 and P3 treatments. In addition, the storage root yield, R/T ratio, commodity potato yield, and commodity potato rate under the P1 and P4 treatments were significantly lower than the P3 treatment, but there was no significant difference in shoot yield.

Effects of P application on the yield benefit of purple-fleshed sweetpotato. From Table 1, it can be seen that the yield-increasing benefits of purple-fleshed sweetpotato under different phosphorus levels were different. In 2018, the increased profit and net profit of P2 treatment were the highest, while those of P4 treatment was the lowest. In 2019, the P3 treatment had the highest increased profit and net profit, followed by the P2 treatment, and the P4 treatment was the lowest. However, the fertiliser investment rate of P2 treatment was the highest in the two years. And in 2019, the fertiliser investment rate from large to small was P2 > P3 > P1 > P4.

Effects of P application on the nutrient quality of purple-fleshed sweetpotato. The effects of P application on the nutrient quality of sweetpotato were significantly different in the two years (Table 2). In 2018, the soluble sugar under the P1 treatment was the highest, significantly increasing by 12.4% compared with P0, but its starch content significantly decreased by 3.86% compared with P0. In contrast, the starch content was the highest under the P2 treatment, and the reducing sugar content was the highest under the P4 treatment, which significantly increased by 10.5%, and 14.8% compared with P0, respectively. In 2019, compared with the P0 treatment, the starch content under each P application treatment increased significantly, and the starch content of the P4 treatment was the highest, which significantly increased by 8.65% compared

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Table 1. Yield and commodity potato yield of purple-fleshed sweetpotato under different phosphorus (P) application

Year	Treatment	Shoot yield (t/ha)	Storage root yield (t/ha)	Root-top ratio (R/T)	Commodity potato yield (t/ha)	Commodity potato rate (%)	Increased input of P fertiliser (USD/ha)	Increased profit (USD/ha)	Increased net profit (USD/ha)	Fertiliser investment rate
2018	P0	37.39 ± 1.01^{b}	12.27 ± 1.28^{bc}	0.33 ± 0.04^{b}	8.35 ± 0.75^{b}	68.23 ± 0.03^{b}	–	–	–	–
	P1	37.76 ± 2.01^{b}	13.37 ± 1.25^{ab}	0.35 ± 0.05^{b}	8.70 ± 1.53^{b}	64.83 ± 0.06^{b}	70.2	147.5	77.3	1.10
	P2	32.37 ± 3.72^{b}	14.86 ± 1.50^{a}	0.46 ± 0.07^{a}	11.74 ± 0.82^{a}	79.22 ± 0.30^{a}	140.5	1 428.9	1 288.4	9.17
	P4	47.10 ± 3.71^{a}	10.08 ± 0.85^{c}	0.22 ± 0.15^{c}	8.20 ± 0.40^{b}	81.71 ± 0.08^{a}	281	–63.2	–344.2	–1.22
2019	P0	18.84 ± 0.54^{b}	11.63 ± 0.31^{d}	0.62 ± 0.00^{b}	9.77 ± 0.70^{b}	83.94 ± 3.79^{b}	–	–	–	–
	P1	20.98 ± 0.69^{a}	12.87 ± 0.29^{c}	0.61 ± 0.03^{b}	10.72 ± 0.34^{b}	83.34 ± 0.75^{b}	70.2	400.4	330.2	4.70
	P2	19.73 ± 0.41^{b}	14.49 ± 0.51^{ab}	0.73 ± 0.01^{a}	12.94 ± 0.50^{a}	89.31 ± 0.27^{a}	140.5	1 336.2	1 195.7	8.51
	P3	20.97 ± 0.54^{a}	15.34 ± 0.51^{a}	0.73 ± 0.01^{a}	13.80 ± 0.70^{a}	89.98 ± 1.56^{a}	210.7	1 698.6	1 487.9	7.06
	P4	21.28 ± 0.11^{a}	13.74 ± 0.36^{bc}	0.64 ± 0.01^{b}	10.66 ± 0.12^{b}	77.61 ± 1.29^{c}	281	375.1	94.1	0.33
Significance test (*F*-value)										
Year		541.82**	2.14	476.28**	33.18**	38.34**	–	–	–	–
Treatment		14.34**	13.44**	22.06**	25.78**	7.24**	–	–	–	–
Year × treatment		12.05**	8.24**	7.47**	0.87	9.60**	–	–	–	–

