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Dynamic Changes of Nutrients in Different Growth Stages of *Trichosanthes kirilowii* in Shishou City

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Abstract To explore the relationship between soil nutrients, plant nutrients, and the growth and development of *Trichosanthes kirilowii*, the soil pH, organic matter, available nitrogen, available phosphorus, available potassium content, and leaf total nitrogen, total phosphorus, total potassium, and SPAD in different growth stages of *T. kirilowii* in the main production area of Shishou City were measured and analyzed. The changes in soil nutrient content and leaf nutrient content at different growth stages of *T. kirilowii* were compared, and correlation analysis was conducted. The results showed that the average soil pH, organic matter content, alkaline nitrogen content, available phosphorus content, and available potassium content during the entire growth period of *T. kirilowii* were 7.03, 14.01 g/kg, 98.79 mg/kg, 14.84 mg/kg, and 135.20 mg/kg, respectively; the average total nitrogen content, total phosphorus content, total potassium content, and SPAD of the leaves were 0.55%, 0.23%, 1.78%, and 77.66, respectively. The nutrient dynamics of *T. kirilowii* at different growth stages exhibited certain regularity, with most nutrients reaching their maximum values during the flowering and fruiting stages, and then showing a decreasing or stabilizing trend. There was a varying degree of correlation between the nutrient content of leaves and soil, among which the nitrogen, phosphorus, and potassium contents of leaves were significantly or extremely significantly correlated with soil organic matter and alkaline nitrogen content. It can be seen that the nutrient abundance or deficiency level of soil in *T. kirilowii* field significantly affected the nutrient content of the leaves at different growth stages, thereby restricting its growth and development status.

Key words *Trichosanthes kirilowii*; Soil nutrients; Leaf nutrients; Dynamic changes; Correlation analysis

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Trichosanthes kirilowii Maxim is a perennial climbing vine of Cucurbitaceae, widely distributed in China, especially in provinces such as Shandong, Hebei, Anhui, and Zhejiang where the planting area is relatively large. *T. kirilowii* was originally a wild plant. After artificial selection and domestication, it began to be artificially cultivated, forming different cultivated species[1–2]. *T. kirilowii* has high medicinal value, and its roots, bark, and seeds can all be used as medicine. The root of *T. kirilowii* is often used to make Trichosanthis Radix, which has the effects of clearing away heat, purging fire, producing fluid and thirst, reducing swelling and pus, and can be used to treat diabetes, hepatitis and other diseases[3–4]. The bark of *T. kirilowii* also has the effect of clearing heat and resolving phlegm, and can be used to treat phlegm heat cough, chest tightness, *etc*[5–6]. Due to its rich aroma, good taste, high unsaturated fatty acid content after stir frying, and the effects of clearing the lungs, resolving phlegm, smoothing the intestines, and promoting bowel movements, the seed of *T. kirilowii* is often used as a functional snack food and is deeply loved by consumers[7–8]. Therefore, harvesting seeds has become the main purpose for farmers to actively plant *T. kirilowii*. Due to the good economic benefits of planting *T. kirilowii*, it is increasingly valued by farmers in central provinces of China. The cultivation area has been expanding year by year, and the development momentum is good. It has become a good way for farmers to get rich[9].

The growth and development of *T. kirilowii* are influenced by multiple factors such as variety, soil conditions, and field management. Lin Yifan *et al.* conducted hybrid breeding of "Wanlou 7" and "Wanlou 1". By comparing and selecting the traits of the dominant individual plants in the offspring of the two varieties, the female offspring "Wanlou 15" was screened[10]. Based on the variety "Wanlou 9" of *T. kirilowii*, Xu Jinyan *et al.* used its excellent mutant individual plant 9-1519 as the female parent and wild *T. kirilowii* HB-05 from the Wudang Mountain in Shiyan of Hubei as the male parent. By combining their respective excellent traits, *T. kirilowii* variety "Sulou 1" was cultivated[11]. Zhang Tingting *et al.* found that external application of auxin like substances (IAA) can promote the synthesis of chlorophyll in *T. kirilowii* and regulate its chlorophyll fluorescence parameters to enhance stress resistance[12]. Chen Feng *et al.* integrated the cultivation of *T. kirilowii* with the breeding of Sanhuang chickens, developed circular agriculture, and achieved good results[13]. Zuo Qingwen *et al.* used the intercropping method of *T. kirilowii* and *Amor-*

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phophallus konjac to improve the light and water resources in the field, achieve three-dimensional cultivation, and achieve a soil utilization rate of 95%[14]. Research by Qiao Xiaoyan *et al.* has shown that the mixed application of nitrate nitrogen and ammonium nitrogen can promote the root vitality of *T. kirilowii* seedlings[15]. The fertilizer efficiency experiment by Wang Xiao *et al.* has confirmed that the application of nitrogen fertilizer had a better yield increasing effect than phosphorus and potassium fertilizers, and different ratios of nitrogen, phosphorus, and potassium significantly affected yield formation[16]. However, there is relatively little research on the dynamic changes of soil nutrients and plant nutrients during different growth stages of *T. kirilowii*. Therefore, this paper intended to investigate the soil nutrient status and leaf nutrient status of *T. kirilowii* fields at different growth stages in Zinandi Village, Dongsheng Town, Shishou City. It aimed to explore the dynamic changes of nutrients at different growth stages of *T. kirilowii*, and explore the relationship between soil nutrition and *T. kirilowii* growth and development, in order to provide reference for the development of the local *T. kirilowii* industry.

1 Materials and methods

1.1 Overview of the experimental area The experimental area is located in *T. kirilowii* base of Hubei Zhuangcheng Agricultural Technology Development Co., Ltd., Zinandi Village, Dongsheng Town, Shishou City, Hubei Province (29°43′5″ N, 112°30′37″ E, altitude 33 m), with a planting scale of approximately 140 hm^2. Shishou City is located in the southern part of Hubei Province, which belongs to the subtropical monsoon climate zone. It has distinct four seasons, abundant light energy, rich heat, and a long frost free period. As shown in Fig. 1, the average annual temperature is 18.3 ℃, and the annual precipitation is 901.9 mm during the growth period of *T. kirilowii*. The distribution of precipitation throughout the year is uneven, with precipitation mostly concentrated from April to July, accounting for 58% of the annual rainfall. The field management of *T. kirilowii* followed the habits of local farmers, such as timely weeding after germination and timely application of water-soluble fertilizers during flowering and fruiting periods.

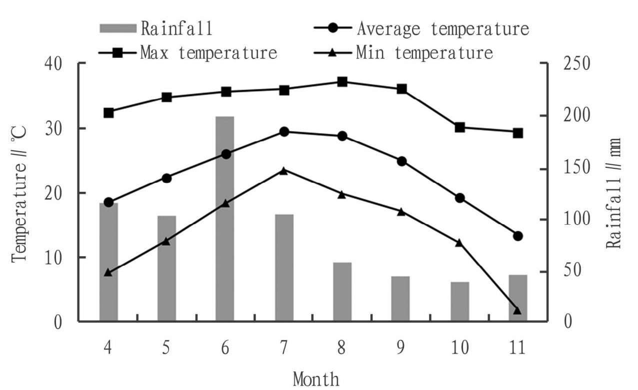


Fig.1 Weather conditions during the growth period of *T. kirilowii*

1.2 Sample collection and determination methods

1.2.1 Sample collection. After the germination of *T. kirilowii*, a random multi-point sampling method was used to collect 10 soil samples (0–20 cm) from the plow layer at the end of each month from April to November, for a total of 80 soil samples. After removing weeds, roots, gravel, and other debris from the collected soil samples, a portion was taken and broken into the pieces <1 cm. After air drying and crushing, they were sieved through a 1 mm sieve. They were packed in self sealing bags, marked and labeled for future use. Starting from the germination of *T. kirilowii*, a random multi-point sampling method was used to collect several mature leaves at the end of each month. After bringing them back, they were dried, crushed, and stored in self sealing bags for future use.