P0 – 0 kg P/ha; P1 – 10.9 kg P/ha; P2 – 21.8 kg P/ha; P3 – 32.7 kg P/ha; P4 – 43.6 kg P/ha. The market price of commodity potato was calculated at 0.42 USD/kg, the price of P fertiliser was calculated at 6.45 USD/kg, fertiliser investment rate = increased net profit/increased fertiliser input. Data are means ± standard deviation (n = 3), means within the same column followed by different letters (a, b and c, etc.) are significantly different between treatments in the same year ($P < 0.05$, Duncan's test).$^{*}P < 0.05$; $^{**}P < 0.01$

to P0. The contents of reducing sugar and soluble sugar under the P2 treatment were not significantly different from P0, but those under P1, P3, and P4 treatments were significantly decreased compared with P0, respectively. However, the protein content under the P2 treatment was the lowest, while the P1, P3, and P4 treatments significantly increased the protein content by 10.8, 9.82, and 11.9% compared with P0, respectively.

Characteristics of P accumulation and dry matter production in purple-fleshed sweetpotato under different P applications. As can be seen from Figure 1, the P accumulation in the shoot was higher than that in the storage root at the early growth stage. With the development of the growth period, the proportion of P accumulation in the storage root increased, but the proportion of P accumulation in the shoot was still lower than 50% at the harvest stage. On day 60, the P accumulation in storage root under P1, P2, P3, and P4 treatments was significantly higher than that under P0 treatment, which was 96.9, 92.1, 105, and 71.3% higher than that under P0 treatment, respectively. The P accumulation in shoot under P2 and P4 treatment was significantly higher than that under P0 treatment. On day 90, P application significantly increased the P accumulation in the storage root, and the P accumulation was the highest under the P4 treatment, which was 167.3% higher than P0. However, the P accumulation in the shoot was significantly decreased under P1, P2, and P3 treatments. On day 120, the P accumulation of all P application treatments was significantly higher than that of the P0 treatment. The P accumulation in the storage root was the highest under the P3 treatment, but the P accumulation in the shoot was the highest under the P2 treatment, which was significantly increased by 25.9% and 42.2% compared with P0, respectively.

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Table 2. The nutrient quality of purple-fleshed sweetpotato under different phosphorus (P) application

Year	Treatment	Starch content	Reducing sugar content	Soluble sugar content	Protein content
		(%)			
2018	P0	55.86 ± 0.12[c]	3.92 ± 0.07[b]	12.77 ± 0.03[c]	9.15 ± 0.04[a]
	P1	53.70 ± 0.33[d]	3.90 ± 0.39[b]	14.35 ± 0.39[a]	9.39 ± 0.31[a]
	P2	61.74 ± 0.45[a]	3.70 ± 0.24[b]	13.21 ± 0.18[b]	5.34 ± 0.02[c]
	P4	57.85 ± 0.03[b]	4.50 ± 0.02[a]	13.56 ± 0.05[b]	6.85 ± 0.05[b]
2019	P0	60.63 ± 0.10[d]	4.01 ± 0.04[a]	9.31 ± 0.25[a]	6.21 ± 0.12[b]
	P1	63.18 ± 0.12[c]	3.21 ± 0.04[b]	8.32 ± 0.02[b]	6.88 ± 0.05[a]
	P2	64.70 ± 0.24[b]	4.03 ± 0.46[a]	9.14 ± 0.48[a]	5.52 ± 0.23[c]
	P3	64.59 ± 0.43[b]	3.05 ± 0.13[b]	8.39 ± 0.11[b]	6.82 ± 0.03[a]
	P4	65.88 ± 0.39[a]	2.99 ± 0.22[b]	8.31 ± 0.50[b]	6.95 ± 0.17[a]
Significance test (*F*-value)					
Year		2 904.53**	21.35**	1 604.36**	442.04**
Treatment		346.37**	5.45**	2.64	284.40**
Year × treatment		161.82**	78.99**	24.26**	183.08**

P0 – 0 kg P/ha; P1 – 10.9 kg P/ha; P2 – 21.8 kg P/ha; P3 – 32.7 kg P/ha; P4 – 43.6 kg P/ha. Data are means ± standard deviation (n = 3); means within the same column followed by different letters (a, b and c, etc.) are significantly different between treatments in the same year (P < 0.05, Duncan's test). **P < 0.01