1.2.2 Sample determination. The soil pH was determined using the potentiometric method, and the soil organic matter was determined using the potassium dichromate volumetric method – external heating method. The soil alkaline nitrogen was determined using the alkaline diffusion method, the soil available phosphorus was determined using 0.5 mol/L of $NaHCO_3$ leaching-molybdenum antimony colorimetric method, and the soil available potassium was determined using the NH_4Ac leaching-flame photometry method[17]. The SPAD value of *T. kirilowii* leaves can be directly measured using a SPAD meter. The nitrogen content of *T. kirilowii* leaves was determined using the $H_2SO_4-H_2O_2$ digestion Kjeldahl nitrogen determination method, the phosphorus content was determined using the $H_2SO_4-H_2O_2$ digestion vanadium molybdenum yellow colorimetric method, and the potassium content was determined using the $H_2SO_4-H_2O_2$ digestion flame photometer method[17].

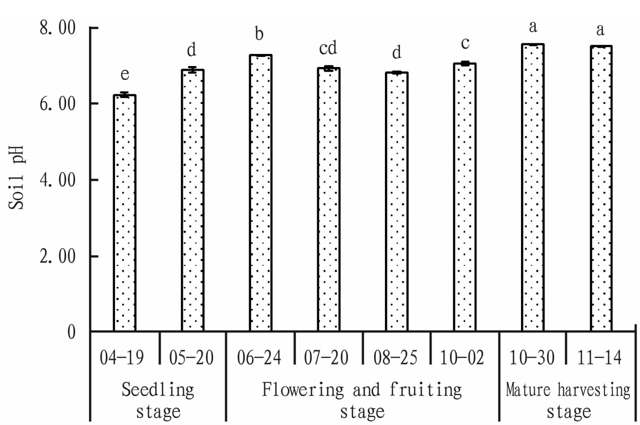
1.3 Data processing and analysis Excel 2021 was used for data processing and graphical plotting, DPS software was used for one-way ANOVA, and the Least Significant Difference (LSD) method was used for comparison ($P<0.05$).

2 Results and analysis

2.1 Spatial distribution and growth of *T. kirilowii* at different growth stages Fig. 2 showed the spatial distribution and growth status of *T. kirilowii* at different growth stages and its fruit morphology. As shown in Fig. 2a, as the growth period of *T. kirilowii* progressed, the growth of the leaves shifted with the growth center. During the flowering and fruiting period, the leaves on the main stem of *T. kirilowii* began to wither or fall off. Fig. 2b showed that the outer peel of *T. kirilowii* fruit changed from green to yellow until orange red from the flowering and fruiting period to the mature harvesting period. The longitudinal cutting diagram of *T. kirilowii* fruit showed that the internal material morphology of the fruit changed significantly, from solid to liquid, and the color changed from green black to dark green. The fruit peel also gradually became soft from hard.

2.2 Changes in soil pH during different growth stages of *T. kirilowii* pH is a comprehensive reflection of soil physicochemical properties and has a significant impact on soil nutrient availability. From Fig. 3, it can be seen that the soil pH from the seedling stage to the mature harvesting stage of *T. kirilowii* changed between 6.24 and 7.51, and the soil changed from slightly acidic to neutral. During the mature harvesting period, the soil pH reached its highest value of 7.56. With the advancement of the reproductive process, soil pH showed a sequential upward trend, manifested as a trend of fast in the early stage, slow in the middle stage, and stable in the later stage.

Fig. 2 Growth changes of *T. kirilowii* at different growth stages



Note: Different lowercase letters indicate significant difference of 0.05 among treatments.

Fig. 3 Changes in soil pH values at different growth stages of *T. kirilowii*

2.3 Changes in soil nutrients at different growth stages of *T. kirilowii* As shown in Fig. 4, the range of soil organic matter content from the seedling stage to the mature harvesting stage of *T. kirilowii* was between 11.26 and 16.60 g/kg, with the highest organic matter content at 16.60 g/kg during the mature harvesting period. Overall, with the advancement of the reproductive process, the soil organic matter content showed a gradually increasing trend. The lowest organic matter content (11.26 g/kg) was on April 19 during the seedling stage, and gradually stabilized between 12.39 and 12.65 g/kg. It began to rise on August 25 during the flowering and fruiting stage, and then began to decrease or stabilize after reaching its maximum value. The range of soil alkaline nitrogen content was between 87.79 and 115.71 mg/kg. Among them, the soil alkaline nitrogen content was highest on October 30 during the mature harvesting period, reaching 115.71 mg/kg. As the growth process of *T. kirilowii* progressed, the trend of changes in soil alkaline nitrogen content was similar to that in organic matter content. The range of available phosphorus content in *T. kirilowii* soil was between 9.20 and 22.70 mg/kg. It grew rapidly from the seedling stage to the flowering and fruiting stage, and reached a maximum value of 22.70 mg/kg on July 20. Then, it began to decline, and stabilized between 11.22 and 14.84 mg/kg. Overall, the changes in available phosphorus in *T. kirilowii* soil exhibited a phenomenon of being light at both ends and heavy in the middle. The range of available potassium content in *T. kirilowii* soil was between 110.26 and 190.48 mg/kg, and its trend of change was similar to that of available phosphorus content.

2.4 Changes in leaf nutrients at different growth stages From Fig. 5, it can be seen that the total nitrogen content of the leaves from the seedling stage to the mature harvesting period of *T. kirilowii* was from 0.67% to 0.46%. Overall, the total nitrogen content of the leaves showed a trend of first increasing and then decreasing from the seedling stage to the mature harvesting period of *T. kirilowii*, and reached its lowest point of 0.46% after harvesting. The total phosphorus content of leaves ranged from 0.31% to 0.13%, which was similar to the trend of changes in total nitrogen content of leaves. It was the highest at 0.31% during the flowering and fruiting stages, and gradually decreased with the advancement of the growth process. It showed a slow decline in the early flowering and fruiting stages, a fast decline in the middle and late stages, and a stability in the mature harvesting period. The total potassium content of the leaves ranged from 2.28% to 1.10%, indicating significant changes in the total potassium content of *T. kirilowii* leaves. Similar to the trend of nitrogen and phosphorus content changes in leaves, the total potassium content in leaves was the highest during the flowering and fruiting stages, reaching 2.28%, and began to decrease as the growth process progressed. During the late stage of flowering and fruiting until harvest, the potassium content in the leaves tended to stabilize at 1.4%. After harvest, the potassium content in the leaves decreased to the lowest point of 1.10%, a decrease of 51.75% compared to the potassium content during flowering and fruiting stage. The SPAD value of the leaves ranged from 46.27 to 99.87. During the seedling stage and early flowering and fruiting stages, the SPAD value of the leaves first stabilized and then gradually increased. By August 25, the SPAD value of the leaves reached its highest value of 99.87, and then gradually decreased until the SPAD value reached its lowest point after harvesting.