The dry mass accumulation in the shoot of sweetpotato increased with the development of the growth period, while the dry mass accumulation in the storage root reached the maximum value at 90 days and remained until 120 days (Figure 2). On day 60, dry matter accumulation in the shoot was higher than storage root. The dry mass accumulation of shoots under all P application treatments was significantly higher than that under the P0 treatment, and the highest was under the P2 treatment, which was 63.2% higher than that under the P0 treatment. The shoot dry mass accumulation under P3 and P4 treatment was also significantly higher than that under the P0 treatment. At 90 days, dry mass accumulation in storage root was higher than that in shoot except for P0 treatment. The dry mass accumulation in roots under all P application treatments was significantly higher than that under P0 treatment, and the highest was under P2, P3, and P4 treatments, which were 101, 117, and 118 higher than that in P0 treatment,

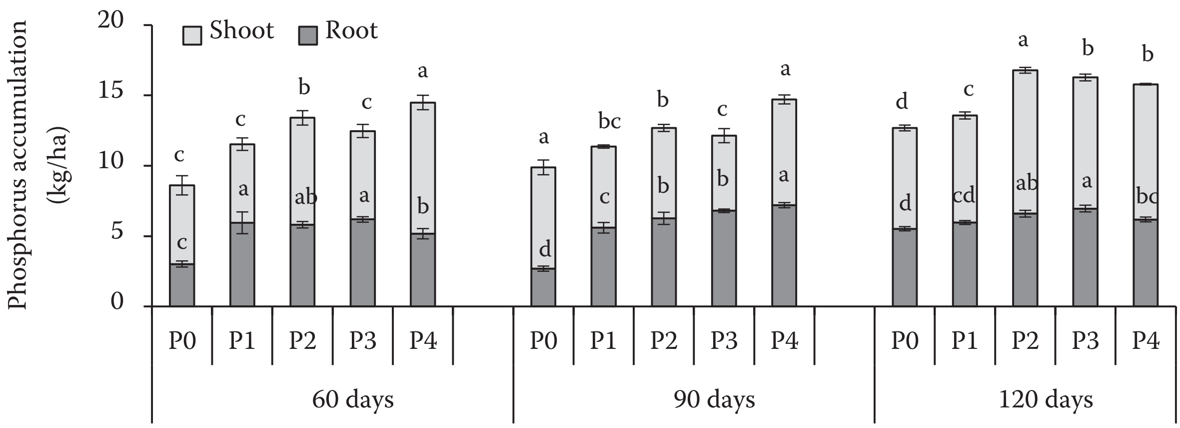

Figure 1. Effects of phosphorus (P) application on P accumulation of purple-fleshed sweetpotato at different growth stages. P0 – 0 kg P/ha; P1 – 10.9 kg P/ha; P2 – 21.8 kg P/ha; P3 – 32.7 kg P/ha; P4 – 43.6 kg P/ha. Data are means ± standard deviation (n = 3), different letters (a, b and c, etc.) meant significant difference in shoot or root at the same time, respectively (P < 0.05, Duncan's test)

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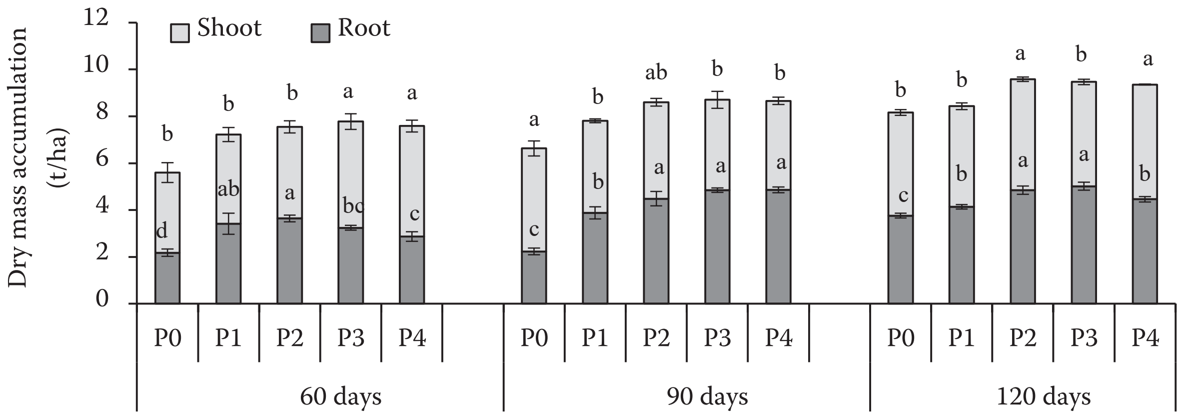

Figure 2. Effects of phosphorus (P) application on the dry mass accumulation of purple-fleshed sweetpotato at different growth stages. P0 – 0 kg P/ha; P1 – 10.9 kg P/ha; P2 – 21.8 kg P/ha; P3 – 32.7 kg P/ha; P4 – 43.6 kg P/ha. Data are means ± standard deviation (n = 3), different letters (a, b and c, etc.) meant significant difference in shoot or root at the same time, respectively (P < 0.05, Duncan's test)

respectively. At 120 days, the dry mass accumulation in root was the highest under P2 and P3 treatment, which was significantly higher than P0 by 29.0% and 33.2%, respectively. Continue to increase the amount of P fertiliser (P4), the dry matter accumulation in the root decreased significantly when compared with the P3 treatment, but the dry matter accumulation in the shoot increased significantly.