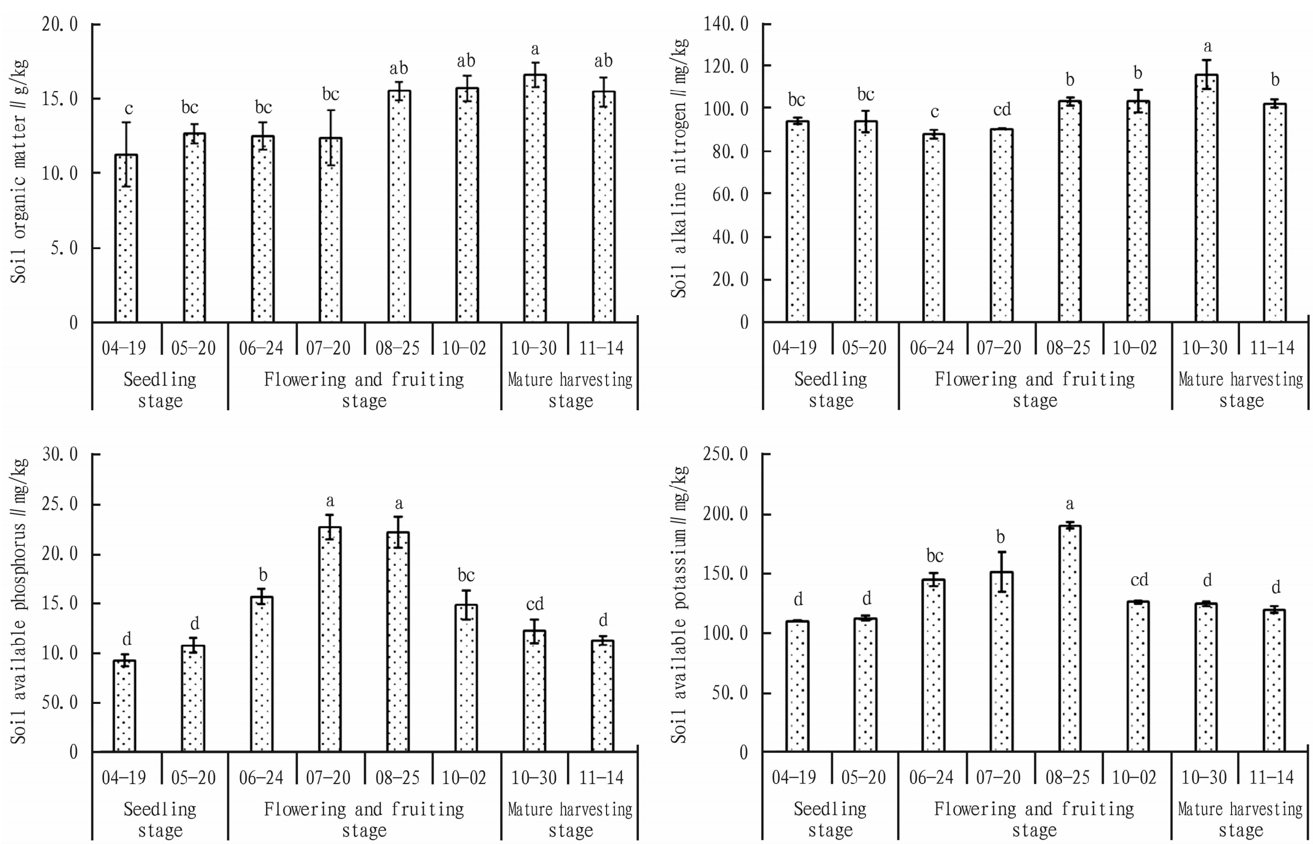


Fig. 4 Changes in soil nutrient content during different growth stages

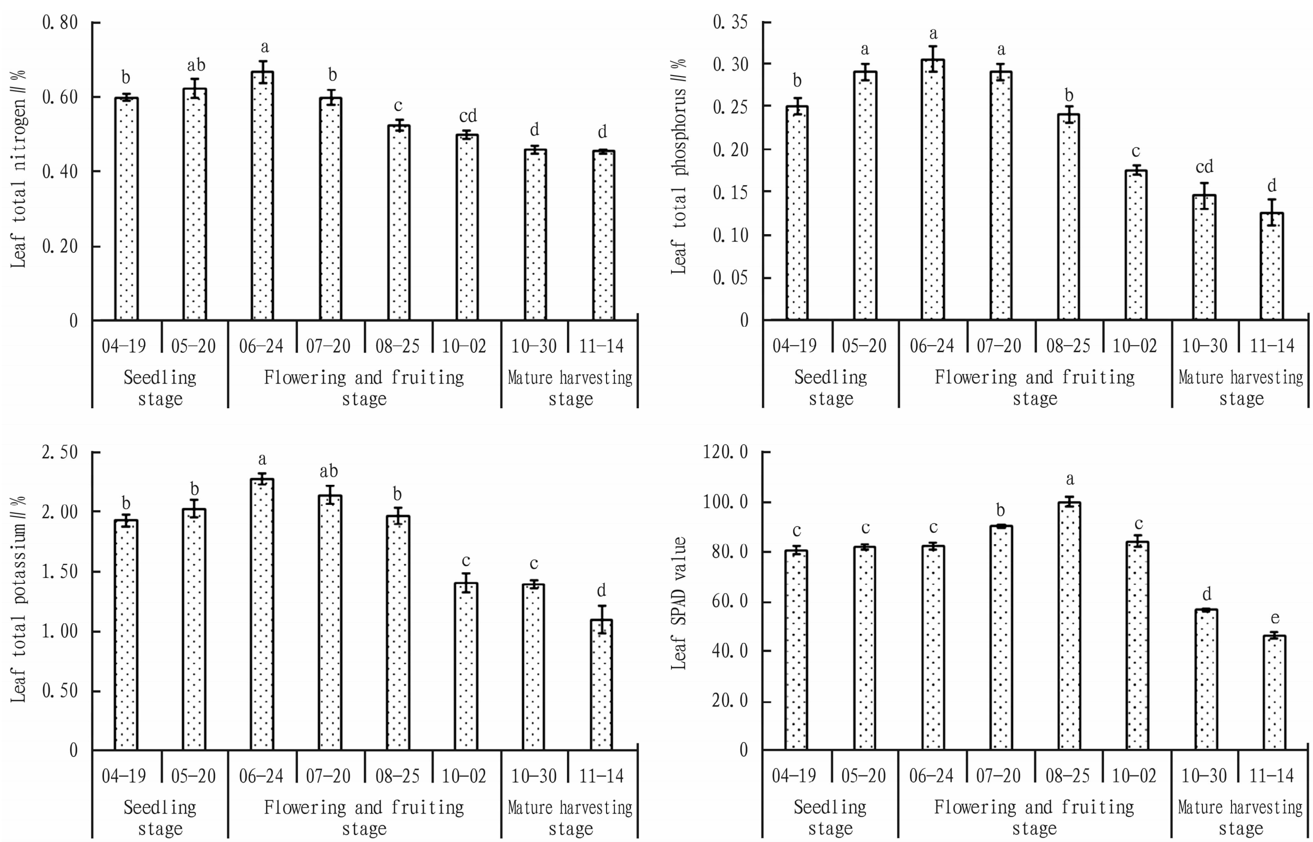
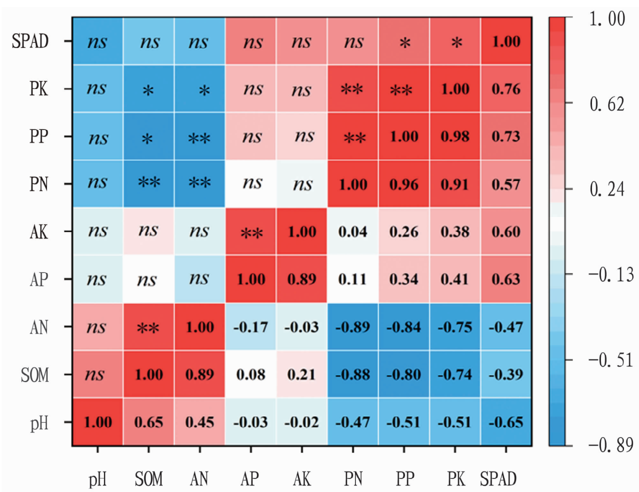


Fig. 5 Changes in nutrient content of leaves at different growth stages

2.4 Correlation analysis between soil nutrients and leaf nutrients As shown in Fig. 6, there was a varying degree of correlation between the nutrient content of *T. kirilowii* leaves and the nutrient content of soil. The nitrogen content (PN) of *T. kirilowii* leaves was extremely significantly negatively correlated with soil organic matter (SOM) ($r = -0.88$) and soil alkaline nitrogen (AN) ($r = -0.89$). The phosphorus content (PP) of *T. kirilowii* leaves was significantly negatively correlated with soil organic matter (SOM) ($r = -0.80$), extremely significantly negatively correlated with soil available nitrogen (AN) ($r = -0.84$), and extremely significantly positively correlated with nitrogen content (PN) of leaves ($r = 0.96$). The potassium content (PK) of *T. kirilowii* leaves was significantly negatively correlated with soil organic matter (SOM) ($r = -0.74$) and soil available nitrogen (AN) ($r = -0.75$), while it was highly significantly positively correlated with leaf nitrogen content (PN) ($r = 0.91$) and leaf phosphorus content (PP) ($r = 0.98$). The SPAD value of *T. kirilowii* leaves was significantly positively correlated with the phosphorus content (PP) ($r = 0.73$) and potassium content (PK) ($r = 0.76$) of leaves, but not significantly correlated with other indicators.



Note: pH. Soil pH; SOM. Soil organic matter content; AN. Soil alkaline nitrogen content; AP. Soil available phosphorus content; AK. Soil available potassium content; PN. Total nitrogen content of leaves; PP. Total phosphorus content of leaves; PK. Total potassium content of leaves; SPAD. Leaf SPAD value. * and ** respectively show significant correlation at the levels of $P < 0.05$ and $P < 0.01$; *ns* shows insignificant correlation at the levels of $P < 0.05$ and $P < 0.01$.

Fig. 6 Correlation analysis between soil nutrients and leaf nutrients

3 Discussion

3.1 Changes in soil nutrient status during different growth stages Through comparative analysis of the main nutrient content in soil at different growth stages of *T. kirilowii*, it was found that the effects of *T. kirilowii* on nutrient forms and content in soil at different growth stages had their own characteristics. Throughout the entire growth process of *T. kirilowii*, there was little change in soil nutrients during the seedling stage, which was relatively stable. During the flowering and fruiting period, except for the initial increase and subsequent decrease in soil available phosphorus and potassium content, all other soil nutrients showed stability or gradually increased. During the mature harvesting period, all soil nutrients showed a decreasing or stable trend, with a more significant decrease in soil alkaline nitrogen content, available phosphorus content, and organic matter content, while other soil nutrients remained unchanged or had a relatively small decrease, tending towards stability. Overall, most soil nutrient changes showed a parabolic trend, with stability or increase in the early stages of growth, rapid rise and reaching maximum values in the middle stages, and a decrease or stabilization in the late stages of growth. The reason for this may be that the field is a transferred land, and the nutrient differentiation management of the entire field was not carried out after the transfer. In addition, the large scale of *T. kirilowii* cultivation resulted in uneven distribution of fertilizer and water, leading to differences in soil nutrients.

At present, research on soil nutrient changes during different growth stages of *T. kirilowii* is relatively weak, but other scholars have conducted corresponding studies on soil nutrient changes during growth stages of different crops. Yang Chunxia *et al*. conducted corresponding analysis and determination of soil nutrient content during the main growth stages of spring wheat in the Yellow River irrigation area of Ningxia, as well as weight analysis of various soil nutrients. Their research showed that there were regular changes in soil nutrients at different growth stages, and there was a correlation among soil nutrients[18], which was consistent with the results of this study.

3.2 Changes in aboveground nutritional status during the growth period of *T. kirilowii* Through comparative analysis on the main nutrient content in the leaves of *T. kirilowii* at different growth stages, it was found that there was a certain regularity in the nutrient changes of *T. kirilowii* leaves at different growth stages. During the entire growth process of *T. kirilowii*, except for the SPAD value of the leaves, which remained relatively stable during the seedling stage, all other measured nutrients showed an upward trend. During the flowering and fruiting stages, except for the SPAD value which first increased and then decreased, all other measured nutrients decreased sequentially as the growth process progressed. During the mature harvest period, all nutrients showed a decreasing trend.

Bai Yongchao *et al*. found a certain relationship between mineral elements in the leaves of *Vaccinium uliginosum* and soil fertility[19]. The variation pattern of nutrients in *T. kirilowii* leaves was roughly similar to that of soil nutrients. In order to further elucidate the relationship between soil nutrients and leaf nutrients on the growth and development of *T. kirilowii*, correlation analysis was conducted. It was obtained that leaf nitrogen, phosphorus, and potassium content were significantly correlated with soil organic matter and alkaline nitrogen content, while leaf SPAD value was not significantly correlated with soil nutrients. This was similar to the discovery by Gao Lin *et al.* that there was a significant relationship between potassium element in plant leaves and soil alkaline nitrogen and organic matter in Shaoguan Citrus Gonggan Garden[20].