Phosphorus utilisation efficiency of sweetpotato under different phosphorus applications. The apparent phosphorus utilisation efficiency (APUE) and phosphorus agronomic efficiency (PAE) of sweetpotato increased firstly and then decreased with the increase of P application amount and were the highest under P2 treatment (Figure 3). The APUE under the P2 treatment was 18.8%, which was significantly higher than the P1 (8.14%), P3 (11%), and P4 (7.11%) treatments. The PAE of the P2 treatment was 131 kg/kg, with no significant difference from that of the P1 (113 kg/kg) and P3 treatment (113 kg/kg), but significantly higher than that of the P4 treatment (47.7 kg/kg).

DISCUSSION

Phosphorus is a multifunctional plant nutrient with the potential to improve plant growth and yield (Wang et al. 2018). Studies have shown that potato has a relatively high P requirement, and adequate P is essential for optimising tuber yield, solids content, nutritional quality, and resistance to some diseases (Rosen et al. 2014).

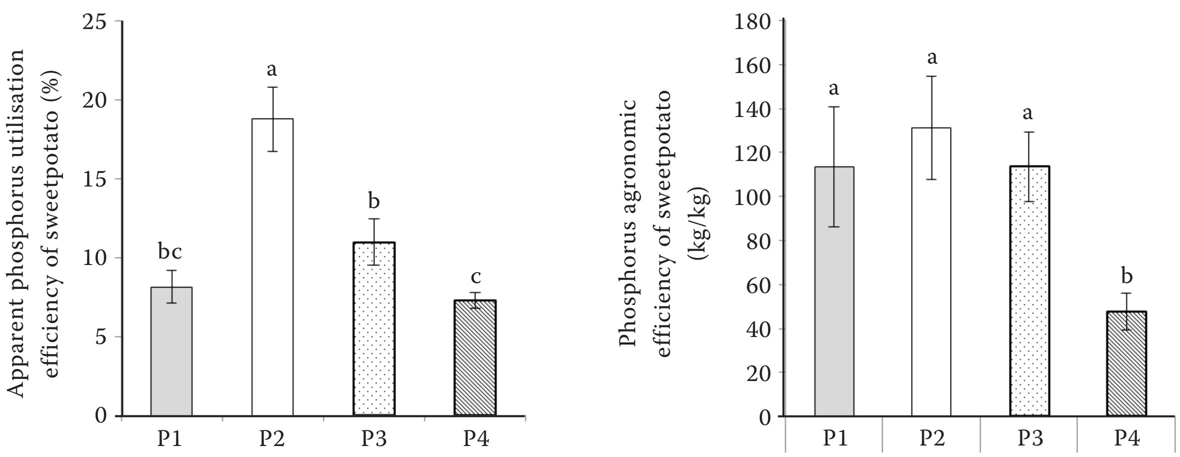

Figure 3. Effects of phosphorus (P) application on apparent phosphorus utilisation efficiency and phosphorus agronomic efficiency of purple-fleshed sweetpotato. P0 – 0 kg P/ha; P1 – 10.9 kg P/ha; P2 – 21.8 kg P/ha; P3 – 32.7 kg P/ha; P4 – 43.6 kg P/ha. Data are means ± standard deviation (n = 3), different letters (a, b and c, etc.) meant significant difference (P < 0.05, Duncan's test)

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However, there is a lack of research on the effect of P fertiliser dosage on the yield and quality of sweetpotato.

In this study, we found that after two years of P fertiliser treatment, the yield and commodity potato yield of purple-fleshed sweetpotato was the highest under the P3 treatment, followed by the P2 treatment (Table 1). This was similar to the report that the highest total sweetpotato yield and marketable potato yield was recorded at 15 t/ha farm yard manure + 30 kg P/ha (Boru et al. 2017). When the amount of P fertiliser was higher than P3 (32.7 kg/ha), the yield and commodity potato yield decreased, indicating that the economic yield of purple-fleshed sweetpotato could be significantly increased by an appropriate amount of P fertiliser but negatively regulated by excessive P fertiliser. However, another study showed that when applying 58.9 kg/ha P fertiliser, the yield and economic characteristics of sweetpotato reached the best (Xie et al. 2014). This may be because the available P content in the test soil (≤ 10 mg/kg) was much lower than that in our test field soil (31.7 mg/kg). Compared with 2019, the above-ground growth in 2018 was more vigorous, and the yield of commodity potatoes was significantly lower, which may be related to the heavy rain in August (data not shown).