At present, research on the changes in aboveground nutritional status of *T. kirilowii* at different growth stages is still relatively weak. But Ma Zhao *et al.* found through analysis and measurement that the potassium content in the leaves of *T. kirilowii* was greater than the phosphorus content[21]. Using 2-year-old *Atractylodes macrocephala* grown under the forest as the experimental materials, Zhang Huafeng *et al.* studied and analyzed the content and distribution of major nutrient elements in various organs during the bud stage of *A. macrocephala* and its correlation with soil nutrients. The results showed that in the nutrient content of *A. macrocephala* leaves, potassium content was greater than nitrogen content and phosphorus content, and the relationship between nutrients in *A. macrocephala* leaves and soil nutrients was relatively close, with significant or extremely significant relationships[22]. This was similar to the conclusion in this paper.

Through a pot experiment, Zhang Jinming *et al.* studied the distribution of dry matter and nutrient absorption in *Momordica charantia*. The results showed that the accumulation of nitrogen, phosphorus, and potassium nutrients in *M. charantia* was the lowest during the seedling stage, and the accumulation of nitrogen, phosphorus, and potassium nutrients in various parts showed an upward trend from the seedling stage to the full fruiting stage[23]. Zhang Chaokun *et al.* found through research that the nitrogen, phosphorus, and potassium in *Psidium guajava* leaves showed a decreasing trend[24]. Wang Xiaolong *et al.* studied Merlot grapes under different fertilization conditions and used correlation analysis to investigate the correlation between leaf, petiole, soil mineral nutrients and fruit mineral elements. The results showed that there was at least one significant correlation between soil N content, P content, K content and leaf N content or P content or K content at each growth stage[25].

The conclusions of the above scholars were similar to this paper. This experiment showed that there was a significant or extremely significant correlation between the nitrogen, phosphorus, and potassium content of plant leaves and SPAD value, and each nutrient of plant showed a certain trend of change.

At present, there is a lack of research on the dynamic changes of soil nutrients and plant nutrients in different growth stages of *T. kirilowii*. In this paper, only the changes in several main nutrients in soil at different growth stages of *T. kirilowii*, as well as the changes in nitrogen, phosphorus, and potassium nutrients in leaves at different growth stages were preliminarily explored, and the relationship between soil nutrients, plant nutrients, and the growth and development of *T. kirilowii* was briefly analyzed. However, there is a lack of research on the changes in soil nutrients and plant nutrient status of *T. kirilowii* at different ages and growth stages. If it can combine the chemical composition of *T. kirilowii* and the changes in nutrient content of aboveground plants to conduct dynamic visualization research on the growth at different growth stages, and establish a framework for evaluating the soil fertility and quality of *T. kirilowii*, this is a problem that needs further discussion for evaluating the soil quality of *T. kirilowii* and producing high-quality *T. kirilowii*.

4 Conclusions

(1) There was a certain regularity in the changes of nutrients in different growth stages of *T. kirilowii*. Overall, it showed a parabolic trend, where the nutrient content stabilized or gradually increased during the early stages of growth, reached its maximum value during the middle stages of growth, and then began to decrease. In the later stages of growth, the nutrient content stabilized or decreased slightly.

(2) There was a correlation between soil nutrients and leaf nutrients in *T. kirilowii*. The nitrogen, phosphorus, and potassium content in leaves was significantly or extremely significantly related to soil organic matter and alkaline nitrogen content, indicating a prominent interdependence and mutual constraint between leaf nutrients and soil nutrients of *T. kirilowii*. The abundance or deficiency of any leaf nutrient could have an impact on the soil nutrients of *T. kirilowii*.

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oped and unpolluted areas such as 1# Beiling Mountain, which are far away from industrial land and residential area, had relatively lower Cu and Cd content.

(4) The evaluation results showed that the relatively high content of Cu and Cd in the soil of industrial land and residential area was the main reason for the increase in Cu and Cd content in the soil of Zhaoqing City, resulting in a decline in soil quality in the entire Duanzhou District of Zhaoqing City.

(5) In Duanzhou District, the accumulation effect of Cd was greater than that of Cu. Therefore, people should pay sufficient attention to the pollution of Cd in soil, especially in industrial land and residential area, to avoid further pollution caused by human factors.

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