Nutrient absorption is the basis of dry matter formation and accumulation, and dry matter and nutrient accumulation are the premises of crop organ differentiation and yield formation (Song and Li 2003). The study on sweetpotato showed that a large amount of P absorption was in the middle and late stage, and appropriate P application could significantly increase the amount and rate of P accumulation in sweetpotato and promote the accumulation of dry matter in the sweetpotato root tuber (Lu and Shi 2015). In this study, the P accumulation in purple-fleshed sweetpotato increased with the growth period (Figure 1), which promoted the accumulation of dry matter in the storage root (Figure 2), but the growth rate slowed down after 90 days. This indicated that the peak of P absorption was about 90 days after planting. When the P application rate was 21.8 kg/ha (P2) and 31.7 kg/ha (P3), sweetpotato showed higher P accumulation (Figure 1), which resulted in higher yield and economic yield (Table 1). Continue to increase the amount of P fertiliser (P4); the yield and the commodity potato yield decreased. This was because the excessive P makes the shoots flourish, affecting the transportation of dry matter to the roots and resulting in a decrease in the R/T ratio and final yield (Table 1). This is in accordance with the results of Jia et al. (2016).

The fertiliser utilisation rate is an important indicator to measure whether fertiliser application is reasonable (Rose and Wissuwa 2012). A study on sweet corn indicated that the utilisation rate of phosphate fertiliser decreases with the increase in phosphate fertiliser usage (Yan et al. 2021). According to the results of this study, when the application amount of P fertiliser was more than 21.8 kg/ha (P2), the apparent utilisation efficiency and agronomic efficiency of P fertiliser also decreased with the increase of the application amount (Figure 3). Compared with no application of P fertiliser (P0), APUE and PAE were significantly improved when P fertiliser dosage was 21.8 kg/ha, indicating that appropriate P fertiliser dosage could achieve the unity of increasing yield and improving P efficiency, which was of great significance for guiding sweetpotato production. Moreover, the application of 21.8 kg P/ha also achieved the highest fertiliser investment rate (Table 1), indicating that the application amount of P fertiliser should be moderate, which is more conducive to improving the yield-increasing benefits of sweetpotato.

Zhang et al. (2013) reported that the appropriate combination of P and K could promote the accumulation of soluble sugar in the early and middle stages of tubers and the transformation of soluble sugar into starch in the late growth stage. In this research, we also found that the contents of starch in purple-fleshed sweetpotato were significantly increased after two years of P fertiliser treatment, but the contents of reducing sugar and soluble sugar significantly decreased (except for P2 treatment) (Table 2). The reason may be that the accumulation of soluble sugar in the early stage was largely converted to starch in root tubers in the later stage. At the same time, P application can also enhance channels that facilitated the transport of substances required for starch biosynthesis, thus increasing starch accumulation increases starch accumulation (Zhang et al. 2017). In addition, compared with 2019, the starch content in 2018 decreased significantly, but the soluble content increased significantly, which may be related to the increase in soluble sugar content and the decrease of starch content caused by flooding stress (Zeng et al. 2021). From the perspective of different treatments, the protein content under the P2 treatment was lower than that of the P3 treatment, but the soluble sugar and reducing sugar content were significantly higher than that of the P3 treatment. As an edible type of sweetpotato, the purple-fleshed sweetpotato treated with P2 may have a better taste.

Two consecutive years of field experiments showed that, although the highest yield of sweetpotato and commodity potato could be obtained with the application rate of 32.7 kg P/ha fertiliser (P3), the APUE and PAE were low. In contrast, the P application rate of 21.8 kg/ha could achieve the same total and economic yield as P3 but significantly improved the APUE and PAE, and the edible taste was better. Therefore, considering the effect of P application rate on the yield, quality, fertiliser investment rate and P fertiliser utilisation rate of purple-fleshed sweetpotato, the optimal P input is 21.8 kg/ha in the conditions of this experiment. The results of this experiment can provide a reference for the production of purple-fleshed type sweetpotato in medium fertility plots, and the P fertiliser input can be appropriately increased in a P deficient plot.

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